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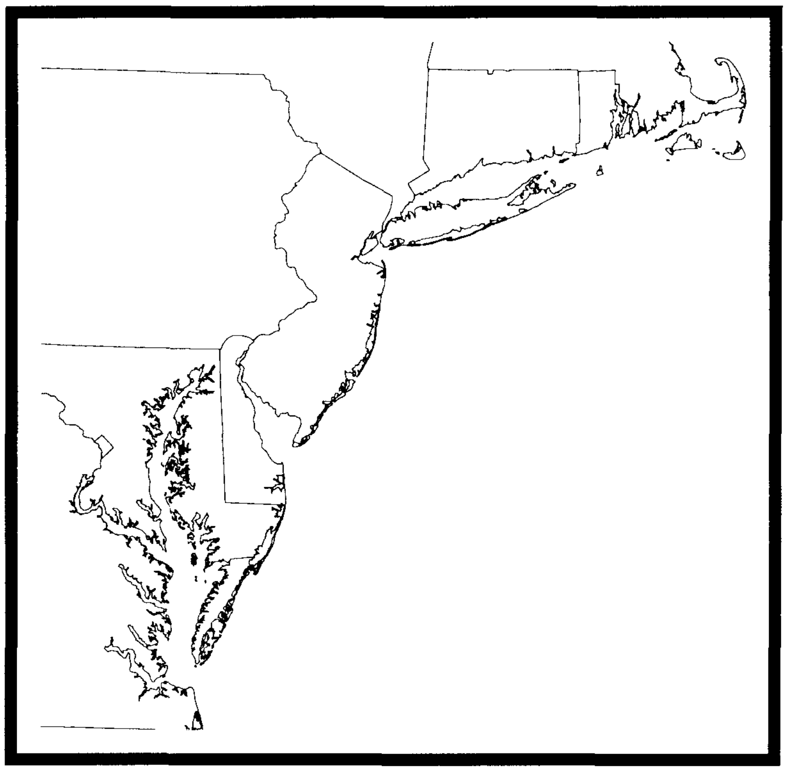
June 1995

Statistical Summary

EMAP-Estuaries Virginian Province 1990 to 1993



Environmental Monitoring and Assessment Program

EPA/620/R-94/026
June 1995

Statistical Summary
EMAP-Estuaries
Virginian Province - 1990 to 1993

by

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ABSTRACT

Annual monitoring of indicators of the ecological condition of bays, tidal rivers, 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, 1990-1993. Data were collected at 425 probability-based 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 impacted resources within the Province for those indicators where "impacted" can be defined. Data are also presented by estuarine class (large estuaries, small estuarine systems, and large tidal rivers).

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 the first four-year cycle of field operations of the Environmental Monitoring and Assessment Program (EMAP). EMAP-Estuaries utilizes a probability-based scientific design necessitating multiple years of sampling to produce estimates of the ecological condition of the Nation's estuarine resources. This document summarizes the data collected collected in the Virginian Province from 1990 to 1993, along with the uncertainty associated with those data. This uncertainty is expressed in the form of 95% confidence intervals around reported values. These confidence intervals were generated from a series of equations (included in Appendix B) based on the distribution of values across the entire Province and do not include a component for measurement error. These equations are currently under review, and, as such, the reported uncertainties should be considered tentative. Please note that this report contains data collected in a short index period (July to September). Appropriate precautions should be exercised when using this information for policy, regulatory or legislative purposes.

PREFACE

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ACKNOWLEDGEMENTS

This report describes the results of the first four year sampling cycle completed by EMAP-Estuaries. The work described in this document is a culmination of the efforts and dedication of dozens of individuals. The authors would like to take this opportunity to acknowledge the tremendous effort of all personnel involved in the EMAP-Virginian Province effort.

First and foremost we would like to acknowledge the efforts of Dr. Fred Holland, the first Technical Director of the Program and Steve Schimmel, the original Province Manager. Their dedication and persistence during the early stages of the Program served as inspiration for us all and proved invaluable in making the EMAP-Virginian Province effort succeed in meeting the highest standards set for marine environmental monitoring.

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Reviewers of this document included Steve Schimmel, John Scott, John Paul, Candace Oviatt, Tom DeMoss, John Hobbie and Mike Hirshfield.

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Nick Wolff
Bill Yates
Madeline Young

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ABBREVIATIONS

AED	Atlantic Ecology Division, NHEERL (formerly ERL-N)
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
ERL-N	Environmental Research Laboratory, Narragansett
MBT	Monobutyltin
mg/L	milligrams per liter = parts per million (ppm)
mg/kg	milligrams per kilogram = parts per million (ppm)
kg/m^3	kilograms per cubic meter
ND	Not Detected
ng/g	nanograms per gram = parts per billion (ppb)
NHEERL	National Health and Environmental Effects Research Laboratory (U.S. EPA)
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
QA	Quality Assurance
QC	Quality Control
SEM	Simultaneously Extracted Metals
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:

The EMAP 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 km² of estuarine resources including 11,469 km² in Chesapeake Bay and 3,344 km² in Long Island Sound.

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

In 1990 EMAP-E initiated a four-year demonstration project in the estuaries of the Virginian 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 is 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 large tidal rivers. The third class was the small estuaries and small tidal rivers which includes those systems whose surface areas fall between 2.6 km^2 and 260 km^2. This class represents 4,875 km^2 of the Virginian Province.

A total of 446 Base Sampling Sites were identified for sampling over the four-year period (1990-1993).

A total of 446 Base Sampling Sites (BSS: the probability-based sites used to characterize conditions in the Province) were identified for sampling over the four-year period (1990-1993). Of these 446 sites, 21 were deemed inaccessible due to inadequate water depth or other logistical constraints. The 425 sites sampled represent 94% of the estuarine surface area of the Province. All sites were sampled by three crews during the summer index period (late July through September).

The purpose of this report is to provide estimates of the ecological condition of the estuarine resources of the Virginian Province for the first complete four-year cycle of sampling

The purpose of this report is to provide regional managers and administrators with estimates of the ecological condition of the estuarine resources of the Virginian Province for the first complete four-year cycle of sampling. A separate Assessment Report (Paul *et al.*, in preparation) is currently being produced to evaluate associations between indicators as well as to evaluate the overall design of the Program. In addition, interim reports and Statistical Summaries have been produced describing the results of the 1990, 1991, and 1992 sampling efforts (Weisberg *et al.*, 1993; Schimmel *et al.*, 1994; Strobel *et al.*, 1994).

All EMAP-VP data used in the generation of this report were subjected to rigorous quality assurance measures as described in the 1993 Quality Assurance Project Plan (Valente and Strobel, 1993).

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.*

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 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 constructed from the combined 1990 - 1993 data and was developed to represent a combination of ecological measurements that best discriminates between good and poor ecological conditions. This index represents EMAP-E's attempt to reduce many individual benthic indicators into a single value that has a high level of discriminatory power between good and poor environmental conditions.

A benthic index critical value of zero was determined from the combined 1990 - 1993 Virginian Province dataset. Twenty three (± 3) percent of the bottom area of the Virginian Province had an index value of < 0, indicating likely impacts on the benthic community (Figure 1). The lowest incidence was found in the large estuaries (18 ± 4%).

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 36 ± 3% of the Province (Figure 2).

The incidence of gross external pathologies (growths, lumps, ulcers, and fin erosion) among fish collected in the Virginian Province was 0.3%

The incidence of gross external pathologies (growths, lumps, ulcers, and fin erosion) among fish collected in the Virginian Province was 0.3%. Of the over 16,000 fish examined, 55 were identified as having one or more of these conditions.

Twenty three (± 3) percent of the bottom area of the Virginian Province had an index value of < 0, indicating likely impacts on the benthic community.

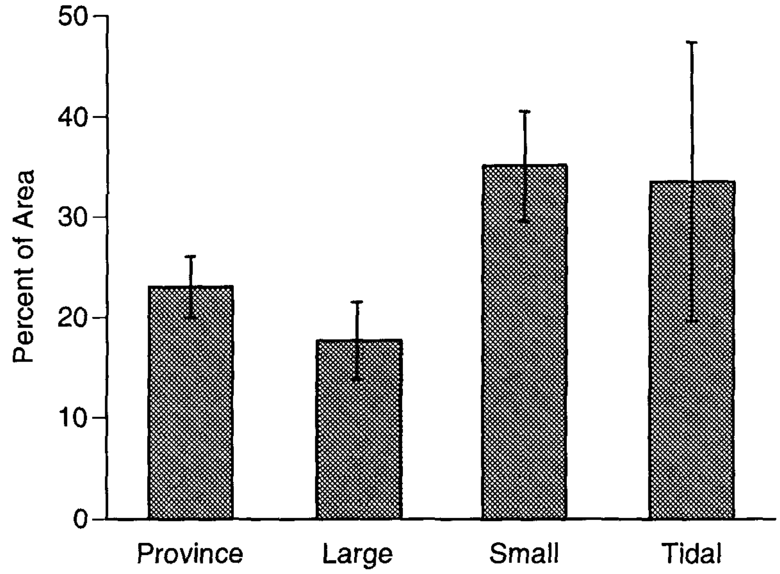

Figure 1. Percent area of the Virginian Province by estuarine class with a benthic index value below 0. (Error bars represent 95% confidence intervals).

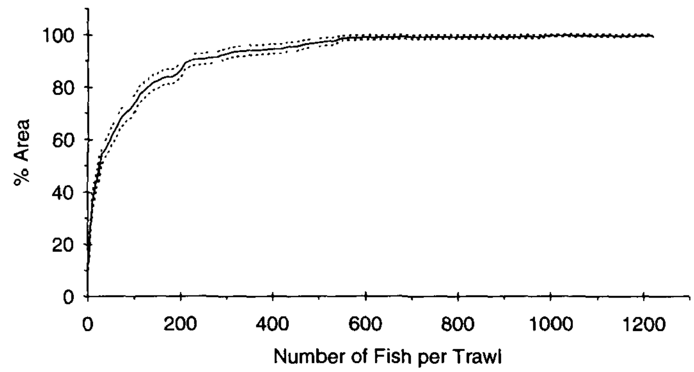

Figure 2. Cumulative distribution of fish abundance in numbers per standard trawl as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

Abiotic Condition Indicators

Abiotic condition indicators *quantify the levels of stresses to which organisms are exposed.*

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 5 mg/L are values employed by EMAP to define severe and moderate hypoxia, respectively. Approximately 25 ± 3% of the sampled area of the Province contains bottom waters with DO concentrations less than or equal

Approximately 25 ± 3% of the sampled area of the Province contains bottom waters with DO concentrations less than or equal to 5 mg/L.

Approximately 5 ± 2% of the sampled area exhibited bottom DO conditions ≤2.0 mg/L.

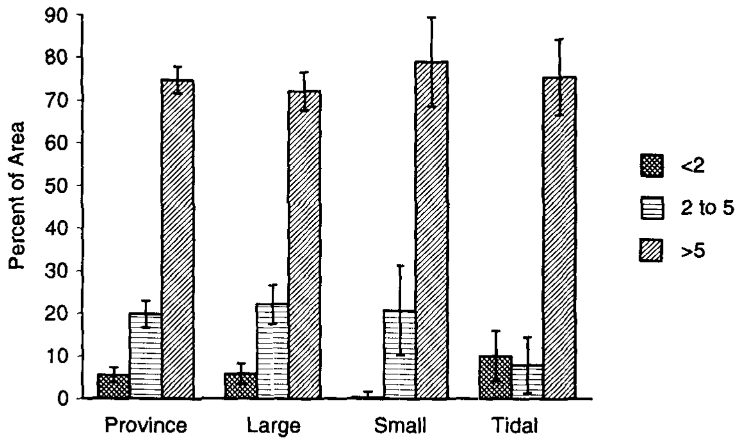

Figure 3. The percent of area by class that had a low (≤ 2 mg/L), medium (2 to 5 mg/L), or high (>5 mg/L) oxygen concentration in the bottom waters. (Error bars represent 95% confidence intervals).

to 5 mg/L (Figure 3). "Bottom" is defined as one meter above the sediment-water interface. Approximately 5 ± 2% of the sampled area exhibited bottom DO conditions ≤2.0 mg/L. Dissolved oxygen conditions ≤2.0 mg/l were evident in all three classes of estuaries (Figure 3).

In addition to measuring contaminants in sediments, acute 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 10 ± 2% of the sampled area of the Virginian Province contained sediments which were toxic to the amphipod during 10-day exposures (Figure 4). Sediments were highly toxic (*i.e.*, survival < 60% of control) in 2 ± 1% of the area of the Province.

Approximately 10 ± 2% of the sampled area of the Virginian Province contained sediments which were toxic to the amphipod Ampelisca abdita *during 10-day exposures.*

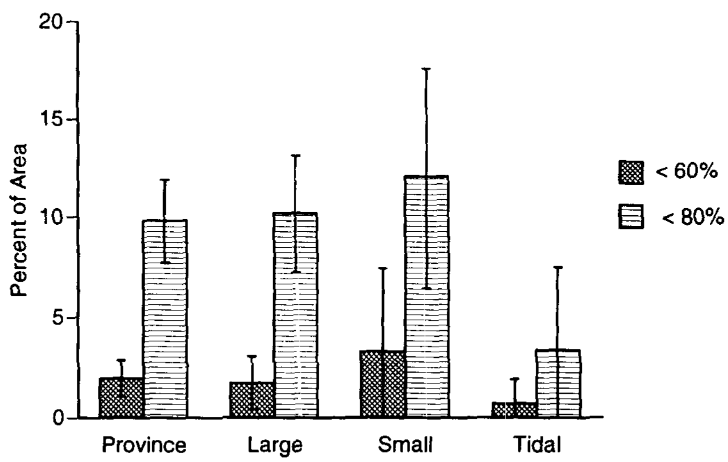

Figure 4. Percent of area in the Virginian Province, by estuarine class, with low (<80% of control) or very low (<60% of control) amphipod survival in sediment toxicity tests. (Error bars represent 95% confidence intervals).

75% of the area of the Province contained sediments with concentrations of PAHs ≤1,200 ng/g, with a maximum measured concentration at any station of 80,100 ng/g.

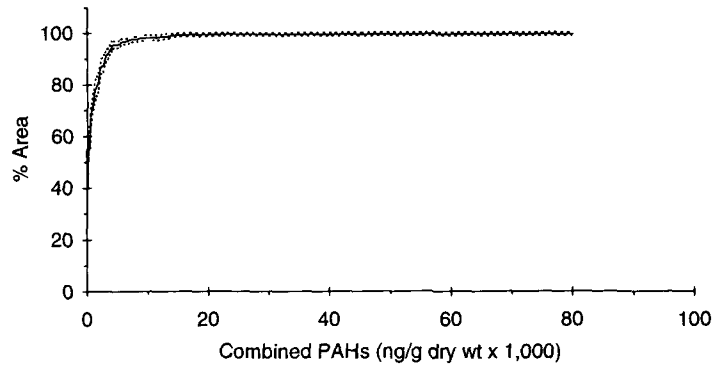

Figure 5. Cumulative distribution of combined PAHs in sediments as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

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. Although no definitive statement can be made estimating the overall aerial extent of sediment contamination in the Virginian Province, the results of several different approaches are presented and discussed.

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. The 75th percentile for total PAHs was approximately 1,200 ng/g (*i.e.*, 75% of the area of the Province contained sediments with concentrations of PAHs ≤1,200 ng/g), with a maximum measured concentration at any station of 80,100 ng/g.

Draft Sediment Quality Criteria for PAHs were exceeded at only one station within the Province.

Draft EPA Sediment Quality Criteria (SQC) are currently available for the PAHs acenaphthene, phenanthrene, and fluoranthene; and the pesticide dieldrin. Draft PAH SQC were exceeded at only one small estuary station within the Province (*ca.* 0.07% of the area).

Stations representing only 1 ± 1% of the area of the Province exceeded any Long and Morgan ER-M value for PAHs.

Stations representing only 1 ± 1% of the area of the Province exceeded any ER-M (Effects Range-Median from Long *et al.*, 1995) value for PAHs.

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. The process utilized was inefficient for several metals (*i.e.*, r^2 for the regression < 0.4), but performed well for As, Cr, Fe, Hg, Mn, Ni, Sb, and Zn. The percent area of the Virginian Province with sediments enriched by metals pertains only to the metals mentioned above. Figure 6 presents the results of this normalization. The metal exhibiting the greatest extent of enrichment is manganese. Approximately 46 ± 5% of the area of the Province showed enrichment of sediments with at least one metal. Thirty seven (± 7), 64 ± 3, and 69 ± 16

Approximately 46 ± 5% of the area of the Province showed enrichment of sediments with at least one metal. Note that enrichment does not imply potential ecological effects.

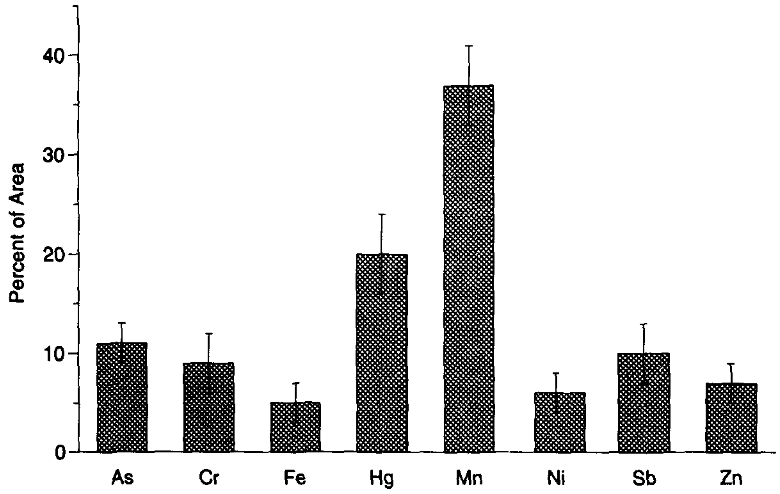

Figure 6. Percent area of the Virginian Province with enriched concentrations of individual metals in sediments. (Error bars represent 95% confidence intervals).

percent of the large estuary, small estuary, 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; therefore, this does not imply concentrations are elevated to the point where biological effects might be expected. As shown below, sediment from only a fraction of this area contains concentrations of metals high enough to result in ecological effects.

Stations representing only 4 ± 2% of the area of the Province exceeded any Long and Morgan ER-M value for metals.

Stations representing only 4 ± 2% of the area of the Province exceeded any ER-M (Effects Range-Median from Long *et al.*, 1995) value for metals. It should be noted that earlier EMAP-E documents utilized the Long and Morgan (1990) values. ER-M and ER-L values have subsequently been updated (Long *et al.*, 1995) and it is these newer values that are used in this report. The major difference is an increase in the ER-M values for metals, resulting in a significant reduction in the percent area of the Province in exceedence.

Presence of marine debris in fish trawls was documented by field crews as being encountered at stations representing 20 ± 3% of the Virginian Province area (Figure 7). The small estuary class had the largest percent area (35 ± 9%) where trash was found.

Presence of marine debris in fish trawls was documented by field crews as being encountered at stations representing 20 ± 3% of the Virginian Province area.

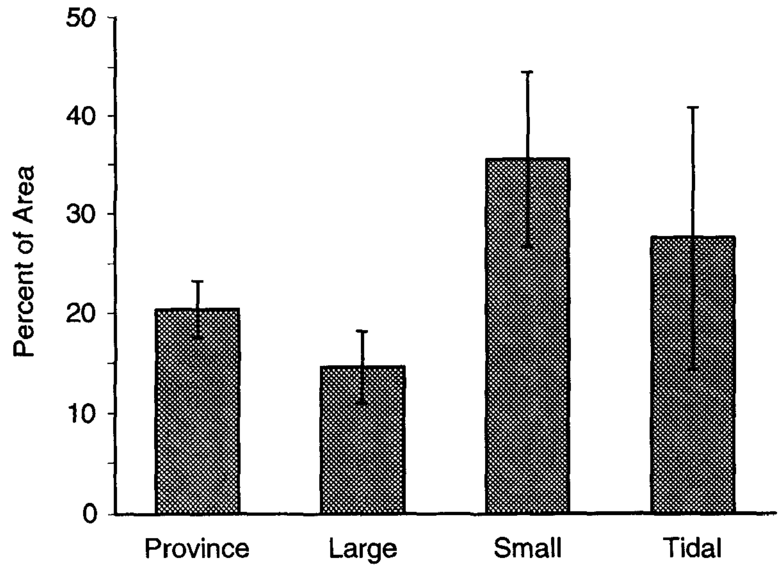

Figure 7. The percent of area of the Virginian Province by estuarine class where anthropogenic trash was collected in fish trawls. (Error bars represent 95% confidence intervals).

Habitat Characterization

Habitat indicators *describe the natural physical and chemical conditions of the sites sampled.*

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.

Based on the sampling design where a single station represents a statistical area (*e.g.*, 70 km^2 for large estuary sites), 6% of the area of the Province could not be sampled due to inadequate water depth or inaccessibility.

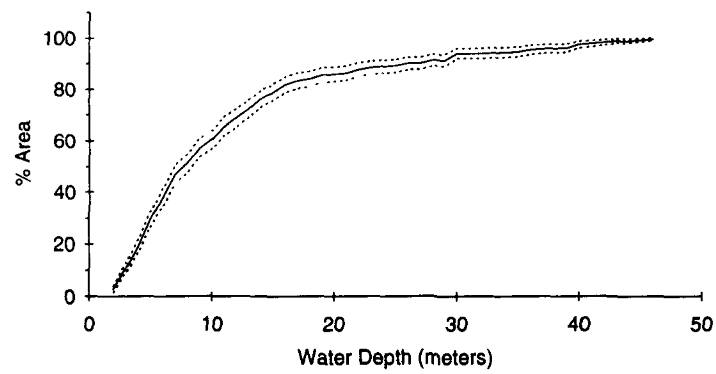

Figure 8. Cumulative distribution of water depth as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

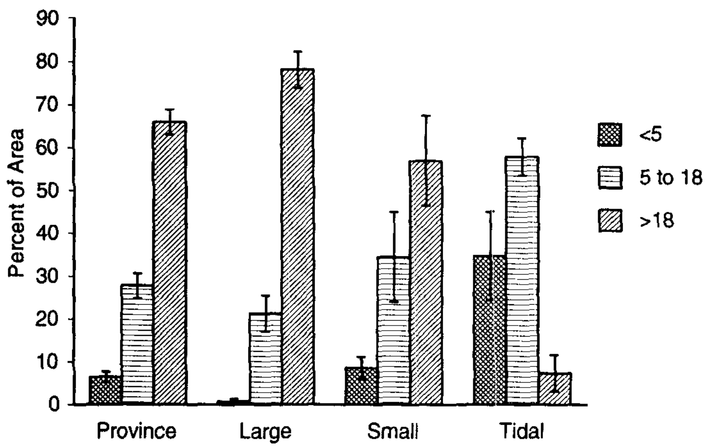

Figure 9. The percent of area by estuarine class classified as oligohaline (<5‰), mesohaline (5 to 18‰), or polyhaline (>18‰). (Error bars represent 95% confidence intervals).

Bottom water temperatures in the Virginian Province ranged from 12°C to 30°C during the summer sampling season.

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 difference in σ_t (sigma-t, a density measurement) between surface and bottom waters. Approximately 72 ± 3% 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 13 ± 3% of the Province area was strongly stratified ($\Delta\sigma_t$ >2).

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 (*i.e.*, only 10% of incident sunlight reaches a depth of one meter; light attenuation coefficient ≥ 2.303). 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 (*i.e.*, only 25% of incident sunlight reaches a depth of one meter; light attenuation coefficient ≥ 1.387). Water clarity was good in 81 ± 3% of the area of the Virginian Province (Figure 11). Water of low clarity was found in 6 ± 2% of the Province and an additional 13 ± 2% had water of moderate clarity.

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.

The majority of the water in the Virginian Province was well-mixed. Only 13 ± 3% of the Province area was strongly stratified.

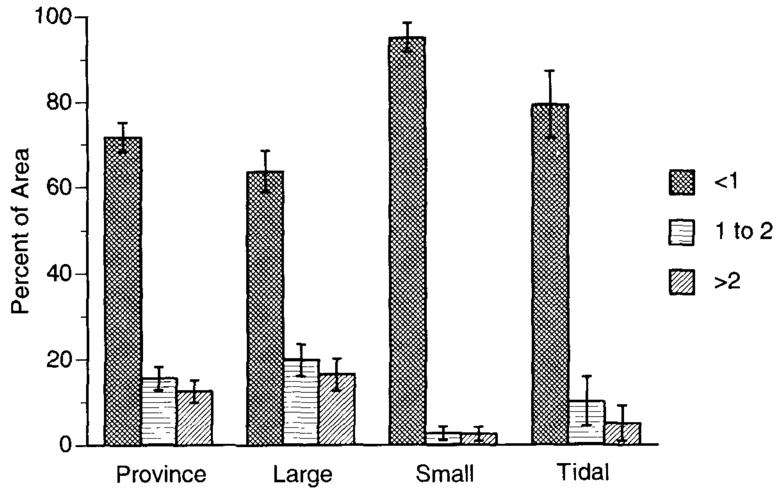

Figure 10. The percent of the area by estuarine class that had a low (<1), medium (1 to 2), or high (>2) degree of stratification ($\Delta \sigma_t$ as kg/m^3). (Error bars represent 95% confidence intervals).

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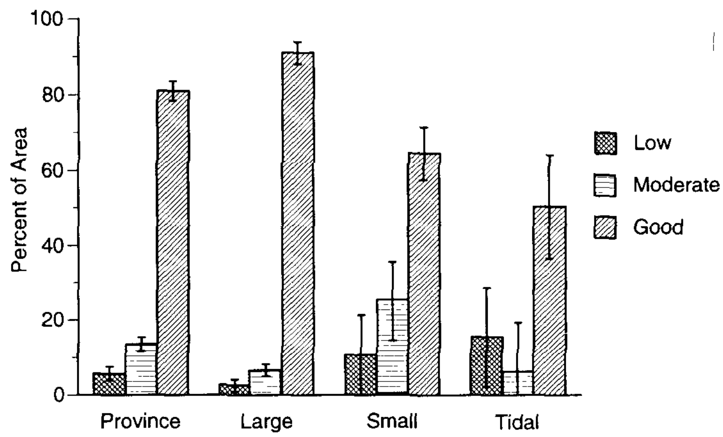


Figure 11. The percent of area by estuarine class where water clarity was poor, moderate, or good. (Error bars represent 95% confidence intervals).

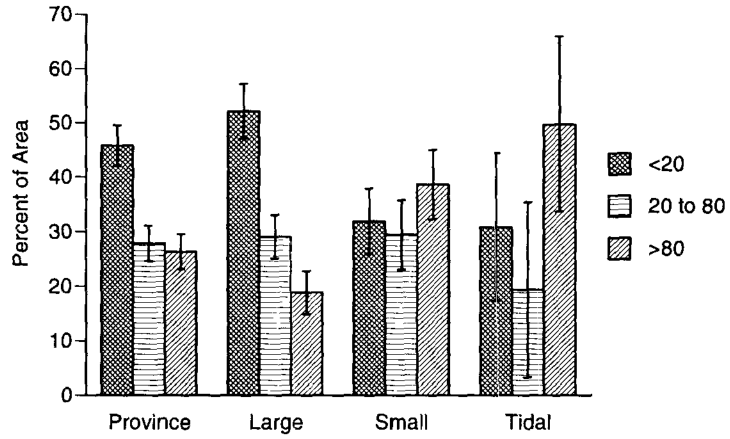


Figure 12. The percent of area by estuarine class with a low (<20), medium (20 to 80), or high (>80) percent silt/clay in the sediments. (Error bars represent 95% confidence intervals).

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.

EMAP-E initiated a four-year Demonstration Project in 1990 in the estuaries of the Virginian Province (*i.e.*, estuaries, bays and sounds between Cape Cod, MA and Cape Henry, VA: Holland, 1990; 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.

1.1 Objectives of Virginian Province Monitoring Activities

The objectives of the EMAP-Estuaries monitoring program, as described in the EMAP-Estuaries Program Plan (Holland 1990), are as follows:

- Provide a quantitative assessment of the regional extent of coastal environmental problems by measuring pollution exposure and ecological condition,
- Measure changes in the regional extent of environmental problems for the nation's estuarine and coastal ecosystems,
- Identify and evaluate associations between the ecological condition of the nation's estuarine and coastal ecosystems and pollutant exposure, as well as other factors known to affect ecological condition (*e.g.*, climatic conditions, land use patterns), and
- Assess the effectiveness of pollution control actions and environmental policies on a regional scale (*i.e.*, large estuaries like Chesapeake Bay) and nationally.

Additional objectives of the Virginian Province monitoring program were to:

- 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.

Data collected in the first EMAP cycle (1990 - 1993) will be used to establish baseline conditions in the Virginian Province for future trends analyses.

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) during the index sampling period, the period when many estuarine responses to anthropogenic and natural stresses are anticipated to be most severe. This index period was identified in 1990 based on dissolved oxygen conditions in the Province to be the end of July through the end of September. The 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

EMAP is designed to provide data on a regional scale. This design creates a 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 and the Near Coastal Program Plan (Holland, 1990) for additional information on the statistical design.

1.4 Purpose and Organization of This Report

This Statistical Summary is meant to provide large quantities of information without including extensive interpretation of these data. The purpose of this report is to provide estimates of the ecological condition of the estuarine resources of the Virginian Province based solely on selected individual indicators. These estimates are based on samples collected during a four-year sampling period, 1990-1993. A separate interpretative Assessment Report is currently being produced to evaluate associations between indicators as well as to evaluate the overall design of the Program (Paul *et al.*, in preparation). This report will provide more detail on the condition of ecological resources (in addition to Province-wide estimates, it will present results for the major estuarine watersheds in the Province), evaluate associations between ecological condition and other indicators, and attempt an evaluation of the effectiveness of the program in meeting its objectives. In addition, interim reports and Statistical Summaries have been produced describing the results of the 1990, 1991, and 1992 sampling efforts (Weisberg *et al.*, 1993; Schimmel *et al.*, 1994; Strobel *et al.*, 1994).

This report is organized into sections addressing the objectives and results of the 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 provides a brief overview of the sampling effort, including providing maps showing all sampling locations.

Section 3 is the statistical summary of the data collected during the survey. Also included in this section is pertinent Quality Assurance/Quality Control information.

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

Section 5 lists the references cited in this report.

Appendix A provides an overview of the sampling design used for base-level monitoring, as well as details concerning special studies conducted to assess spatial variability. This appendix also describes the selected indicators used in this study.

Appendix B presents the equations utilized in the construction of Cumulative Distribution Functions (CDFs) and the associated confidence intervals.

Appendix C 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.

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 Virginian Province survey was conducted annually during late July through early September from 1990 to 1993. 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.

Four hundred and forty six stations in the Virginian Province, located between Cape Cod (MA) and Cape Henry (VA), were scheduled for sampling over four years.

Sample collection in the Virginian Province focused on ecological indicators during the index sampling period, 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 (Schimmel, 1990; Strobel *et al.*, 1992). A more detailed discussion of the indicators and sampling methods can be found in Appendix A.

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. Four hundred and twenty five BSS were sampled during the index period over four years. A total of 446 were scheduled for sampling; however 21 were deemed unsampleable due to inadequate water depth or inaccessibility.

Stations sampled each year 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 five or six consecutive days (depending on the year). During this 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 uniformly sampled across the Province in a North-South series. Each Base Sampling site was visited once during the index period. Figures 2-2, 2-3, and 2-4 present maps of all the Base Sampling Sites scheduled for sampling in the Virginian Province monitoring program.

Each year prior to sampling all crew members were required to attend an intensive 4-6 week training course covering all aspects of sampling. Crews were also required to participate in one week of "dry runs" prior to sampling.

The 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 sampling plan is reflected in the high percentage of stations for which usable data were obtained for the variety of parameters measured. As stated above, 21 stations could not be sampled. These stations represent only six percent of the area of the Province. Although the remaining stations (425) were successfully sampled, not all stations were sampled for all parameters. The number of stations with valid data are included in the discussion of each indicator in Section 3.

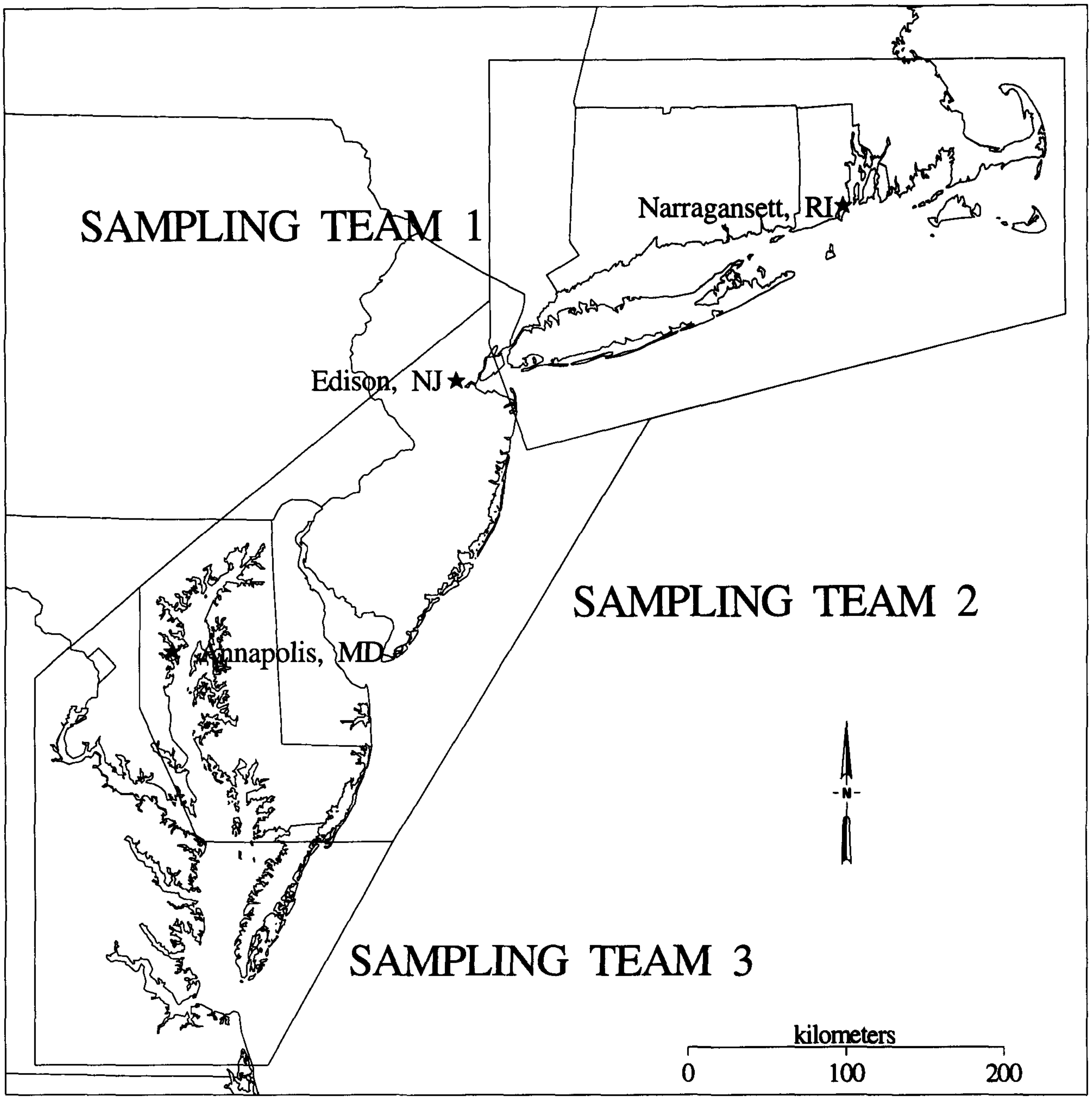


Figure 2-1. Areas of Responsibility of the EMAP-VP Sampling Teams.

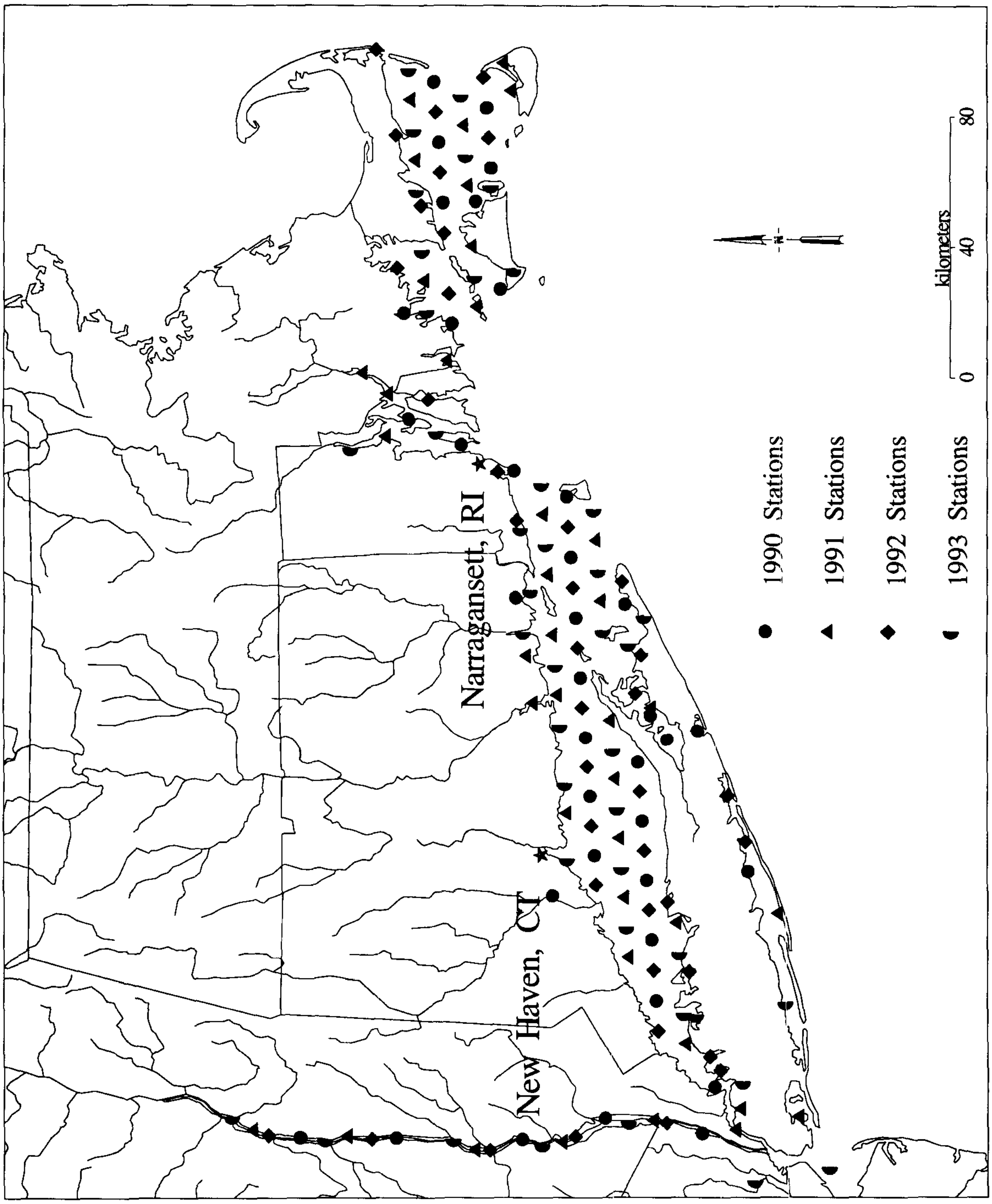


Figure 2-2. Team 1 Base Sampling Stations.

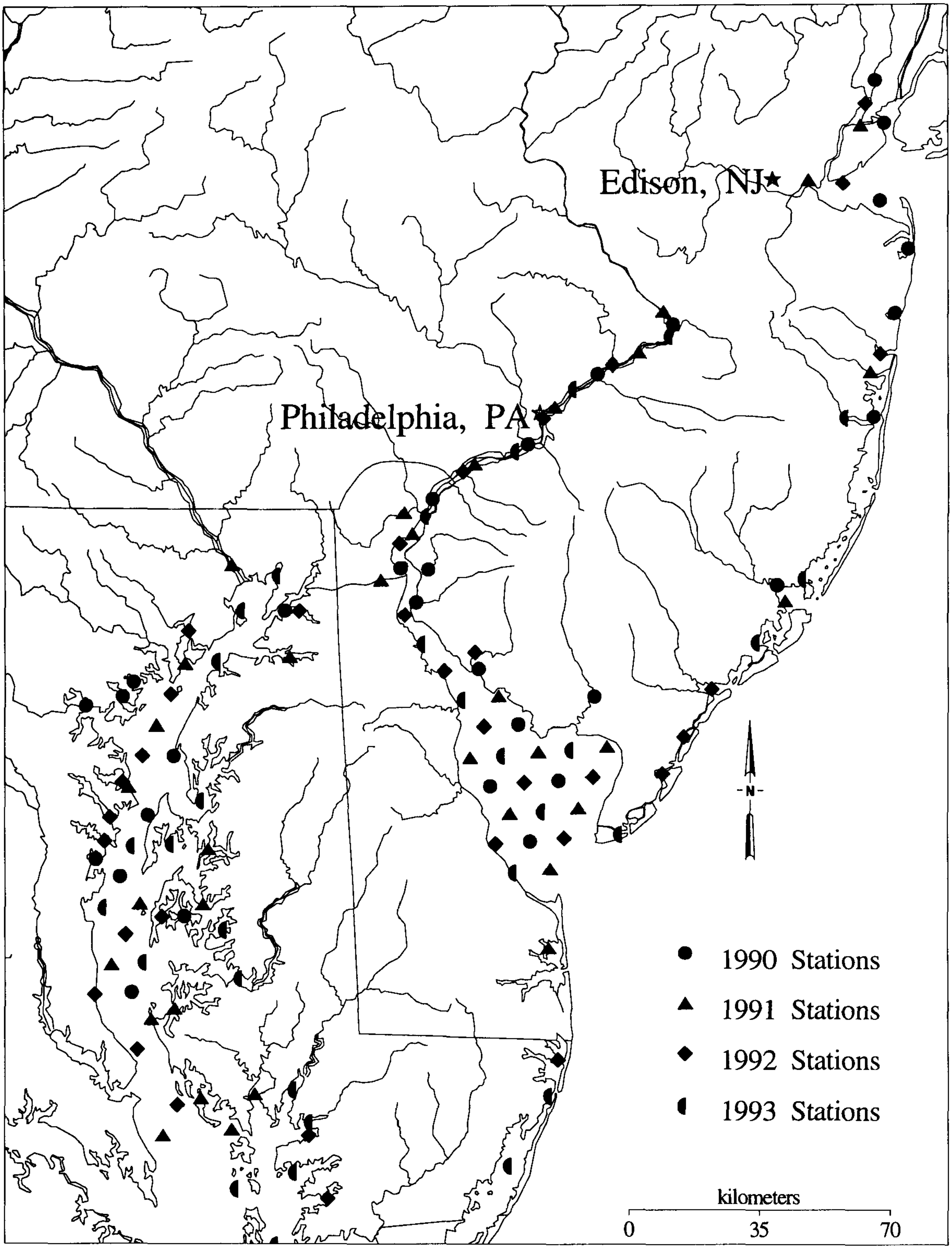


Figure 2-3. Team 2 Base Sampling Stations.

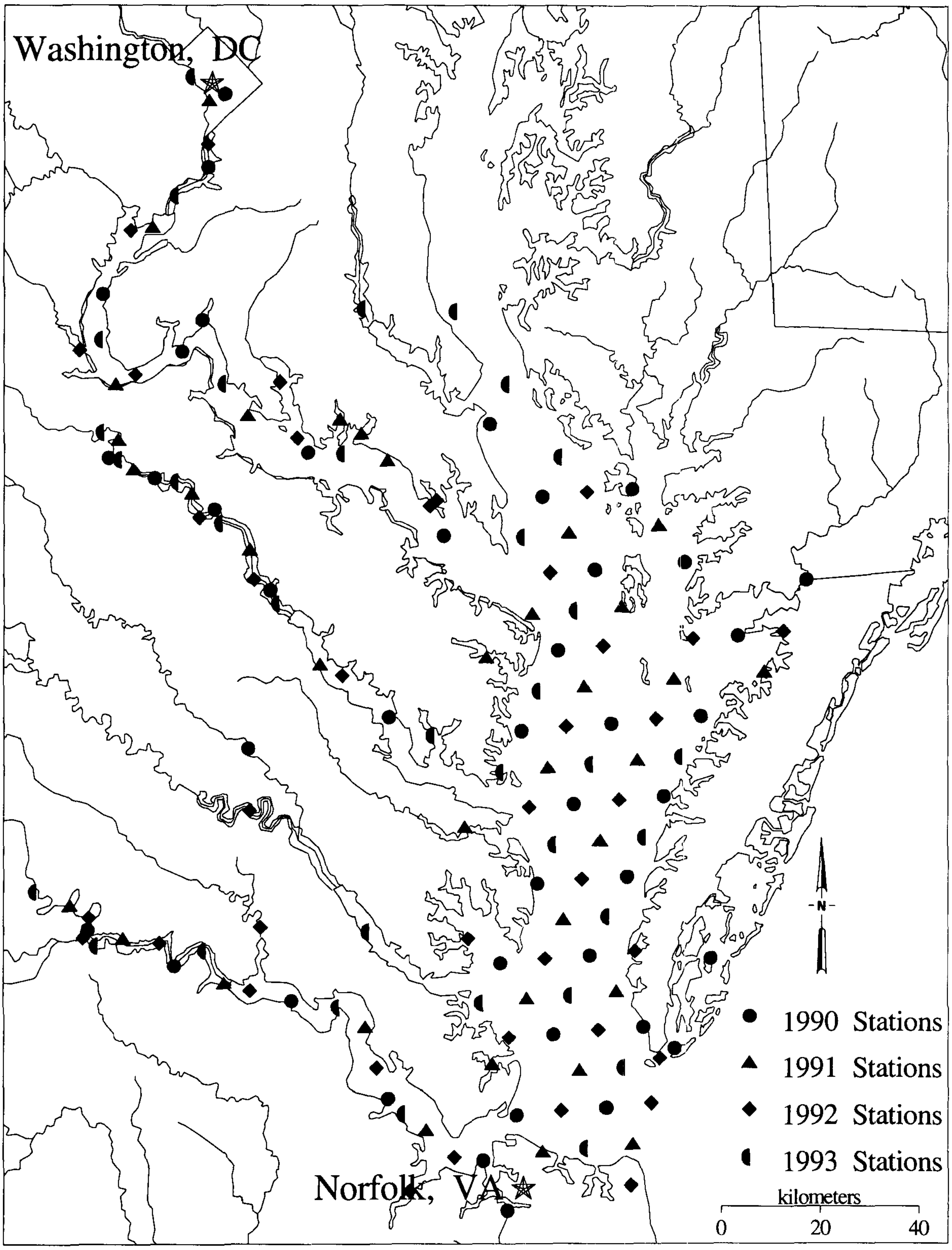


Figure 2-4. Team 3 Base Sampling Stations.

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 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 present the frequency of occurrence of observations within the Province. Bar graphs are also presented, where appropriate, to delineate the proportions of the Province or estuarine class resources that are impacted, or falling above or below values of interest. Methods are only briefly discussed for individual indicators. A more thorough discussion can be found in Appendix A.

The term "impacted" is used throughout this document. EMAP is using this terminology when scientific data are available to distinguish between good and poor ecological conditions. As an example many states consider a dissolved oxygen concentration below 2 mg/L to be deleterious to aquatic life. We are therefore defining the portion of the Virginian Province with a dissolved oxygen concentration below 2 mg/L to be "impacted". It is important to note that available criteria for defining "impacted" conditions do not exist for all EMAP indicators of ecological condition.

As described in Section 1.4, this is not intended as an interpretative report. Results are summarized and reported in this section with only limited interpretation provided. Interpretation and conclusions will be provided in a separate interpretative Assessment Report (Paul *et al.*, in preparation).

CDFs display the full distribution of the values observed for an indicator plotted against the cumulative

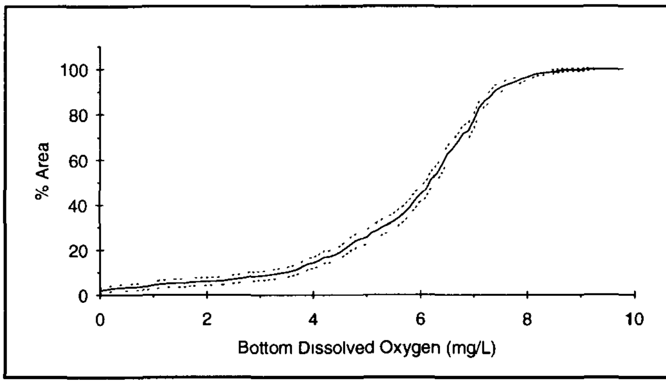


Figure 1. Example cumulative distribution of bottom dissolved oxygen as a percent of area. (Dashed lines are the 95% confidence intervals).

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 observed DO concentrations 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 intersects with the cumulative area in the Province at 5 ± 2%. The reader might also be interested in a state regulatory criterion of 5 mg/L, and the CDF shows that 25 ± 3% of the estuarine bottoms waters had DO concentrations below these levels. 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 approximately 23 ± 3% of the bottom waters in the Province were observed to be above 7 mg/L DO (*i.e.*, 77 ± 3% ≤ 7 mg/L).

Criteria values for the assessment of impacted versus non-impacted 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 impacted.

Equations used in the generation of the CDFs and associated confidence intervals are provided in Appendix B. These equations were provided by EMAP-Estuaries, and estimate confidence intervals based solely on the distribution of values across the Province, regardless of measurement error. The reader should note that the equations for large estuaries and large tidal rivers differ from those used for generating single-year estimates in the 1991 and 1992 Statistical Summaries. The original equations were designed solely for use with single-year data and are not appropriate for use in this report. It should be noted that these equations are still under review and may be further refined in the future to address additional measurements of variability. Comparing results generated using the "old" *vs* "new" equations shows only small changes resulting.

3.1 BIOTIC CONDITION INDICATORS

Biotic condition indicators (previously termed response 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.

3.1.1 Benthic Index

Condition of the benthic community was 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.

Three 440cm^2 grab samples were collected at each station and sieved through a 0.5 mm sieve. Organisms and debris collected on the sieve were preserved in 10% formalin and returned to the laboratory for sorting, identification, enumeration, and biomass determination.

A benthic index which uses measures of 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 all four years of sampling and was constructed 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. The reader should note that this index is different from the one used in earlier EMAP-VP reports. This index was determined using all four years of data as part of the assessment exercise currently underway.

The process for developing an index of benthic community condition has been documented for the 1990 (Weisberg *et al.*, 1993) and, separately, for the 1990-91 (Schimmel *et al.*, 1994) data sets. This process entails several discrete steps: identification of a set of benthic parameters to define conditions that include components of faunal and functional diversity and structure; determination of the statistical relationships between these benthic parameters and habitat variables; normalization of those benthic parameters that are strongly associated with habitat condition; identification of a test data set that clearly distinguishes relatively pristine sites from those exhibiting toxic contamination, hypoxia, or both; and application of discriminant analysis to the test data set to determine those benthic parameters whose variation is most closely associated with differences in reference and impacted condition. This same process was used with the 1990-93 data set.

The development of this index is detailed in the EMAP-Virginian Province Four-Year Assessment Report (Paul *et al.*, in preparation) and Appendix A of this document.

The three benthic parameters of the index were: salinity-normalized expected Gleason's D (Washington, 1984) for infaunal and epifaunal species, salinity-normalized expected number of tubificids, and abundance of spionids. The richness measure is associated with reference conditions (positive contribution) and the latter two measure are associated with impacted conditions (negative contribution).This index results in a slightly better classification efficiency (ca. 90% for the test data set) than the index utilized in the 1991 and 1992 Statistical Summaries (ca. 85%). This index also performs much better for low salinity waters than the previous index.

The discriminant score calculation normalizes the individual parameters based on the mean and standard deviation for the parameter in the test data set. The critical value for discriminating between reference and impacted sites was determined to be zero using the following equation:

Benthic Index Score =

1.389 (pct expect Gleason - 51.5) / 28.4
- 0.651 (normalized tubificid abundance - 28.2) / 119.5
- 0.375 (spionid abundance - 20.0) / 45.4

Where:

Percent Expected Gleason diversity index value =

Gleason / (4.283 - 0.498*bottom salinity
+ 0.0542 * bottom salinity^2
- 0.00103* bottom salinity^3) * 100

Normalized Tubificid Abundance =

Tubificids - 500 * $e^{-15\text{*bottom salinity}}$

Twenty three (± 3) percent of the bottom area of the Virginian Province sampled had an index value of < 0, indicating likely impacts on the benthic community (Figure 3-2). The percent area classified as impacted among the three classes of estuaries are 18 ± 4 %, 35 ± 6 %, and 33 ± 14% for large estuaries, small estuarine systems, and large tidal rivers, respectively (Figure 3-3).

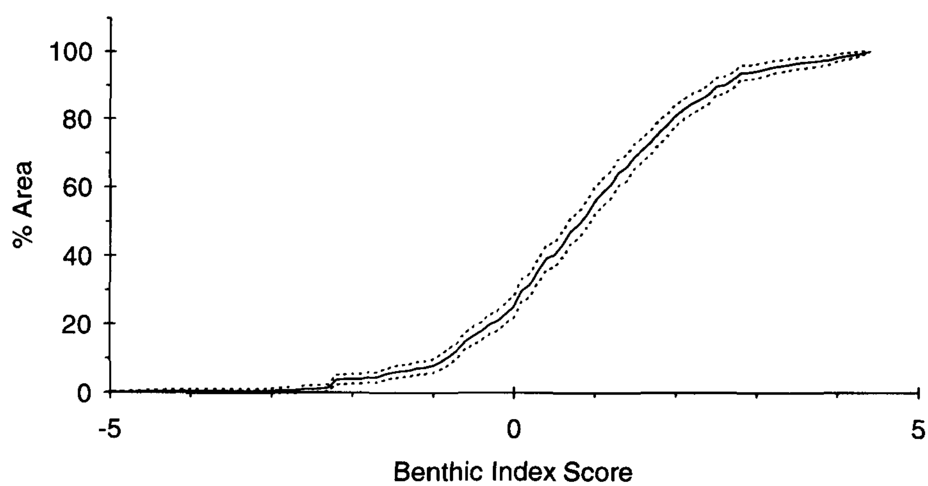


Figure 3-2. Cumulative distribution of the benthic index as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

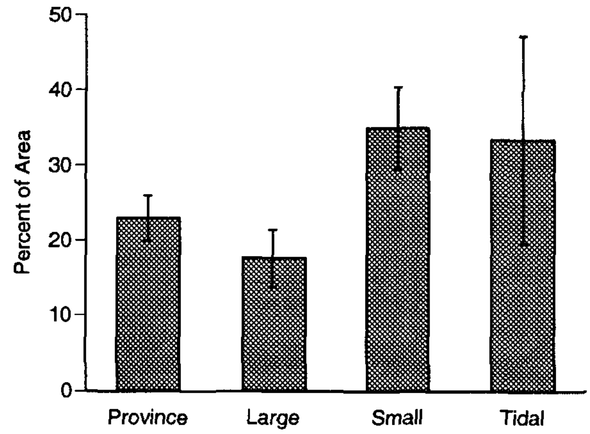


Figure 3-3. Percent area of the Virginian Province by estuarine class with a benthic index value below 0. (Error bars represent 95% confidence intervals).

<u>Quality Assurance</u>

Valid benthic index data exist for 401 of the 446 Base Sampling Sites in the database (90%). The 401 sites sampled represent 88% of the area of the Virginian Province. The current benthic index database contains no QA qualifier flags, indicating that all the data are valid and need no qualification. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

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 68 (Figure 3-4), with the maximum number of species per grab being 68, 52, and 25 in the large estuaries, small estuaries, and large tidal rivers respectively (Figure 3-5).

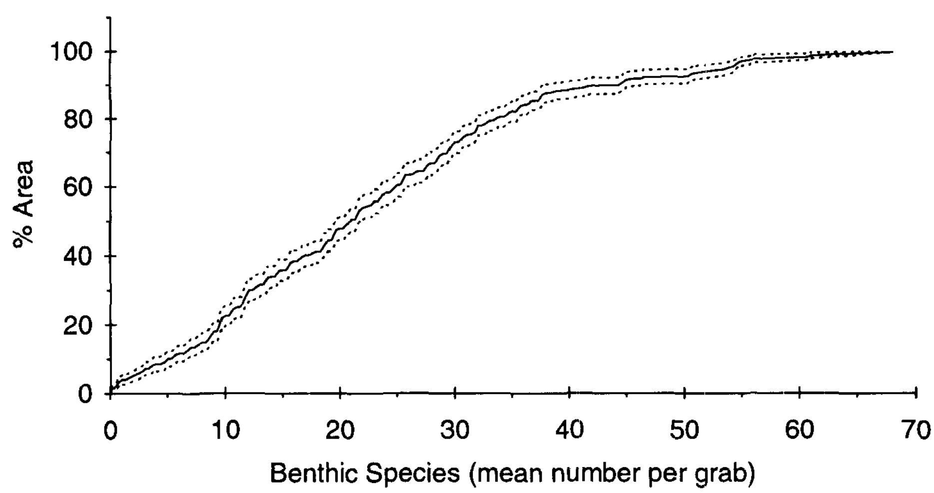
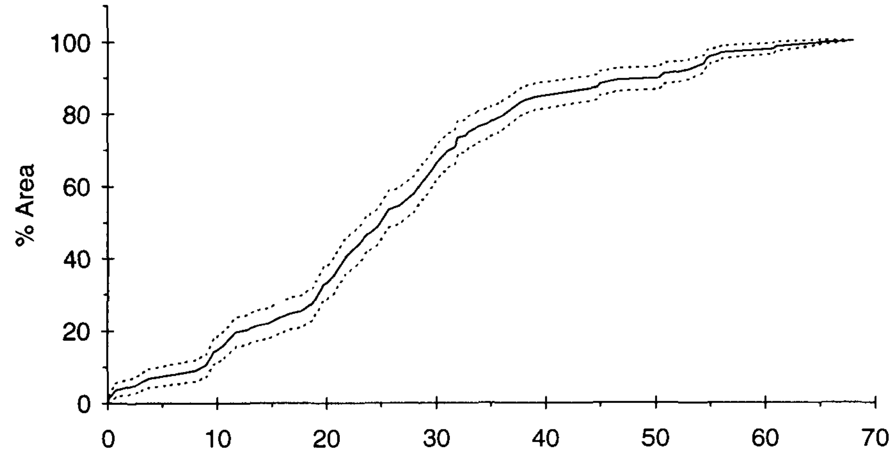
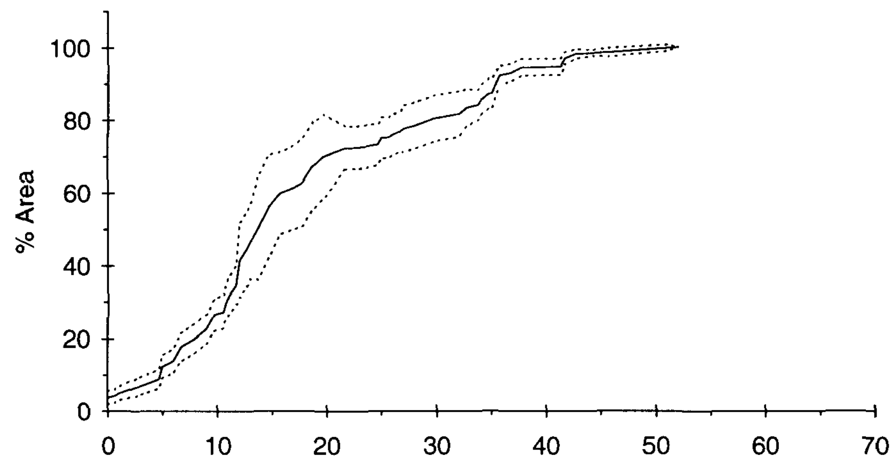


Figure 3-4. Cumulative distribution of the mean number of infaunal benthic species per grab as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

a) Large Estuaries



b) Small Estuaries



c) Large Tidal Rivers

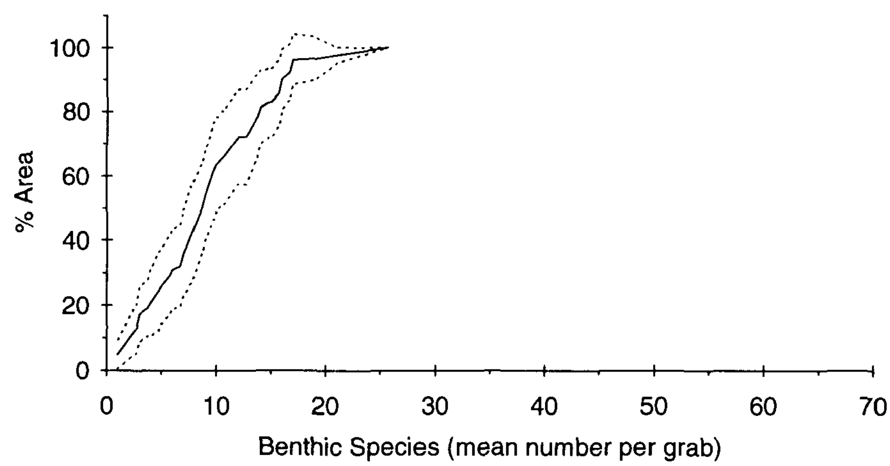


Figure 3-5. Cumulative distribution of the number of infaunal benthic species per grab by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

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 that can be useful in assessing future trends in community structure.

Quality Assurance

Valid benthic data exist for 404 of the 446 Base Sampling Sites in the database (91%). The 404 sites sampled represent 89% of the area of the Virginian Province. The current benthic database contains no QA qualifier flags, indicating that all the data are valid and need no qualification. As part of laboratory QA the analytical laboratory is required to resort, re-identify, and recount 10% of the samples. All reanalysis results were within 10% (QA control limit) of the original data. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

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 138,000 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, 7 ± 2% of the Virginian Province had low abundances, and 9 ± 2% had low to 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 that the community is impacted; however, this information can be useful in detecting trends.

The percent area of low abundance was low in all three estuarine classes. Five ± 2 , 8 ± 3, and 15 ± 9 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 (138,674 per m^2) was found in the large estuary class, with maximums of 76,530 and 20,591 found in the small estuary and large tidal river classes, respectively.

Quality Assurance

Valid benthic data exist for 404 of the 446 Base Sampling Sites in the database (91%). The 404 sites sampled represent 89% of the area of the Virginian Province. The current benthic database contains no QA qualifier flags, indicating that all the data are valid and need no qualification. As part of laboratory QA the analytical laboratory is required to resort, re-identify, and recount 10% of the samples. All reanalysis results were within 10% (QA control limit) of the original data. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

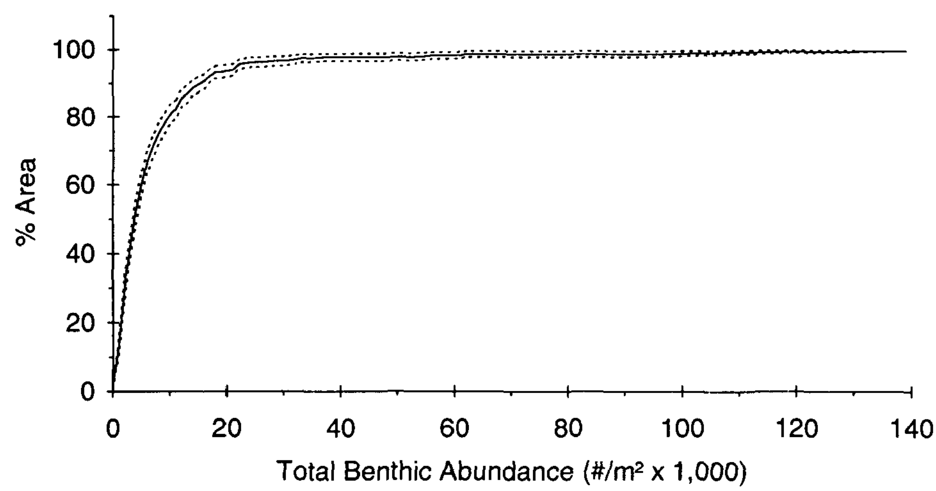


Figure 3-6. Cumulative distribution of the total number of infaunal benthic organisms per m^2 as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

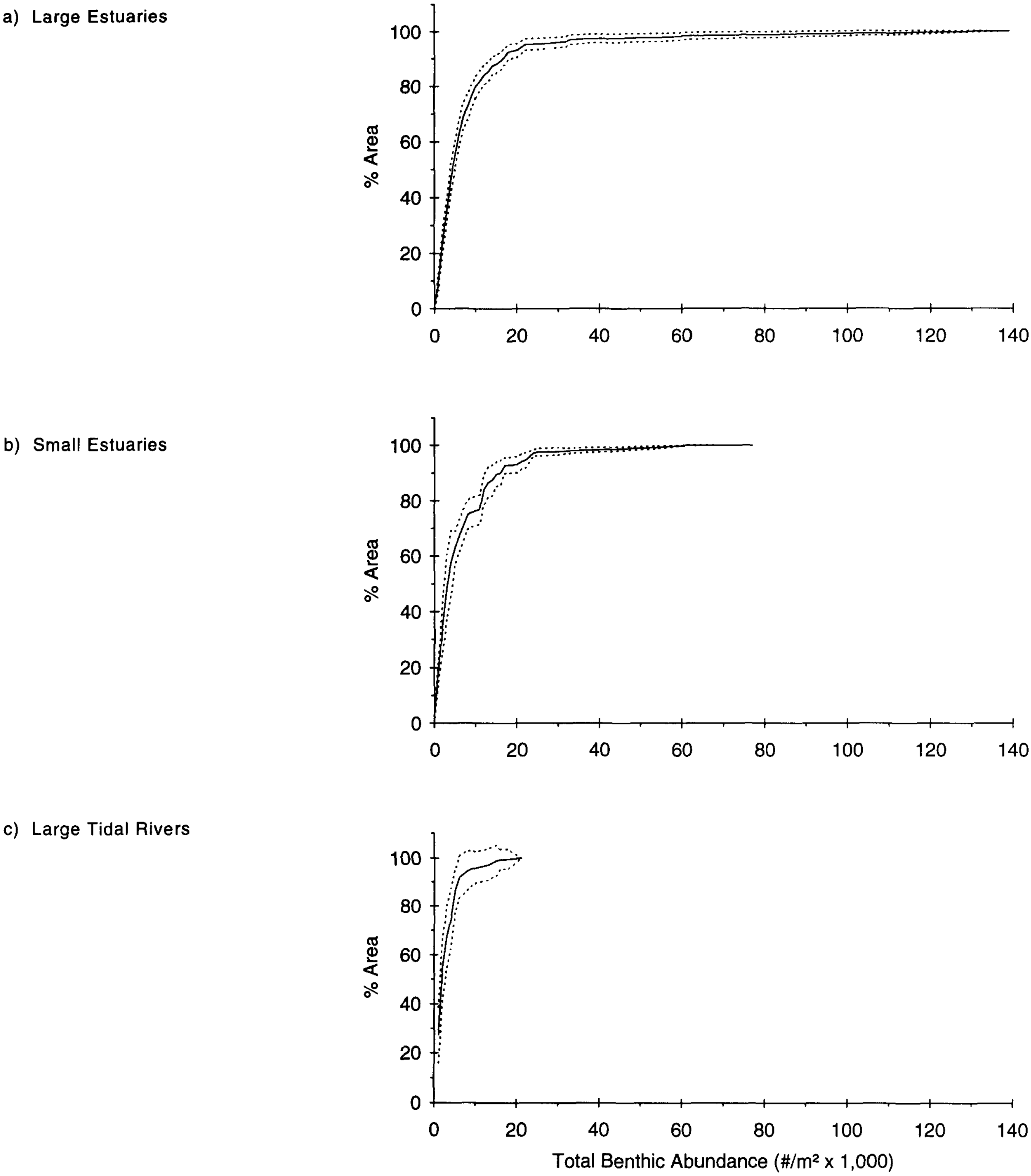


Figure 3-7. Cumulative distribution of the total number of infaunal benthic organisms per m^2 by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

3.1.4 Number of Fish Species

Fish were collected by trawling with a 15 m, high-rise otter trawl with a 2.5-cm mesh cod end. The net was towed for 10 (± 2) minutes against the tide (if significant tidal current existed) between 0.5 and 1.5 m/s (1-3 knots). All fish caught in the trawl were identified to species and counted; up to 30 fish of a species from each collection were measured to the nearest millimeter.

Zero to 17 species of fish were collected from single standardized trawls performed at each base station in the Virginian Province (Figure 3-8). A total of 104 species were collected in standard trawls throughout the Province over four years.

Fish catch can be affected by many variables including salinity, habitat, and migrations; 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 impacted 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. Attempts to develop a fish index, similar to the benthic index described above, have not been successful to date. However, EMAP's efforts to develop such an index are continuing.

Two or fewer species were caught in standard trawls in 30 ± 3% of the Virginian Province. Alternatively, at least five fish species were collected throughout 35 ± 4% of the sampled area of the Province. No fish were collected at 26 stations, representing 7 ± 2% of the area of the Province. The areas producing no fish catch were located primarily in large estuaries (9 ± 3% of the area; Figure 3-9). Fish were collected at all but eight small estuary stations (96 ± 3% of the area) and at all but two large tidal river stations (96 ± 4% of the area: Figure 3-9).

Quality Assurance

Valid fish species composition data exist for 390 of the 446 Base Sampling Sites in the database (87%). The 390 sites sampled represent 87% of the area of the Virginian Province. The current fish community database contains no QA qualifier flags, indicating that all the data are valid and need no qualification.

Each crew was required to preserve the first one or two (depending on the year) individuals of each species collected. These fish were shipped to an analytical laboratory for taxonomic verification by a fisheries expert.

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.

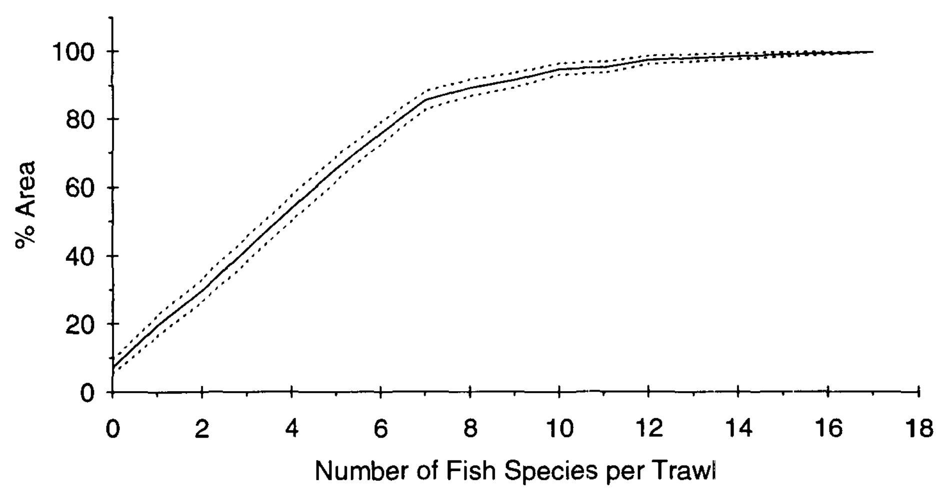


Figure 3-8. Cumulative distribution of the number of fish species per standard trawl as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

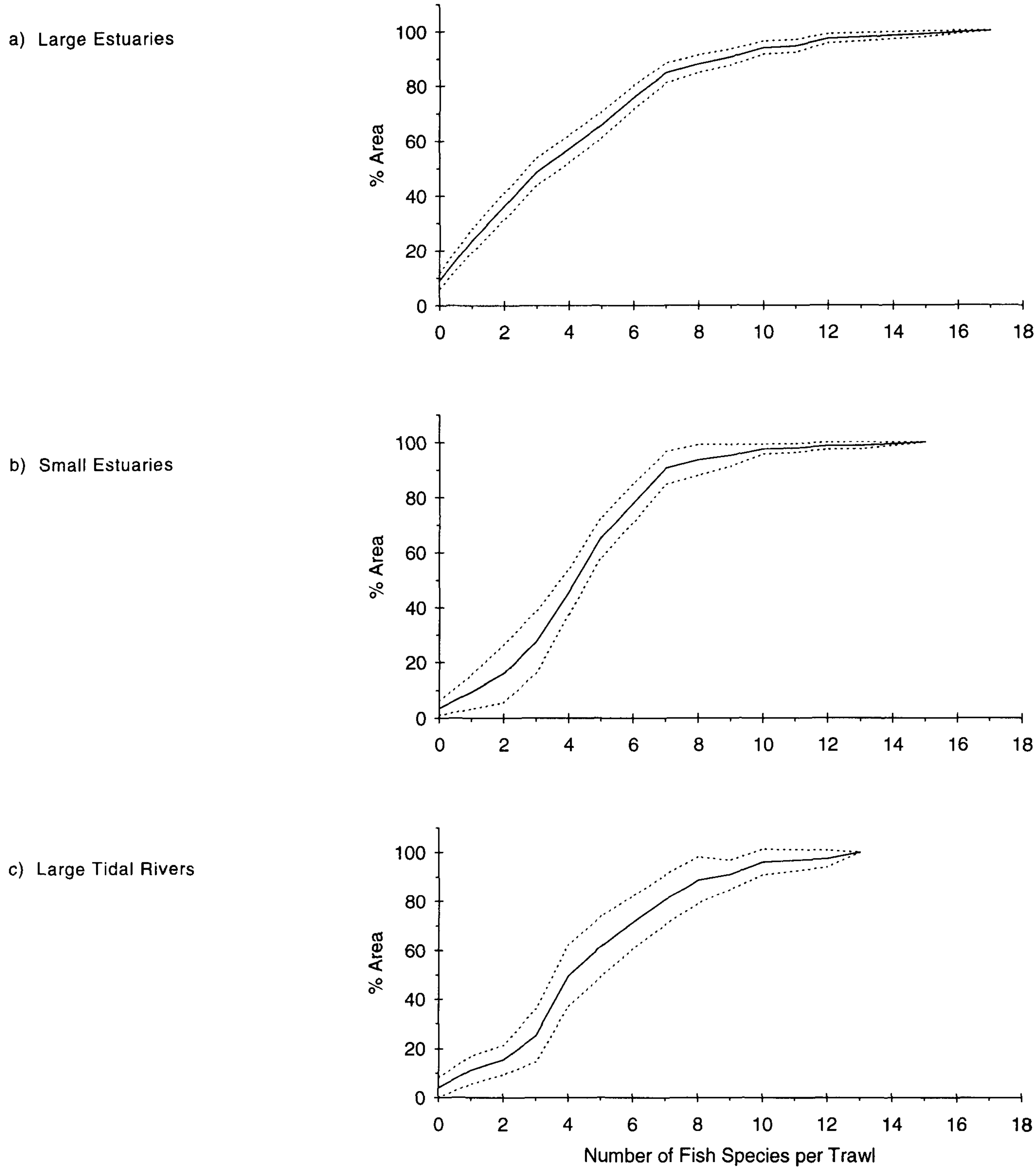


Figure 3-9. Cumulative distribution of the number of fish species per standard trawl as a percent of area by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

The second type of error was misidentifications. 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.

Unidentified fish were sent in as either unknowns or partial unknowns (*e.g.*, herring uncl.). Most misidentified or partially identified individuals were juveniles.

A total of 43,049 fish, representing 112 species, were collected in all trawls (both standard and non-standard) from Base Sampling Sites during the Project. The percentage of errors detected was less than one percent and all except the incomplete identification of individuals of five species were corrected in the database. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

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 1,244 fish per trawl throughout the Province (Figure 3-10). A total of 35,489 fish were collected in standard trawls conducted at Base Sampling Sites in 1990-1993.

Figure 3-11 illustrates fish abundance by system class. Low fish catches (≤10 fish per trawl) were experienced in 38 ± 5%, 37 ± 9%, and 21 ± 8% of the area in large estuaries, small estuaries, and large tidal rivers, respectively. Overall, low catches were experienced in 36 ± 3% of the area in the Virginian Province. As with the fish species indicator, only high versus low catches are reported with no inference made as to the quality of the area relative to this indicator.

Quality Assurance

Valid fish abundance data exist for 390 of the 446 Base Sampling Sites in the database (87%). The 390 sites sampled represent 87% of the area of the Virginian Province. The current fish community database contains no QA qualifier flags. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

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). In 1991 crews were only required to examine ten target species (Table 3-1).

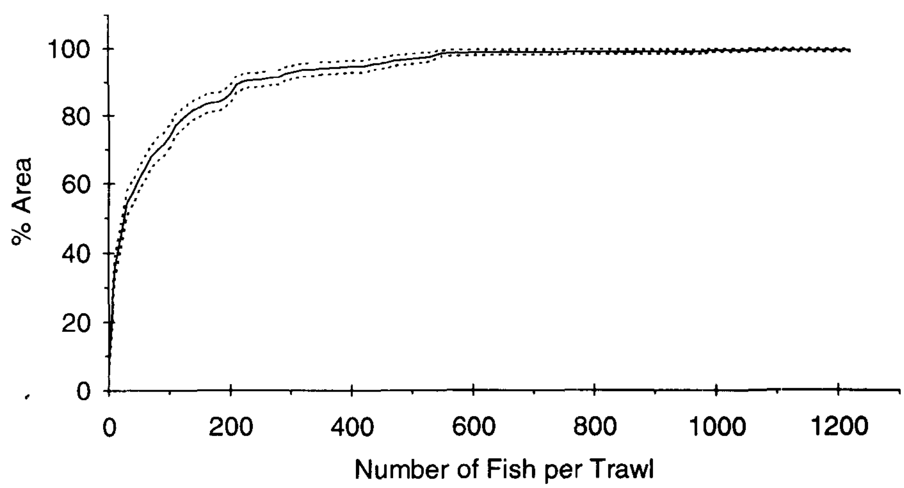


Figure 3-10. Cumulative distribution of fish abundance in numbers per standard trawl as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

a) Large Estuaries

b) Small Estuaries

c) Large Tidal Rivers

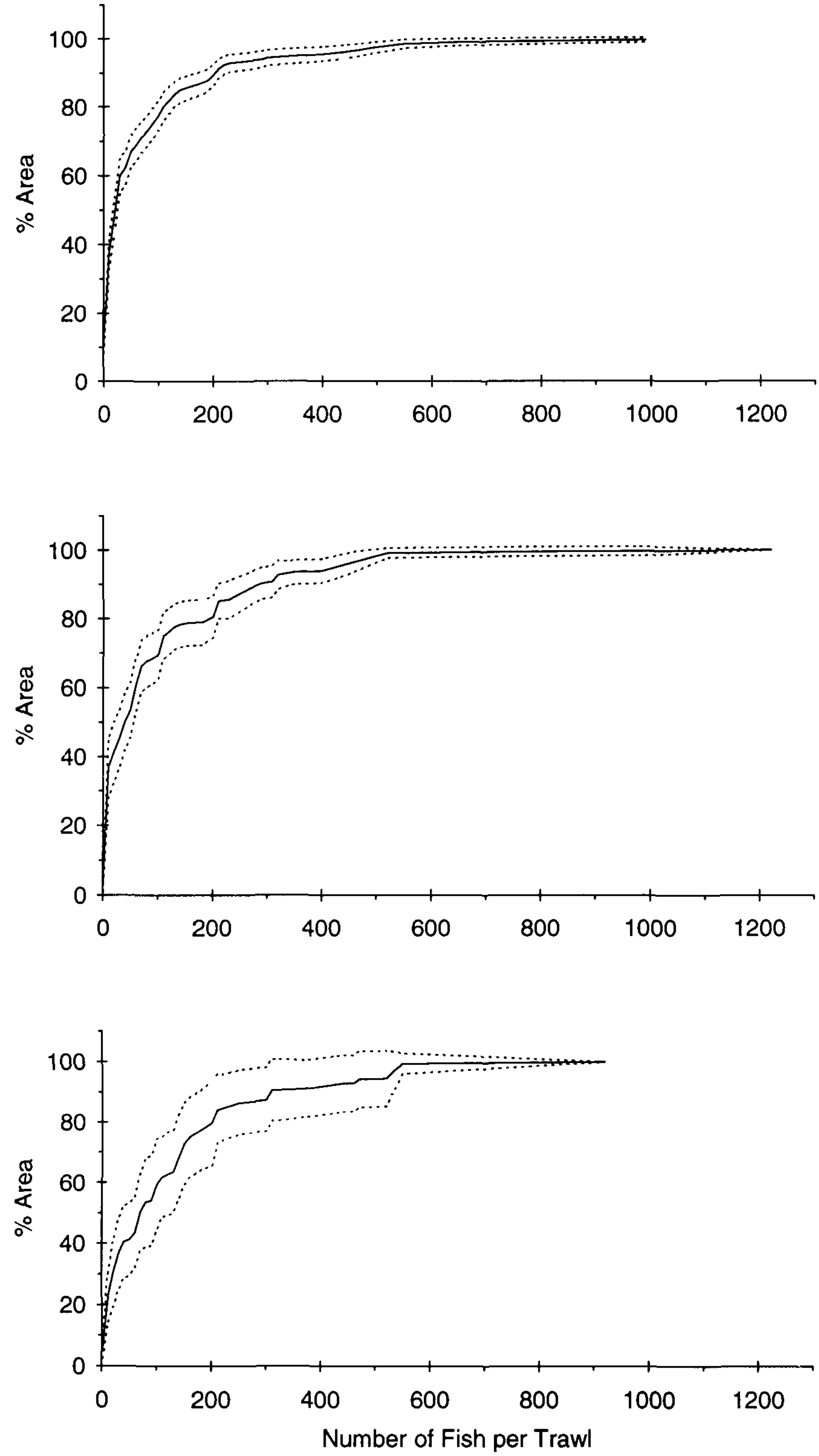


Figure 3-11. Cumulative distribution of fish abundance in numbers per standard trawl as a percent of area by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

The results of these examinations are presented in Table 3-2. The overall incidence of gross external pathologies in examined fish was approximately 0.3%, or three per thousand. This value was fairly consistent between years. Species dwelling or feeding on the bottom had the highest incidence of occurrence.

Table 3-1. 1991 target species examined for external pathology and saved for chemical residue analysis.

Common Name	Scientific Name
Atlantic Croaker	*Micropogonias undulatus*
Bluefish	*Pomatomus saltatrix*
Channel Catfish	*Ictalurus punctatus*
Scup	*Stenotomus chrysops*
Spot	*Leiostomus xanthurus*
Summer Flounder	*Paralichthys dentatus*
Weakfish	*Cynoscion regalis*
White Catfish	*Ameiurus catus*
White Perch	*Morone americana*
Winter Flounder	*Pleuronectes americanus*

Quality Assurance

Valid fish pathology data exist for 390 of the 446 Base Sampling Sites in the database (87%). The 390 sites sampled represent 87% of the area of the Virginian Province. The current fish community database contains numerous QA qualifier flags describing the results of quality assurance exercises.

Crews were required to preserve all fish with a pathology and a subset of pathology-free fish for examination by an expert pathologist. However, in 1990 to 1992 fish were also collected for contaminant analyses (although only those collected in 1991 were analyzed) which took priority over pathology QA. Therefore, a fish with a noted pathology could have been processed for chemical analysis rather than pathology QA. Because of this, pathology results reported for 1990 to 1992 were based on the crews' observations. The 1991 and 1992 Statistical Summaries report high rates of "false positive" based on the laboratory review of preserved specimens.

Table 3-2. Incidence of gross external pathology among fish caught in the Virginian Province (standard trawls only).

	Lumps	Growths	Ulcers	Fin Rot	Total[a]
All Species (1991 excluded)					
Frequency	6	10	20	19	55
Total # Fish Examined	16,884	16,884	16,884	16,884	16,884
Percent Incidence	0.04%	0.06%	0.12%	0.11%	0.33%
Target Species Only (see Table 3-1)					
Frequency	6	6	18	11	40
Total # Fish Examined	11,845	11,845	11,845	11,845	11,845
Percent Incidence	0.05%	0.05	0.15	0.09	0.34

[a] "Total" need not equal the sum of lumps, growths, ulcers and fin rot if multiple pathologies were found on a single fish.

Thousands of specimens were sent in "blind" each year, meaning the pathologist did not know which fish were identified by the crew as having a pathology or being pathology-free. Because of the quantity of specimens the pathologist needed to examine and the effect of preservation on the condition of these pathologies, we began to feel that the errors may be due to the QA process and not the crews' observations. In 1993 fish were no longer collected for chemical analysis. Crews were instructed to send in all fish observed to have a pathology (as well as a subset of pathology-free fish). Unlike previous years, these fish were identified for the pathologist as "pathology fish" or "reference fish". Because all fish suspected of having a pathology were sent in for verification, 1993 results are based on the pathologist's observations. It should be noted that whenever the pathologist disagreed with the crew's classification, a second pathologist also examined the fish.

As mentioned above, the incidence of pathology in the Virginian Province was similar among years, suggesting that the 1990-1992 field observations reported in earlier EMAP reports were valid. Nevertheless, pathology results should be used with caution. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

3.2 ABIOTIC CONDITION INDICATORS

Abiotic condition indicators (previously termed exposure 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 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. DO was measured in two ways over the four years: instantaneous point measurements (vertical profiles), and continuous measurements (from deployed instruments) at base stations for a minimum of 24 hours (1991 only). "Bottom" relative to dissolved oxygen and other water quality measurements is defined as one meter above the sediment/water interface.

Vertical profiles of dissolved oxygen and other water quality parameters were obtained using a SeaBird SeaLogger CTD. DO data included in this report are point measurements from this profile taken one meter above the sediment/water interface. As a QA measure, and backup to the CTD, beginning in 1991 additional bottom measurements of DO were obtained at every station using a YSI model 58 DO meter.

In addition to single point measurements of DO at a station at a specific time, in 1991 continuous bottom measurements of DO were made for a minimum of 24 hours using a Hydrolab DataSonde 3 datalogger deployed one meter off the bottom at base stations. Measurements were taken every 15 minutes until the unit was retrieved. Continuous DO measurements should provide a more complete picture of the dissolved oxygen conditions at a station (*i.e.*, by monitoring the periods when benthic and water column respiration is higher) than instantaneous measurements. Minimum DO concentrations, as determined from the full Hydrolab data set from each base station over the entire Province, ranged from 0.0 to 8.3 mg/L. The 1991 data show that approximately 8 ± 7% of the sampled area of the Province experienced DO concentrations as low as 2 mg/L over the 24 hour period of deployment, compared to an estimate of 5 ± 5% for instantaneous measurements.

The percent area classified as impacted based on a value of ≤2 mg/L in the Virginian Province calculated from continuous and instantaneous DO measurements do not differ significantly. Data collected during the 1990 Demonstration Project show that temporal variability in DO concentration has a weaker diurnal component than is present in other regions (*i.e.*, the Gulf of Mexico), and that a much longer time series is required to "better" classify a station as impacted than is attained using a simple point measurement. This, in addition to the logistics and additional cost involved in the relatively short-term deployment of the DataSondes, resulted in continuous measurements being discontinued after 1991.

3.2.1.1 Bottom Dissolved Oxygen

Data collected from 1990 to 1993 indicate that approximately 25 ± 3% 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 ± 2% 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 in all three estuary classes (Figures 3-13 and 3-14). Approximately 6 ± 2%, 0.2 ± 1.3%, and 10 ± 6% of the areas of large estuaries, small estuaries, and large tidal rivers, respectively, contained measured concentrations of bottom DO of ≤ 2 mg/L. Most of the severely hypoxic water in the large tidal river class was found in the lower Potomac River in 1990. Twenty eight ± 5%, 21 ± 11%, and 18 ± 6% of the area of large estuaries, small estuaries, and large tidal rivers, respectively, contained measured dissolved oxygen concentrations ≤5 mg/L in bottom waters.

<u>Quality Assurance</u>

Valid bottom DO data exist for 420 of the 446 Base Sampling Sites in the database (94%). The 420 sites sampled represent 92% of the area of the Virginian Province. The process of quality assuring water quality data is lengthy, and includes a review of the CTD profiles and QA data,

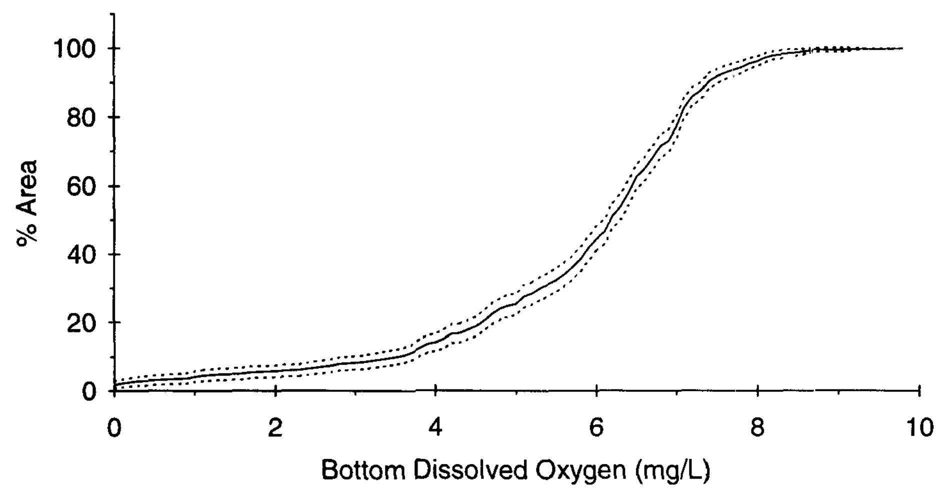


Figure 3-12. Cumulative distribution of bottom dissolved oxygen concentration as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

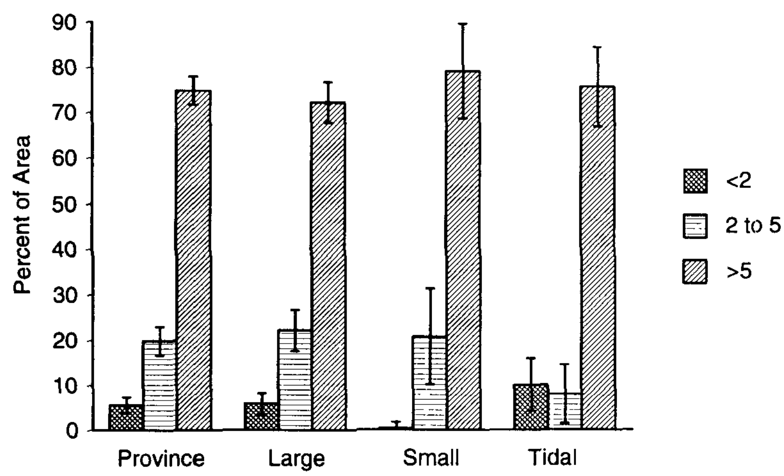


Figure 3-13. The percent of area by class that had a low (≤ 2 mg/L), medium (2 to 5 mg/L), or high (>5 mg/L) oxygen concentration in the bottom waters. (Error bars represent 95% confidence intervals).

a) Large Estuaries

b) Small Estuaries

c) Large Tidal Rivers

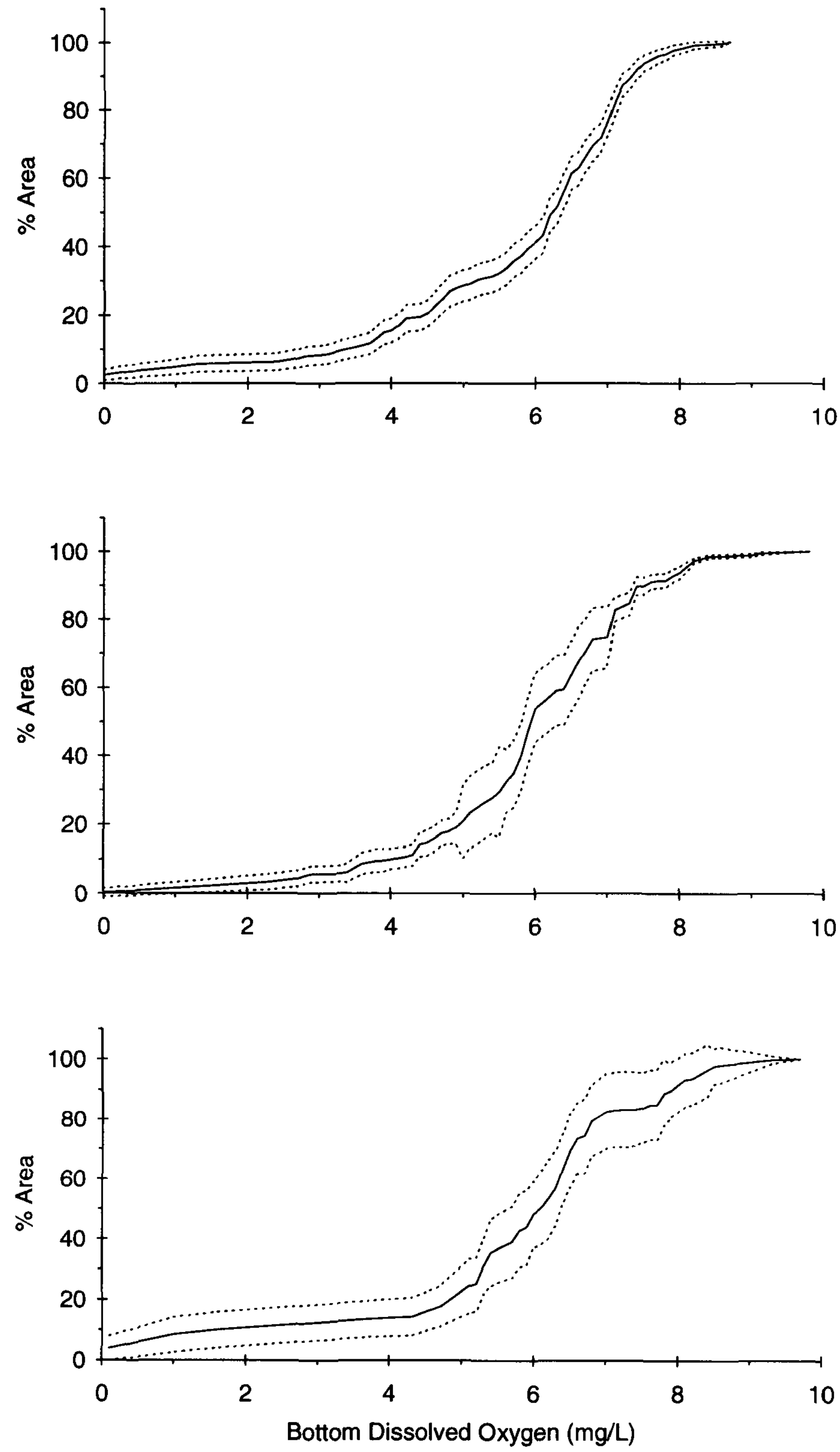


Figure 3-14. Cumulative distribution of bottom dissolved oxygen concentration as a percent of area by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

automated checks, splitting of profiles into multiple files, and determining the appropriate values to report for surface and bottom measurements. Bottom values reported are generally the mean of the measurements recorded during the bottom soak portion of the profile. The current water quality database contains numerous QA qualifier flags resulting from this process.

The CTDs utilized for the measurement of dissolved oxygen were calibrated prior to the start of the sampling season. In addition, a calibration check was performed at each station by comparing measurements to those obtained using an air-calibrated YSI meter. Acceptable precision was ± 0.5 mg/L.

When multiple visits were made to a station, the data utilized in the generation of this report are from the first visit with valid surface **AND** bottom DO measurements. When valid measurements from the CTD were not available, the YSI measurement was utilized. This allows for the calculation of surface-bottom differences (*i.e.*, stratification) as discussed in the following section. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

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 58 ± 4% of the area of the Province. Approximately 8 ± 2% of the area of the Province showed differences greater than 5 mg/L.

Figure 3-16 illustrates DO differences by estuarine class. Most of the highly stratified area was found in the large estuaries (8 ± 3% of the area with a difference exceeding 5 mg/L), with the largest Δ DO measured being 8.7 mg/L.

<u>Quality Assurance</u>

Four hundred and ten of the 446 Base Sampling Sites in the database (92%) have both valid surface and bottom dissolved oxygen data collected on the same visit, allowing the calculation of DO stratification. The 410 sites sampled represent 91% of the area of the Virginian Province. The process of quality assuring water quality data is lengthy, and includes a review of the CTD profiles and QA data, automated checks, splitting of profiles into multiple files, and determining the appropriate values to report for surface and bottom measurements. The current water quality database contains numerous QA qualifier flags resulting from this process.

When multiple visits were made to a station, the data utilized in the generation of this report are from the first visit with valid surface **AND** bottom DO measurements. When valid measurements from the CTD were not available, the YSI measurement was utilized. Multiple measurement

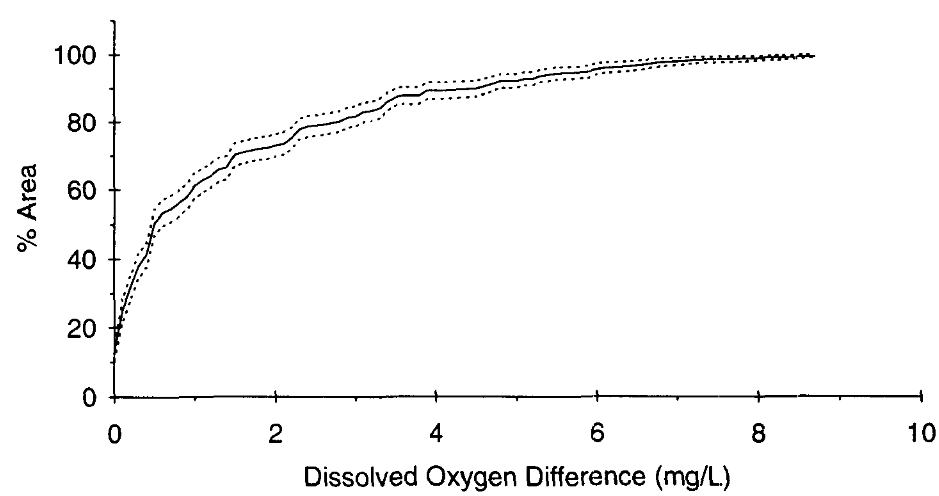


Figure 3-15. Cumulative distribution of the D.O concentration difference between surface and bottom waters as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

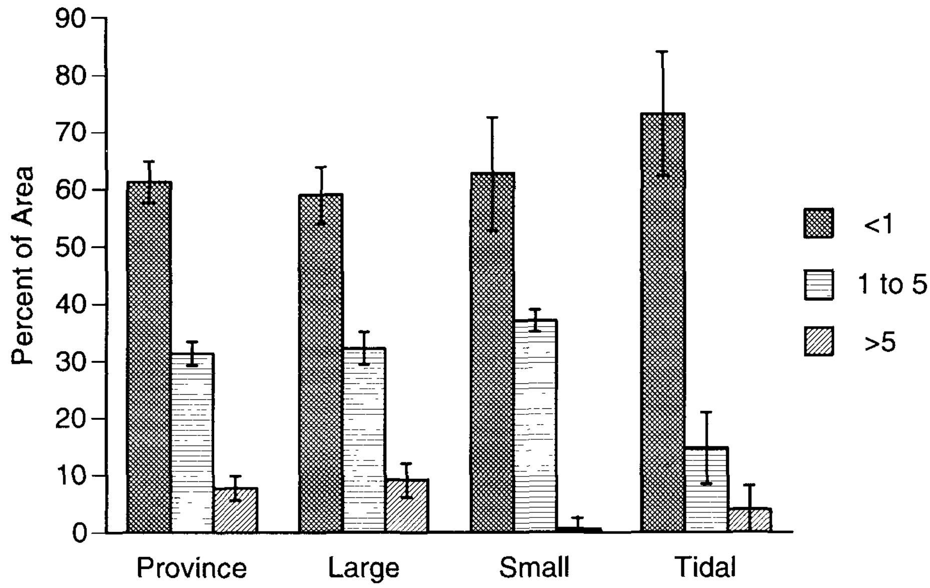


Figure 3-16. The percent of area by estuarine class that had a low (<1 mg/L), medium (1 to 5 mg/L), or high (>5 mg/L) difference in D.O. concentration between the surface and bottom waters. (Error bars are 95% confidence intervals).

types (*e.g.*, YSI and CTD) were never mixed in the determination of DO stratification. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

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 below. Approximately 10 ± 2% of the sampled area of the Virginian Province contained toxic sediments (Figure 3-17). However, only 2 ± 1% of the area had sediments where survival was below 60% of control survival (*i.e.*, sediments were highly toxic). The estuarine class with the largest proportion of toxic sediments was the small estuary class (12 ± 6%), with the large estuaries and large tidal river classes exhibiting a lesser extent of toxicity (10 ± 3% and 3 ± 4%, respectively: Figure 3-18). Highly toxic sediments were evenly distributed among the three classes (2 ± 1%, 3 ± 4%, and 1 ± 1% of the area of large estuaries, small estuaries, and large tidal rivers, respectively).

<u>Quality Assurance</u>

Valid sediment toxicity data exist for 373 of the 446 Base Sampling Sites in the database (84%). The 373 sites sampled represent 82% of the area of the Virginian Province.

As per the QA Project Plan (Valente and Strobel, 1993), the laboratory was required to maintain a control chart for toxicity testing using a reference toxicant. The laboratory used SDS (sodium dodecyl sulfate) or calcium chloride (1990 only) as their reference material, running a standard 48-hour water-only toxicity test with the toxicant 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 one value falling within two standard deviations of the mean as required in the QA Plan. In 1990 the LC50 for calcium chloride ranged from 0.4 to 1.2 mg/L, with all values falling within two standard deviations of the mean.

The LC50 of one reference toxicity test conducted in 1992 (<2.57 mg/L) fell outside of two standard deviations of the mean. Results of the failed reference test, as well

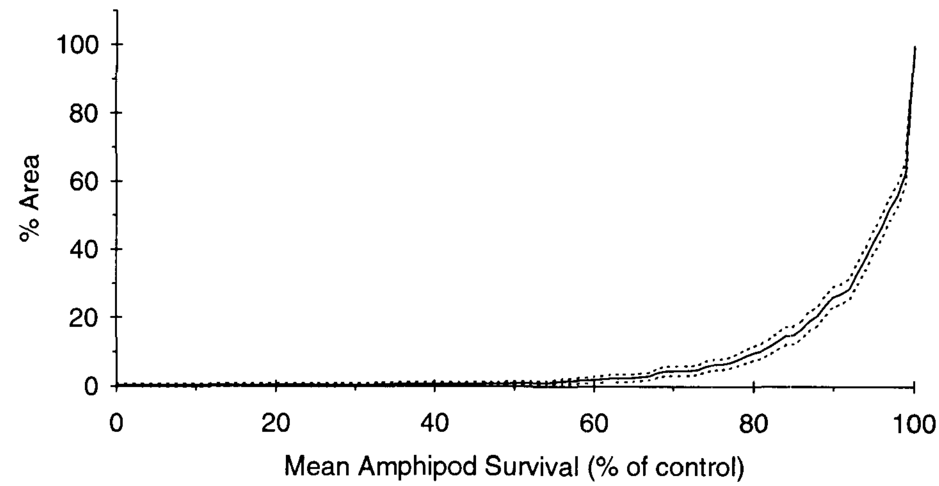


Figure 3-17. Cumulative distribution of mean survival of amphipods in 10-day laboratory toxicity tests (expressed as percent of control survival). (Dashed lines are the 95% confidence intervals).

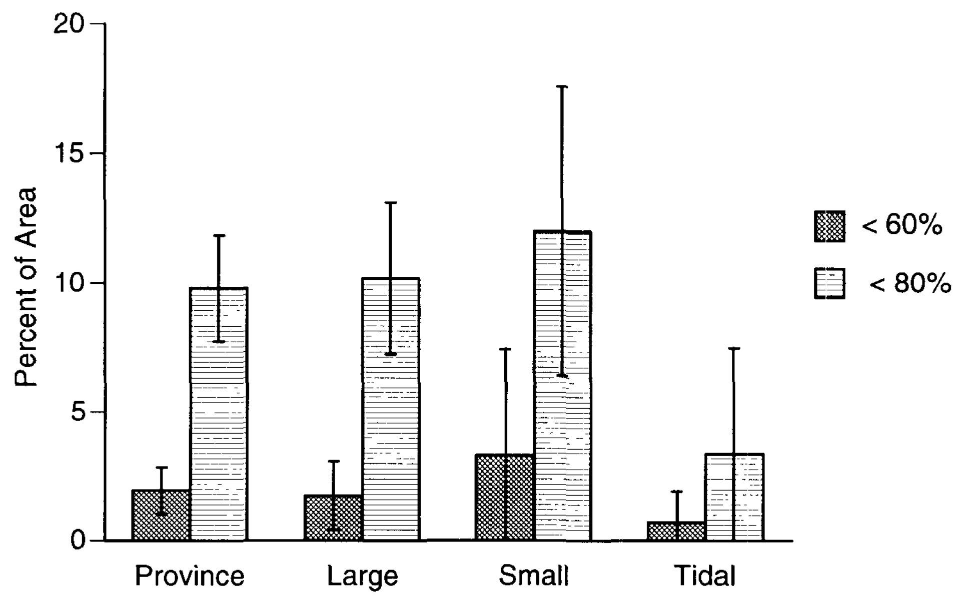


Figure 3-18. Percent of area in the Virginian Province, by estuarine class, with low (<80% of control) or very low (<60% of control) amphipod survival in sediment toxicity tests. (Error bars represent 95% confidence intervals).

as the results of all tests included in that batch, were examined. No anomalies were noted and no re-testing was performed.

In 1991 several tests failed to meet EMAP QA requirements for control organism survival. Of the 19 tests conducted, three exhibited control organism survival less than the required 85% (this was following repeating all tests that failed on the first attempt). These tests were "flagged" in the database (ST-L code) and were not included in the data set utilized to generate this statistical summary. Numerous other data qualifier codes exist in the sediment toxicity database; however, they indicate minor deviations from standards (*e.g.*, fewer than five replicates, or fewer than 20 organisms per replicate). Those data were included in the generation of this report.

Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

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 possible additive, synergistic, and antagonistic interactions among multiple pollutants, the ecological impact of elevated contaminant levels is not well understood. Several strategies for estimating biological effects from contaminant concentrations which will be discussed are the EPA Sediment Quality Criteria approach, the Long and Morgan approach, and the SEM/AVS (simultaneously extracted metals/acid volatile sulfides) approach for metals. Because these various techniques result in different estimates, 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, 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.

SQC values for the four analytes measured are listed in Table 3-3, 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.

Table 3-3. 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

In the approach proposed by Long and Morgan (1990), a database has been accumulated from the scientific literature comparing concentrations of analytes to ecological or toxic effects. Based on this review, effect levels have been established. The ER-M (Effects Range-Median) criterion is concentration representing the median, or 50th percentile of the biological effects data reviewed. The lower ER-L (Effects Range-Low) value represents the 10th percentile. Concentrations below the ER-L value are rarely expected to elicit effects. ER-M and ER-L values as modified by Long *et al.* (1995), are presented in Table 3-4. It should be noted that the values used in earlier EMAP-E documents were the Long and Morgan (1990) values. ER-M and ER-L values have subsequently been updated (Long *et al.*, 1995) and these newer values are used in this report. The major difference is an increase in the ER-M values for metals, resulting in a significant reduction in the percent area of the Province in exceedence. Sediments collected at stations representing approximately 6 ± 2% of the Province exceeded the ER-M value for any analyte, either inorganic or organic. Exceedences were measured in 5 ± 2%, 5 ± 2%, and 14 ± 6% of the area of large estuaries, small estuaries, and large tidal rivers, respectively. The maximum number of exceedences at any station was 13 (in one small estuary), with most stations exceeding for only one or two analytes.

Table 3-4. ER-M and ER-L guideline values for metals and organic contaminants. Values are from Long *et al.*, 1995.

Analyte	ER-M	ER-L
Metals (µg/g or ppm dry weight sediment)		
Arsenic	70	8.2
Cadmium	9.6	1.2
Chromium	370	81
Copper	270	34
Lead	218	46.7
Mercury	0.71	0.15
Nickel	51.6	20.9
Silver	3.7	1.0
Zinc	410	150
Organic contaminants (ng/g or ppb dry weight sediment)		
Acenaphthene	500	16
Acenaphthylene	640	44
Anthracene	1,100	85.3
Fluorene	540	19
2-methyl naphthalene	670	70
Naphthalene	2,100	160
Phenanthrene	1,500	240
Benz(a)anthracene	1,600	261
Benzo(a)pyrene	1,600	430
Chrysene	2,800	384
Dibenzo(a,h)anthracene	260	63.4
Fluoranthene	5,100	600
Pyrene	2,600	665
Total PAHs	44,792	1,700
p,p'-DDE	27	2.2
Total DDT	46.1	1.58
Total PCBs	180	22.7

Using ER-L values, sediments collected at stations representing approximately 47 ± 4% of the Province exceeded the criterion for at least one analyte, with the maximum number of exceedences being for 23 analytes.

Another approach, specific to divalent metals, is to compare the amount of simultaneously-extracted metal (SEM) in the sediment with the amount of acid volatile sulfide (AVS). The SEM/AVS ratio is the molar ratio of the sum of cationic metals to AVS. Samples with a value less than one contain more AVS than metal, suggesting that all the metal would be bound by the AVS (1:1 binding ratio) and none would be bioavailable. Therefore, if the SEM/AVS ratio is < 1, metal-related toxicity or effects should not exist. If the ratio is greater than one, some metal may be bioavailable, depending on the availability of other potential binding agents such as total organic carbon.

Where appropriate, all three of these approaches are presented. It should be noted that no single approach has gained wide acceptance throughout the scientific community. The results of the available analyses are presented without endorsement of any single method for associating ecological effects with sediment contaminant levels.

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 and urbanization or industrialization and, therefore, these compounds are often considered to be indicators of anthropogenic activity.

Range and median concentrations for PAHs measured in the Virginian Province are listed in Table 3-5. 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

Table 3-5. Range and median PAH concentrations in sediments of the Virginian Province (1991 to 1993 only).

Analyte (weight[a]) [b]	MIN	Concentration (ng/g dry weight) MAX	Median	Median Detection Limit[c]
Acenaphthene (L)	ND	1,770	ND	10.0
Acenaphthlylene (L)	ND	209	ND	10.0
Anthracene (H)	ND	2,620	ND	10.0
Benz(a)anthracene (H)	ND	4,000	23.2	10.0
Benzo(b+k)fluoranthene (H)	ND	6,550	68.9	10.0
Benzo(g,h,i)perylene (H)	ND	2,060	25.7	10.0
Benz(a)pyrene (H)	ND	2,970	25.4	10.0
Benz(e)pyrene (H)	ND	2,510	26.6	10.0
Biphenyl (L)	ND	292	ND	10.0
Chrysene (H)	ND	6,590	33.1	10.0
Dibenz(a,h)anthracene (H)	ND	544	ND	10.0
Fluoranthene (H)	ND	19,900	51.9	10.0
Fluorene (L)	ND	2,320	ND	10.0
Indeno(1,2,3-c,d)pyrene (H)	ND	2,240	28.5	10.0
Naphthalene (L)	ND	1,500	15.5	10.0
1-methylnaphthalene (L)	ND	477	ND	10.0
2-methylnaphthalene (L)	ND	1,120	13.0	10.0
2,6-dimethylnaphthalene (L)	ND	489	ND	10.0
2,3,5-trimethylnaphthalene (L)	ND	184	ND	10.0
Perylene (H)	ND	2,020	38.8	10.0
Phenanthrene (H)	ND	11,800	38.4	10.0
1-methylphenanthrene (H)	ND	983	ND	10.0
Pyrene (H)	ND	14,900	55.3	10.0
Combined PAHs	ND	80,100	562	na

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

[b] One station was excluded from these analyses. As stated in the text, this sample was suspected of being contaminated by a chip of PAHs blown out of a smokestack of a passing ship.

[c] 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

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 3-5) showed a large range (ND - 80,100 ng/g) with a median concentration of 562 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. The 75[th] percentile for total PAHs was approximately 1,200 ng/g dry weight. 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.

It should be noted that one large estuary station was eliminated from this analysis. The station, with a concentration of PAHs of 141,000 ng/g located near a shipping channel at the mouth of Chesapeake Bay in a sandy environment. Sediments from this station did not show any toxicity, analytes other than PAHs were not elevated, and the benthic community was not indicative of a degraded environment. All evidence suggests that this exceedence was an artifact, possibly due to a "chip" of material dislodged from the smokestack of a passing ship. Inclusion of this station in the analyses has little effect on the overall distribution of PAH contaminants across the Province.

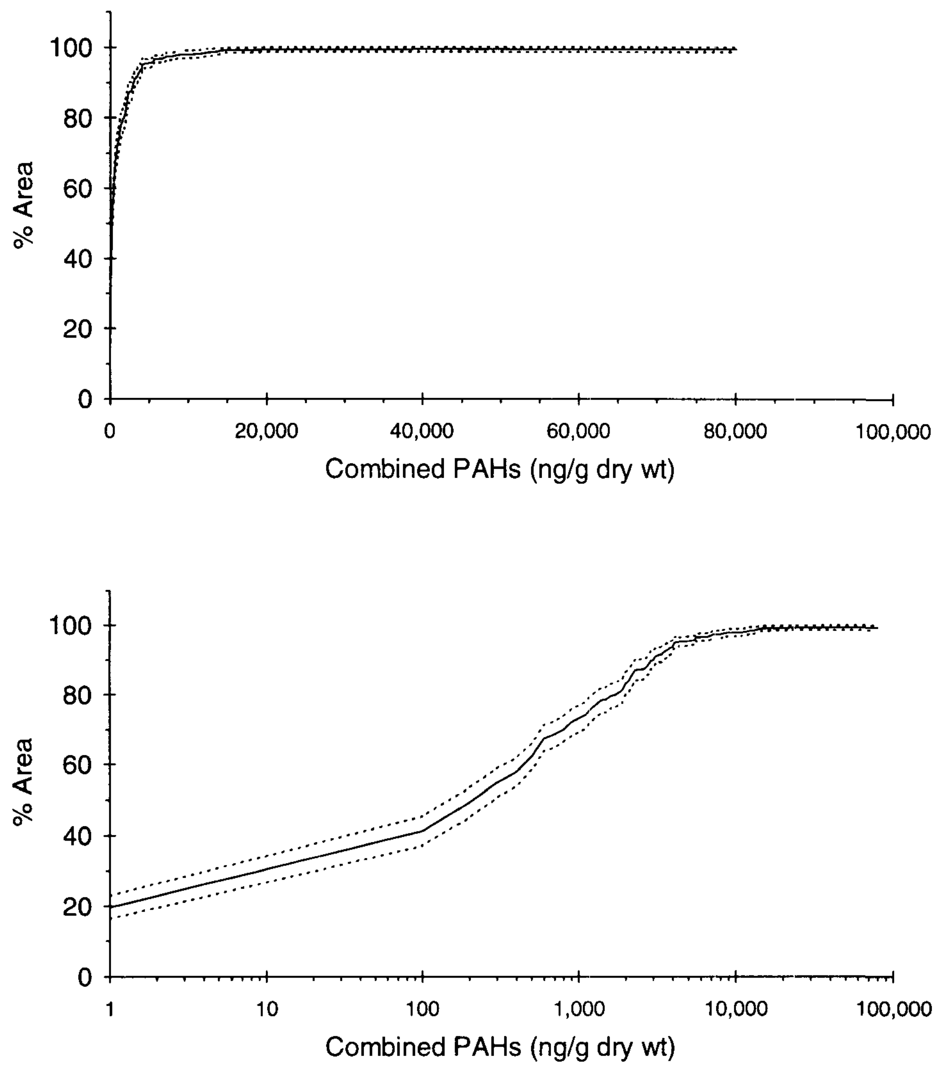


Figure 3-19a&b. Cumulative distribution of combined PAHs in sediments as a percent of area in the Virginian Province (1991-1993): a) Linear scale, b) Logarithmic scale. (Dashed lines are the 95% confidence intervals).

As discussed above, draft Sediment Quality Criteria are available for three PAHs: acenaphthene, phenanthrene, and fluoranthene. The SQCs (see Table 3-3) for freshwater and saltwater sediments were exceeded at only one small estuary station visited over the three years, representing 0.07 % of the area of the Province. This exceedence was for fluoranthene and phenanthrene. Applying the more conservative Lower SQC values in Table 3-3 increases the percentage only slightly (0.4% of the area in exceedence). It is important to note that these estimates were based on only those sediments with a total organic carbon content of ≥0.2% (72 ± 3% of the area of the Province). For the purpose of this exercise, those stations excluded were treated statistically as missing values.

Stations representing only 1 ± 1% of the Province exceeded any ER-M value for PAHs, with the highest incidence found in the large tidal rivers (3 ± 4% of the area).

Using the lower ER-L values, sediments collected at stations representing approximately 24 ± 4% of the Province exceeded the criterion for at least one PAH.

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 3-5). 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.

Quality Assurance

Serious analytical problems were encountered by the laboratory analyzing the 1990 sediment chemistry samples. As a result of these problems, the data generated did not meet the rigid Quality Assurance requirements specified by EMAP, and the 1990 PAH results were deemed of unacceptable quality for use in this assessment. Therefore, the above estimates are based on only three years of data (1991 - 1993), and sediment PAH data exist for only 292 of the 446 Base Sampling Sites in the database (65%). The 292 sites sampled represent 65% of the area of the Virginian Province. Although data were collected in only three of the four years of sampling, as discussed in Appendix B, stations sampled each year are assumed to represent conditions within the Province as a whole, with the four-year estimate being the mean of individual yearly estimates.

The current PAH database contains three QA qualifier flags, two related to non-detects and the detection limit, and one cautioning the user that the data are suspect and should be used with caution (the SC-C code). These data are generally included in this report because, although the exact concentration may be questionable, it does indicate whether the concentration was high or low. In general, all data collected in a given year for an individual analyte were "flagged" if there appeared to be a consistent bias in the results of analysis of QC samples (*i.e.*, Standard Reference Materials or SRMs) for that analyte. These data are utilized in this report because not including these analytes in the "Combined PAH" calculation would result in an artificially low value. The number of analytes with the SC-C code varied between years, but was generally low (*e.g.*, the only PAH flagged in 1993 was chrysene and this was because the mean percent recovery for chrysene from the SRM was 135.5% [acceptable range 70-130%]). Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

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 *et al.*, 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 has 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 3-6). 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 3-6. 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 1,040 ng/g dry weight with a median concentration of 4.61 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 37 ± 4% of the area of the Province. The 75th percentile for total PCBs was approximately 10 ng/g dry weight. 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.

Stations representing only 2 ± 1% of the Province exceeded the ER-M value for total PCBs, with the highest incidence found in the large tidal rivers (10 ± 3% of the area). The relatively high value for large tidal rivers is due to PCB contamination of the Hudson River.

Table 3-6. Range and median PCB concentrations in sediments of the Virginian Province (1991 to 1993 only).

	Concentration (ng/g dry weight)			
Analyte	MIN	MAX	Median	Median Detection Limit[a]
PCB8	ND	84.5	ND	0.250
PCB18	ND	76.1	ND	0.250
PCB28	ND	346	0.490	0.250
PCB44	ND	72.6	ND	0.250
PCB52	ND	107	ND	0.250
PCB66	ND	152	0.348	0.250
PCB101	ND	57.8	0.296	0.250
PCB105	ND	34.8	ND	0.250
PCB118	ND	58.8	0.346	0.250
PCB128	ND	134	ND	0.250
PCB138	ND	97.0	0.446	0.250
PCB153	ND	83.8	0.526	0.250
PCB170	ND	49.4	ND	0.250
PCB180	ND	82.0	ND	0.250
PCB187	ND	30.2	ND	0.250
PCB195	ND	10.2	ND	0.250
PCB206	ND	21.6	ND	0.250
PCB209	ND	29.4	ND	0.250
Combined PCBs	ND	1,040	4.61	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

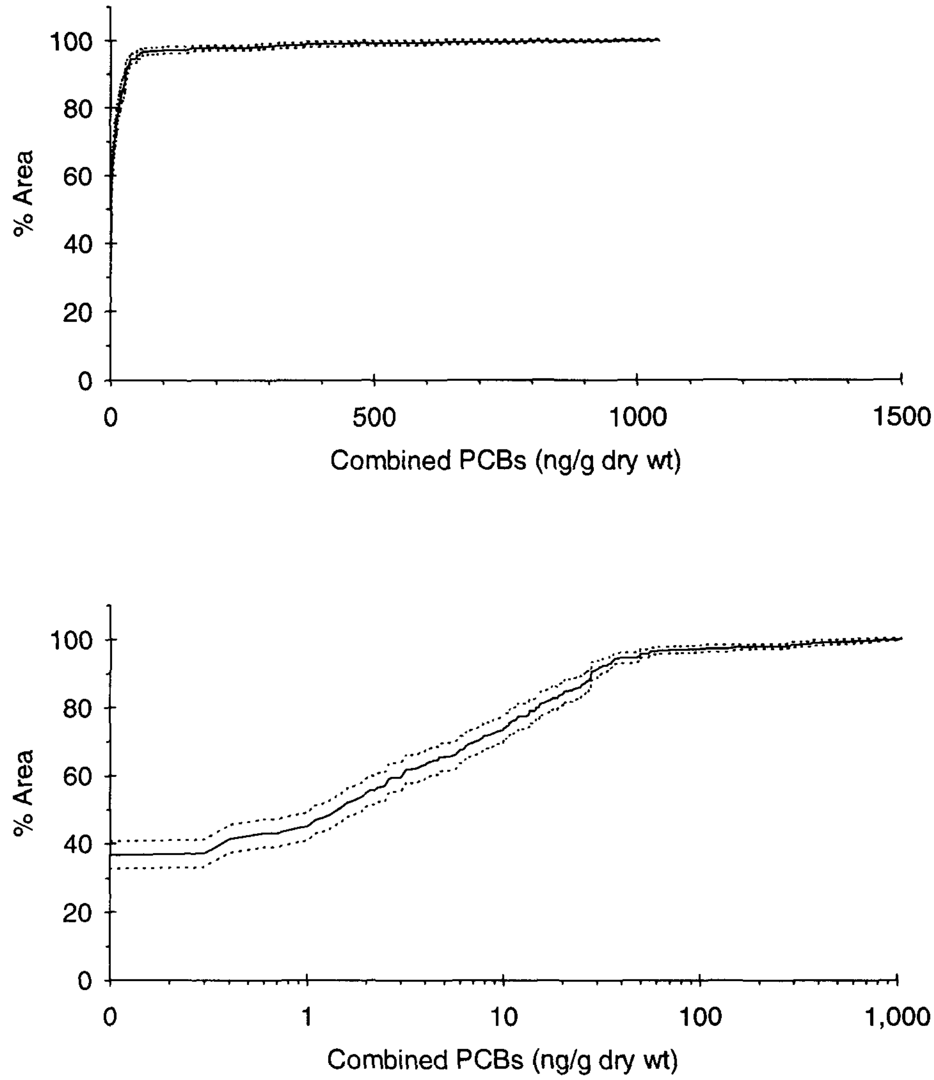


Figure 3-20a&b. Cumulative distribution of combined PCBs in sediments as a percent of area in the Virginian Province (1991-1993): a) Linear scale, b) Logarithmic scale. (Dashed lines are the 95% confidence intervals).

Quality Assurance

Serious analytical problems were encountered by the laboratory analyzing the 1990 sediment chemistry samples. As a result of these problems, the data generated did not meet the rigid Quality Assurance requirements specified by EMAP, and the 1990 PCB results were deemed of unacceptable quality for use in this assessment. Therefore, the above estimates are based on only three years of data (1991 - 1993), and sediment PCB data exist for only 293 of the 446 Base Sampling Sites in the database (66%). The 293 sites sampled represent 66% of the area of the Virginian Province. Although data were collected in only three of the four years of sampling, as discussed in Appendix B, stations sampled each year are assumed to represent conditions within the Province as a whole, with the four-year estimate being the mean of individual yearly estimates.

The current PCB database contains four QA qualifier flags, two related to non-detects and the detection limit, and two cautioning the user that the data are suspect and should be used with caution (the SC-C and SC-D code). These data are generally included in this report because, although the exact concentration may be questionable, it does indicate whether the concentration was high or low. In general, all data collected in a given year for an individual analyte were flagged with the SC-C code if there appeared to be a consistent bias in the results of analysis of QC samples (*i.e.*, Standard Reference Materials or SRMs) for that analyte. These data were utilized in the generation of this report because not including these analytes in the "Combined PCB" calculation would result in an artificially low value. The number of analytes with the SC-C code varied between years, but was generally low (*e.g.*, only two PCB congeners were flagged in 1993). PCB concentrations were "verified" by dual column confirmation, meaning the concentration was measured twice using two different gas chromatograph columns. The SC-D code was applied if the two measurements differed by greater than a factor of three. In these cases the lower value was reported and assigned the SC-D code. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

3.2.3.3 Chlorinated Pesticides

In addition to PCBs, several other chlorinated compounds were monitored in the sediments of the Virginian Province. The analysis of chlorinated pesticides in marine sediments is difficult because of the extremely low concentrations generally present. This, coupled with EMAP's rigorous QA Program, resulted in the need to qualify all pesticide results as being of unknown or questionable quality. Therefore, results of these analyses are not presented in this report and cannot be used in our assessment of conditions within the Province.

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 764 ng/g; DBT and MBT levels were generally lower than those of TBT (Table 3-7). Figure 3-21 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 33 ± 3% of the area of the Province and 79 ± 3% of the area contained sediments with TBT concentrations of less than 25 ng/g. Concentrations exceeding 100 ng/g were detected at stations representing 4 ± 1 % of the area of the Province.

Table 3-7. Range and median butyltin concentrations in sediments of the Virginian Province.

	Concentration (ng *ion* /g dry weight)			
Analyte	MIN	MAX	Median	Median Detection Limit[a]
Monobutyltin (MBT^{+3})	ND	196	ND	17.8
Dibutyltin (DBT^{+2})	ND	108	ND	9.8
Tributyltin (TBT^{+})	ND	764	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

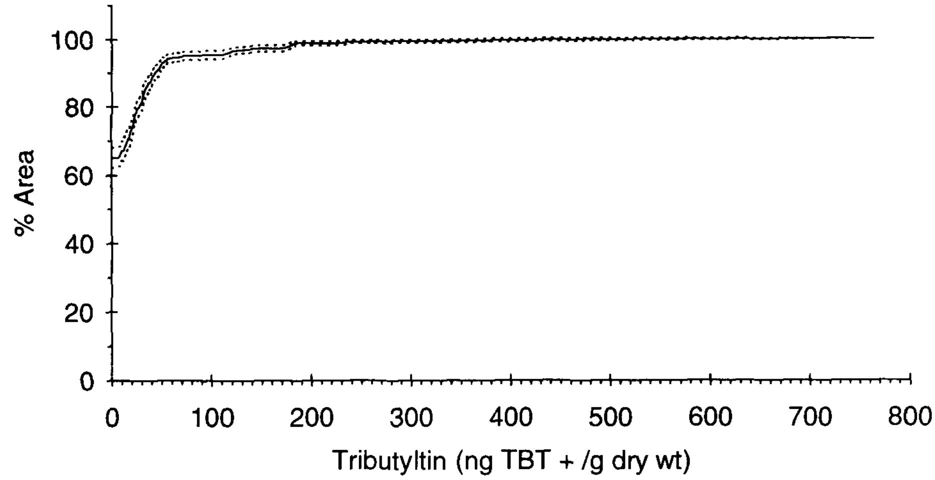


Figure 3-21. Cumulative distribution of tributyltin in sediments as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

Quality Assurance

TBT data exist for 392 of the 446 Base Sampling Sites in the database (88%). The 392 sites sampled represent 87% of the area of the Virginian Province. The current TBT database contains three QA qualifier flags, two related to non-detects and the detection limit, and one cautioning the user that the data are suspect and should be used with caution (the SC-C code). These data are included in this report because, although the exact concentration may be questionable, it does indicate whether the concentration was high or low. In general, all data collected in a given year for an individual analyte were flagged with the SC-C code if there appeared to be a consistent bias in the results of analysis of QC samples (*i.e.*, Standard Reference Materials or SRMs) for that analyte. Because of the analytical difficulties involved in analyzing for butyltins, all butyltin data have been assigned the SC-C code indicating that they should be considered estimates and should be used with caution. This code was applied mainly because of the relatively high detection limit (see Table 3-7) relative to expected environmental concentrations. Percent recoveries for the SRM also generally fell marginally outside of the acceptable range (80-120%). Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

3.2.3.5 Metals

The median and range of metals concentrations measured are listed in Table 3-8. 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 and 1992 Virginian Province Statistical Summaries (Schimmel *et al.*, 1994; Strobel *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. A more detailed description of the metal-aluminum normalization is described in Appendix A.

Figure 3-22 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. As described in Appendix A, data were first statistically screened to generate a set of unenriched stations which could be used to predict the crustal metal-to-aluminum relationship. This process was inefficient for several metals, but performed well

Table 3-8. Range and median metal concentrations in sediments of the Virginian Province.

Analyte	Concentration (µg/g dry weight)			
	MIN	MAX	Median	Median Detection Limit[a]
<u>Major</u>				
Aluminum	1,760	98,300	43,400	na
Iron	653	64,700	22,600	na
Manganese	11.6	6,430	392	na
<u>Trace</u>				
Antimony	ND	152[b]	0.285	0.051
Arsenic	ND	36.2	5.79	0.98
Cadmium	ND	7.99	0.219	0.031
Chromium	ND	856	41 5	1.80
Copper	ND	1,500	16.0	2.35
Lead	ND	13,600[b]	24.8	1.80
Mercury	ND	3.27	0.055	0.004
Nickel	ND	136	15.4	1.70
Selenium	ND	6.87	0.331	0.110
Silver	ND	9.69	0.047	0.007
Tin	ND	80.1	2.19	0.120
Zinc	ND	865	81.5	1.80

[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. Excluding this station results in a maximum antimony concentration of 49.1 µg/g and a maximum lead concentration of 323 µg/g.

na = not applicable

ND = not detected

for As, Cr, Fe, Hg, Mn, Ni, Sb, and Zn. The percent area of the Virginian Province with sediments enriched by metals pertains only to the metals mentioned above. Regressions and regression parameters for these metals are presented in Appendix C. Coefficients (r^2) ranged from 0.39 for antimony to 0.89 for iron.

As can be seen in the regression figures presented in Appendix C, the magnitude of enrichment for individual metals varies from being generally less than a factor of two to greater than an order of magnitude. Often a given station exhibits substantial enrichment of more than one metal. The spatial extent of sediments with elevated concentrations of metals can be estimated once stations with enriched metal concentrations are identified (Figure 3-23). For several metals, the proportion of the Province in which metals concentrations are enriched is substantial, *e.g.*, Hg and Mn. One 1992 station in Chesapeake Bay exhibited sediment concentrations of both Pb and Sb several orders of magnitude higher than

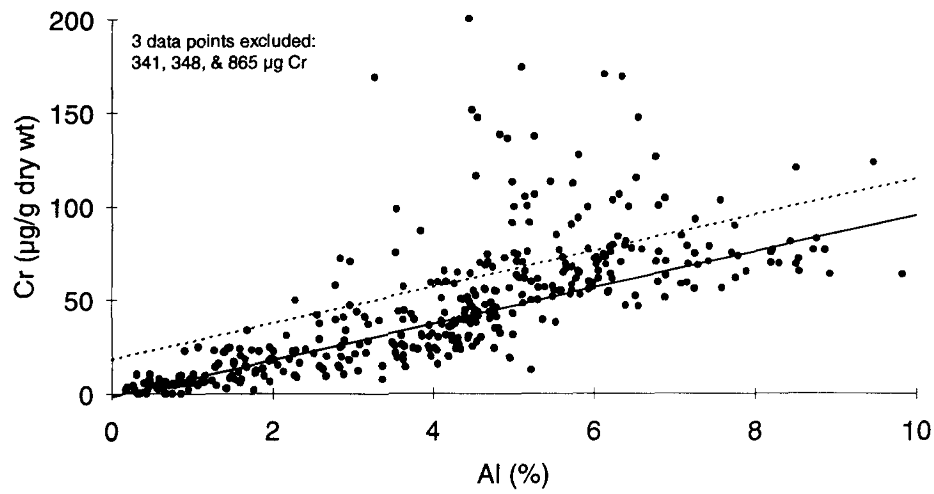


Figure 3-22. Linear regression of Chromium against aluminum. (Dashed line is the upper 95% confidence interval). NOTE: Three data points were excluded for clarity.

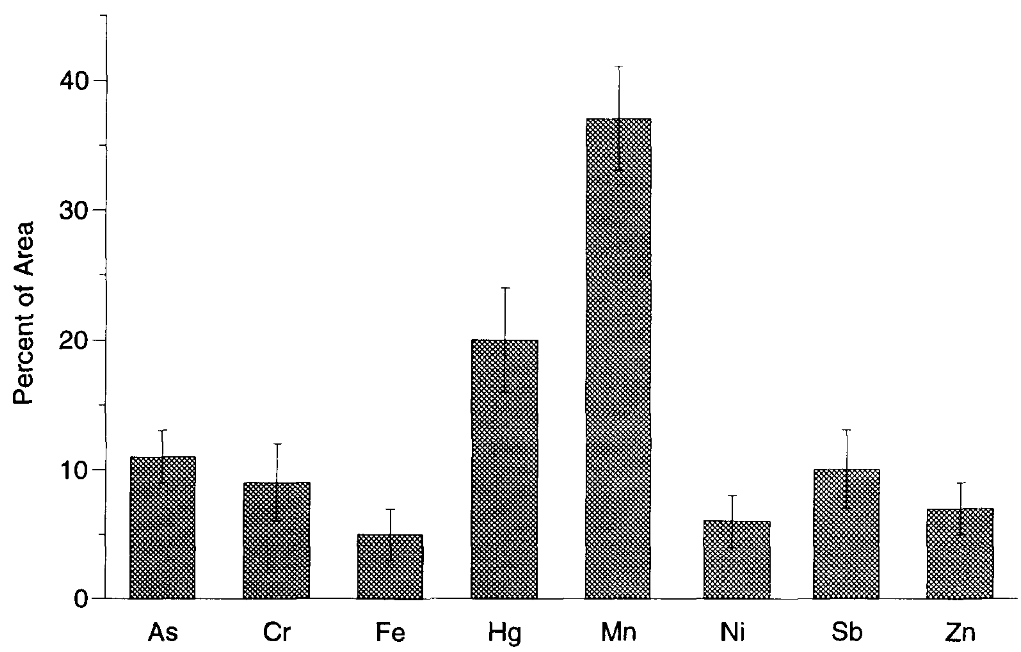


Figure 3-23. Percent area of the Virginian Province with enriched concentrations of individual metals in sediments. (Error bars represent 95% confidence intervals).

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 46 ± 5% of the area of the Province showed enrichment of sediments with at least one metal. Thirty seven (± 7), 64 ± 3, and 69 ± 16 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, making them biologically unavailable (see Section 3.2.3.7).

Stations representing approximately 4 ± 2% of the Province exceeded at least one ER-M value for metals, with the incidence similar across classes.

Using the more protective ER-L values, sediments collected at stations representing approximately 41 ± 5% of the Province exceeded the criterion for at least one metal. It should be noted, as discussed earlier, that most of the metals found in the sediments are likely bound by AVS or TOC and may not be biologically available.

As stated earlier, the values used in earlier EMAP-E documents were the Long and Morgan (1990) values. ER-M and ER-L values have subsequently been updated (Long *et al.*, 1995) and it is these newer values that are used in this report. The major difference is an increase in the ER-M values for metals, resulting in a significant reduction in the percent area of the Province in exceedence.

<u>Quality Assurance</u>

Sediment metals data exist for 396 of the 446 Base Sampling Sites in the database (89%). The 396 sites sampled represent 88% of the area of the Virginian Province. The current sediment metals database contains three QA qualifier flags, two related to non-detects and the detection limit, and one cautioning the user that the data are suspect and should be used with caution (the SC-C code). These data are included in this report because, although the exact concentration may be questionable, it does indicate whether the concentration was high or low. In general, all data collected in a given year for an individual analyte were flagged with the SC-C code if there appeared to be a consistent bias in the results of analysis of QC samples (*i.e.*, Standard Reference Materials or SRMs) for that analyte. The number of analytes flagged with the SC-C code varied by year, but ranged from one to four. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

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 ND to 5,010 mg/kg dry weight sediment. The CDFs of percent area as a function of AVS concentration is shown in Figures 3-24 and 3-25.

<u>Quality Assurance</u>

Virginian Province AVS data exist for 288 of the 446 Base Sampling Sites in the database (65%). The 288 sites sampled represent 65% of the area of the Virginian Province. The collection of AVS data did not begin until 1991. Although data were collected in only three of the

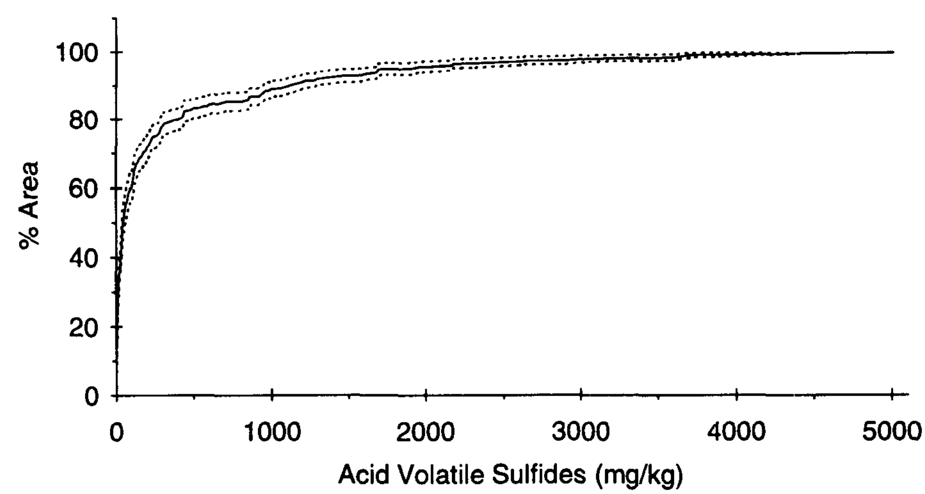
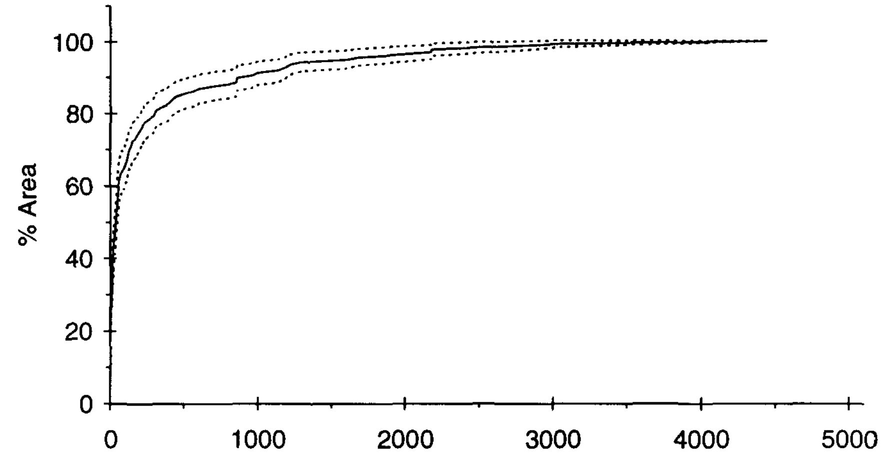
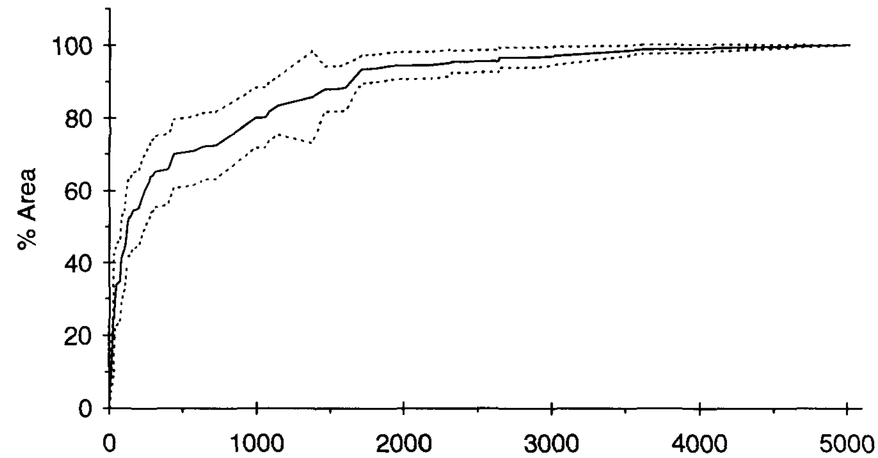


Figure 3-24. Cumulative distribution of the acid volatile sulfide concentration in sediments as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

a) Large Estuaries



b) Small Estuaries



c) Large Tidal Rivers

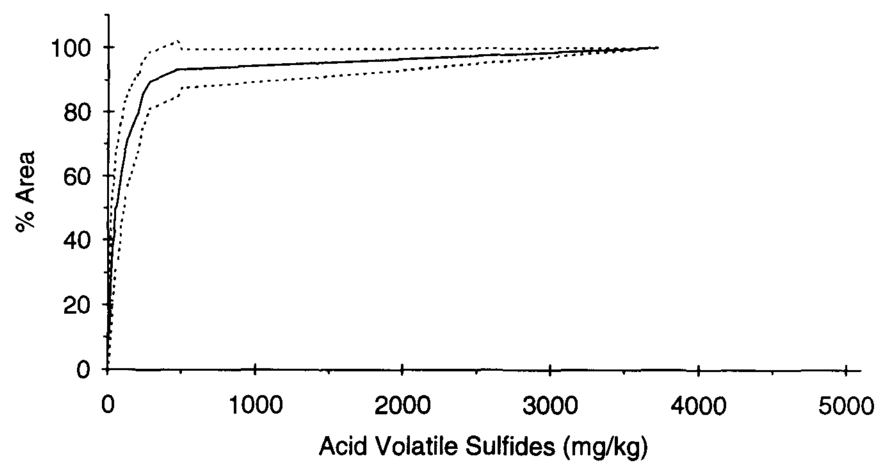


Figure 3-25. Cumulative distribution of the acid volatile sulfide concentration in sediments as a percent of area by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

four years of sampling, as discussed in Appendix B, stations sampled each year are assumed to represent conditions within the Province as a whole, with the four-year estimate being the mean of individual yearly estimates.

AVS data collected in 1991, although included in this assessment, should be used with caution. Because of the collection method employed, samples may have been partially oxidized in the process of sample collection, transport, and analysis. Sediments collected for chemical analysis (including AVS) were a composite of the surficial layer from multiple grabs. The sediments were thoroughly mixed to produce this homogenate. It is possible that this mixing process resulted in the oxidation of some of the AVS, reducing the measured concentrations. Comparison of 1991 results with those of 1992 and 1993 does not support this hypothesis; nevertheless we feel the data should be used with caution. The collection methodology was changed in 1992 to eliminate this problem.

Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

3.2.3.7 SEM/AVS Ratio

As stated above, AVS 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. In 1993 simultaneously-extracted metals (SEM) were measured in addition to total metals (described below). SEM are extracted from sediments as part of the AVS extraction, and represent the fraction which is potentially bioavailable. One factor controlling the bioavailability of metals is AVS (DiToro *et al.*, 1991). The SEM/AVS ratio is the molar ratio of the sum of cationic metals to AVS. Samples with a value less than one contain more AVS than metals, suggesting that all the metals would be bound by the AVS (1:1 binding ratio) and none would be bioavailable. Therefore if the SEM/AVS ratio is < 1, metal-related toxicity or effects should not exist. If the ratio is greater than one, some metal may be bioavailable; however, it is likely that other sediment components such as TOC may bind-up some or all of the residual SEM.

The ratio of SEM to AVS for 1993 Virginian Province data is shown in Figure 3-26. Approximately 74 ± 7% of the area of the Virginian Province contains sediments with an SEM/AVS ratio < 1, indicating that any metals present would be unavailable and no toxic effects would be expected. Only 3 ± 3% of the area contains sediments with a ratio exceeding 10.

Quality Assurance

Virginian Province SEM/AVS data exist for 98 of the 446 Base Sampling Sites in the database (22%). The 98 sites sampled represent 25% of the area of the Virginian

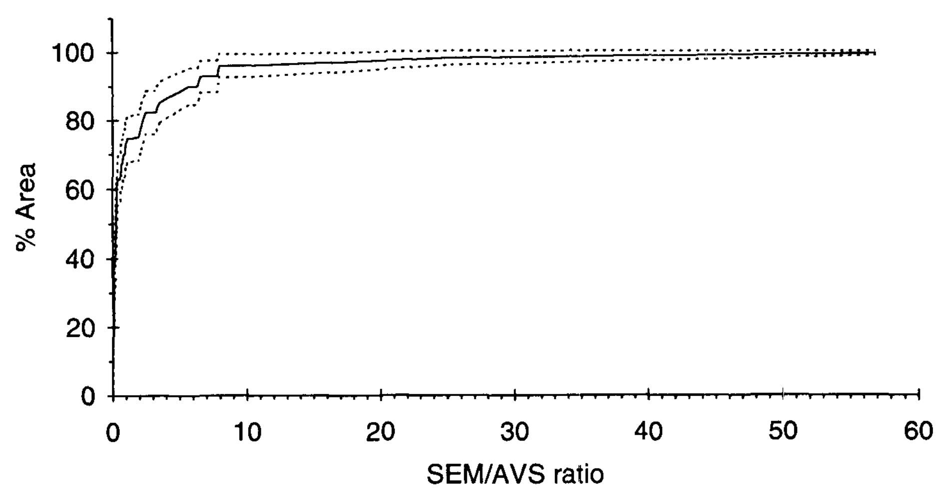


Figure 3-26. Cumulative distribution of the SEM/AVS ratio in sediments as a percent of area in the Virginian Province, 1993 only. (Dashed lines are the 95% confidence intervals).

Province. SEM data were collected only in 1993. Although data were collected in only one of the four years of sampling, as discussed in Appendix B, stations sampled each year are assumed to represent conditions within the Province as a whole, with the four-year estimate being the mean of individual yearly estimates. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

3.2.3.8 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. Organic matter is an important modifier of the physical and chemical conditions 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 to 7.01% 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 3-27. The pattern is largely determined by the large estuaries (Figure 3-28) which account for the largest part of the Province area. Approximately 28 ± 3% of the area of the Province contained TOC concentrations < 0.2%, resulting in the exclusion of this area from analyses using Sediment Quality Criteria.

Quality Assurance

Total organic carbon data exist for 396 of the 446 Base Sampling Sites in the database (89%). The 396 sites sampled represent 88% of the area of the Virginian Province. The current TOC database contains three QA qualifier flags, two related to non-detects and the detection limit, and one cautioning the user that the data are suspect and should be used with caution (the SC-C code). No TOC data have been assigned the SC-C code. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

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.

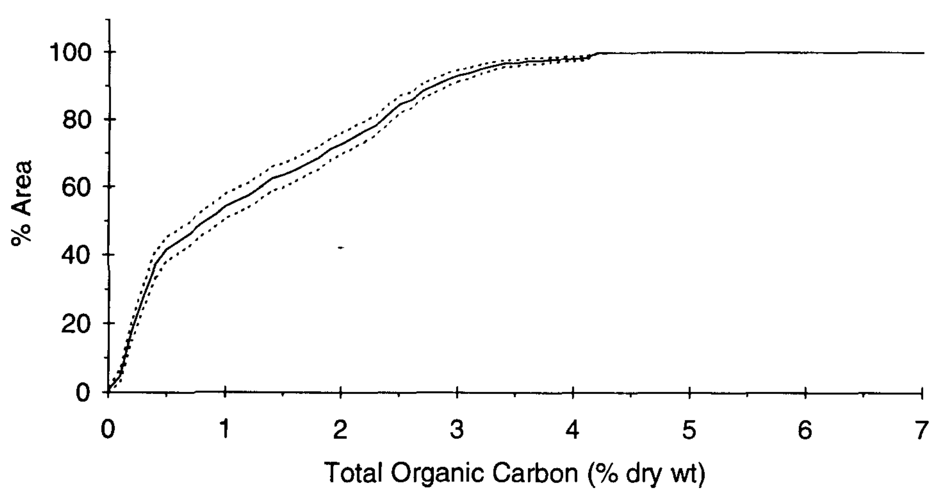


Figure 3-27. Cumulative distribution of the percent total organic carbon in sediments as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

a) Large Estuaries

b) Small Estuaries

c) Large Tidal Rivers

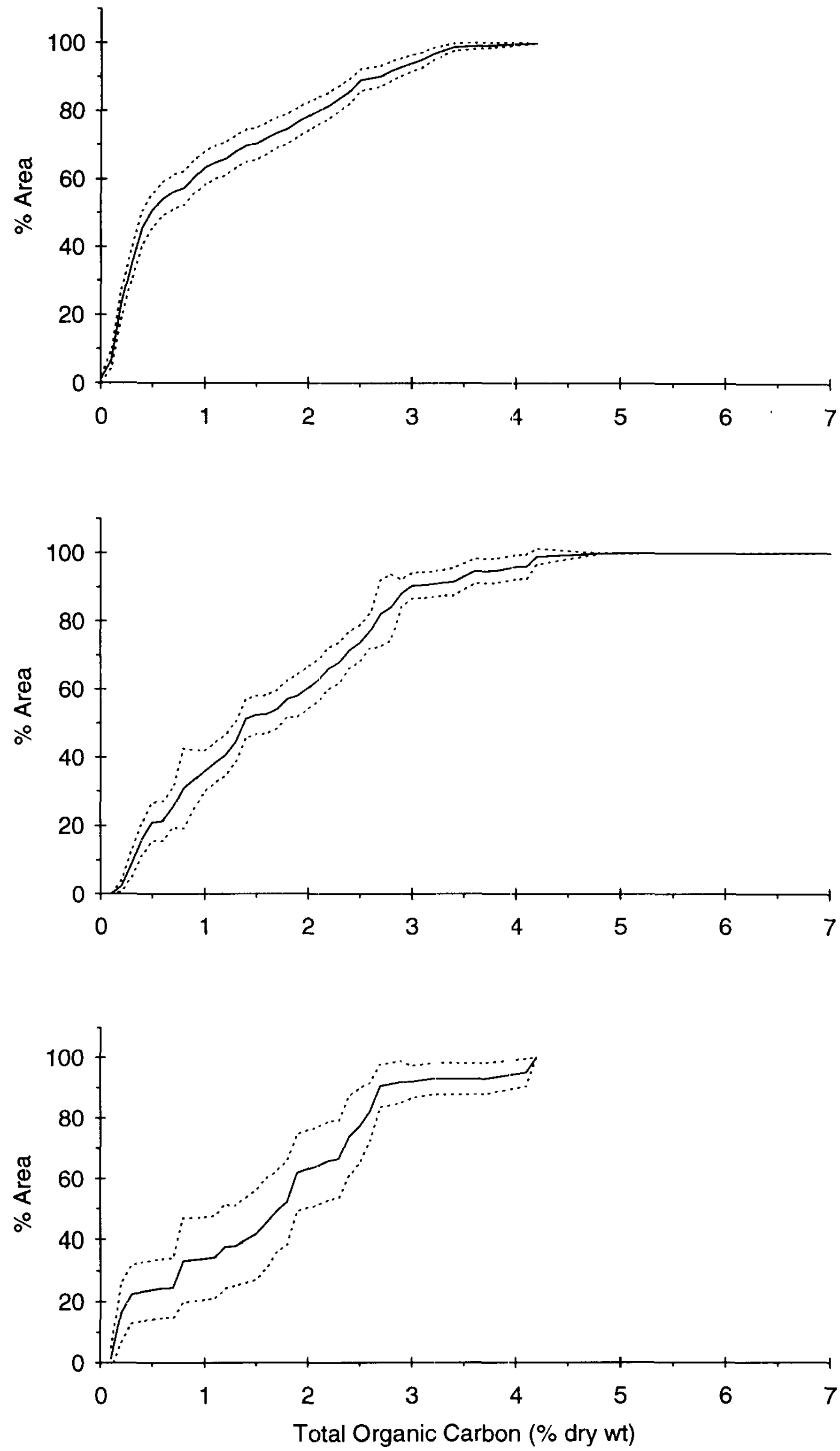


Figure 3-28. Cumulative distribution of the percent total organic carbon in sediments by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

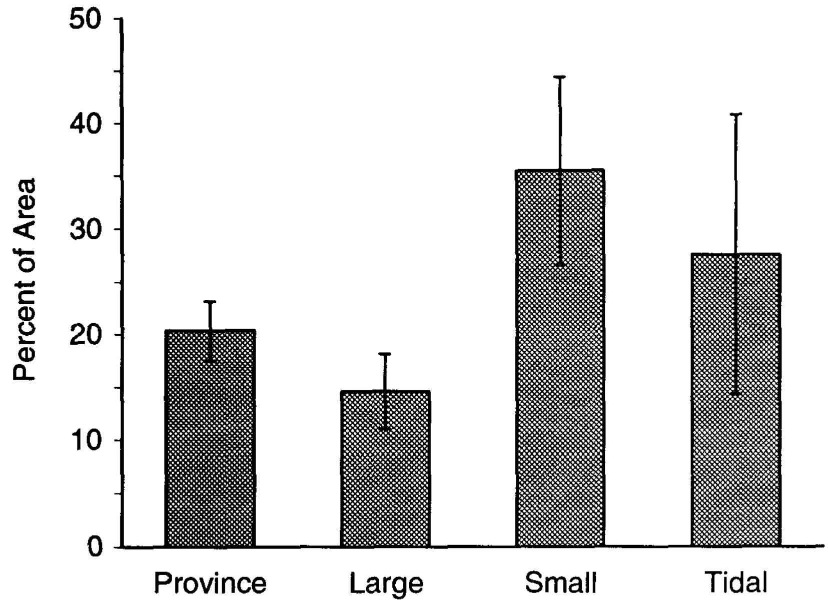


Figure 3-29. The percent of area of the Virginian Province by estuarine class where anthropogenic trash was collected in fish trawls. (Error bars represent 95% confidence intervals).

The debris collected in bottom trawls was examined as an indicator of environmental degradation in the Virginian Province. This indicator was selected over floating debris because it was felt it was less subjective, *i.e.*, the collection and observation methodology was quantitative. Debris was found on the bottom of approximately 20 ± 3% of the Virginian Province area sampled (Figure 3-29). The small estuary class had the largest percent area (35 ± 9%) where trash was found. Trash was found in 15 ± 4% of the area of the large estuaries and 28 ± 13% of the area of large tidal rivers.

Quality Assurance

Valid debris data exist for 392 of the 446 Base Sampling Sites in the database (88%). The 392 sites sampled represent 88% of the area of the Virginian Province. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

3.3 Habitat Indicators

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

3.3.1 Water Depth

The depth distribution in the Virginian Province, as determined from the boat's fathometer, is shown in Figure 3-30. 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, 8% of the area of large estuaries was unsampleable due to inadequate water depth or inaccessibility. Small estuaries were considered unsampleable if the water depth did not exceed 2 m anywhere in the system. Such systems account for approximately 1.3% of the area of small systems in the Virginian Province. Overall, 6% of the area of the Province was deemed unsampleable due to water depth or inaccessibility.

It should be noted that these data are not normalized for stage of the tide. The tidal range at EMAP stations varies from a couple of centimeters in tidal river stations to approximately two meters at some of the northern stations.

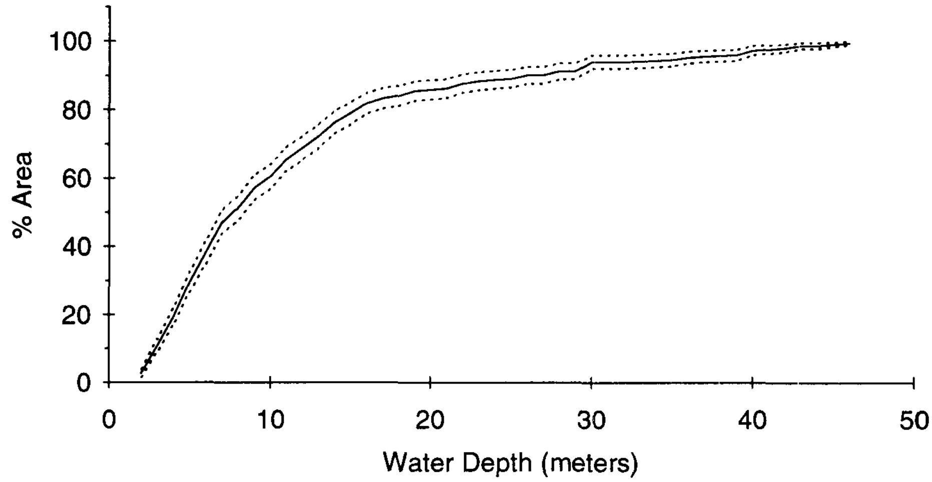


Figure 3-30. Cumulative distribution of water depth as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

Quality Assurance

Valid water depth data exist for 425 of the 446 Base Sampling Sites in the database (95%: all stations visited). The 425 sites sampled represent 94% of the area of the Virginian Province. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

3.3.2 Temperature

Bottom water temperature in the Virginian Province ranged from 12°C to 30°C during the summer sampling period. The cumulative distribution function of bottom temperature is shown in Figure 3-31. 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 12°C to 29°C (Figure 3-32b). Large tidal rivers had a steep CDF (Figure 3-32c) and exhibited the smallest temperature range (23°C to 30°C).

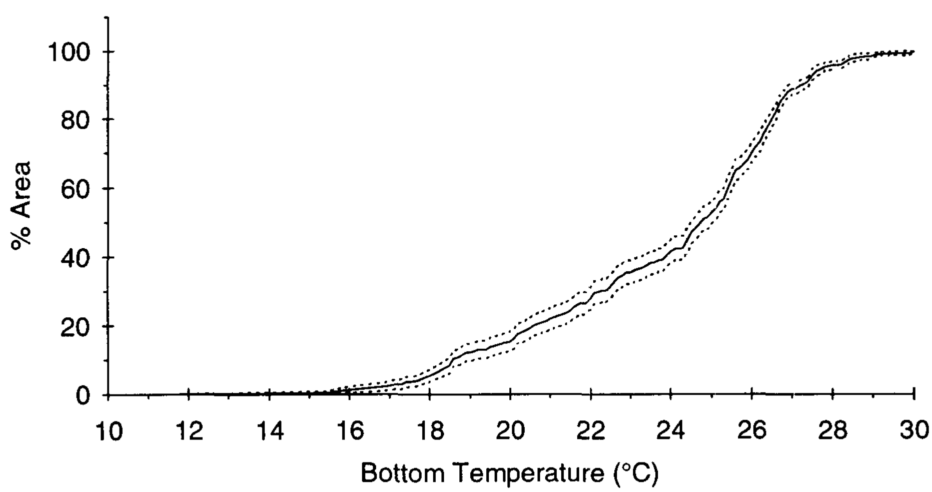
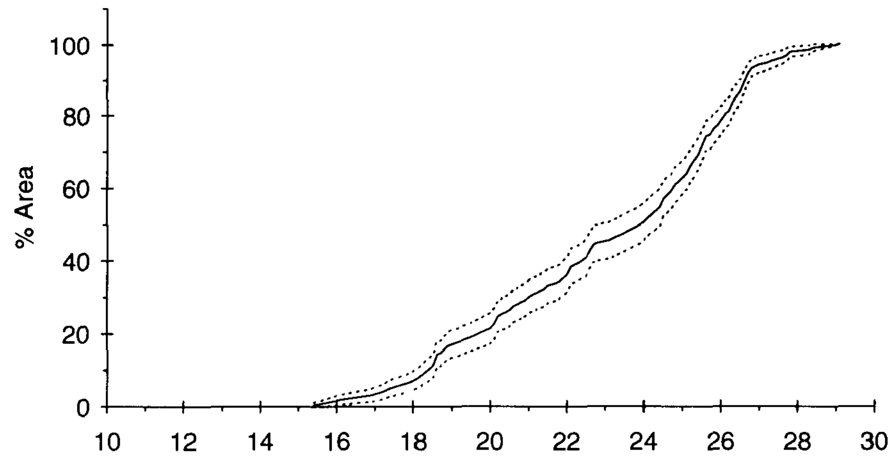
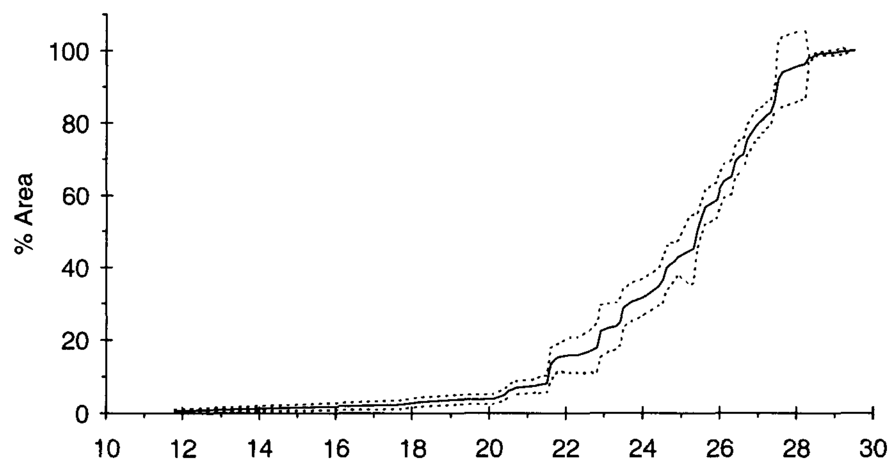


Figure 3-31. Cumulative distribution of bottom water temperature as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

a) Large Estuaries



b) Small Estuaries



c) Large Tidal Rivers

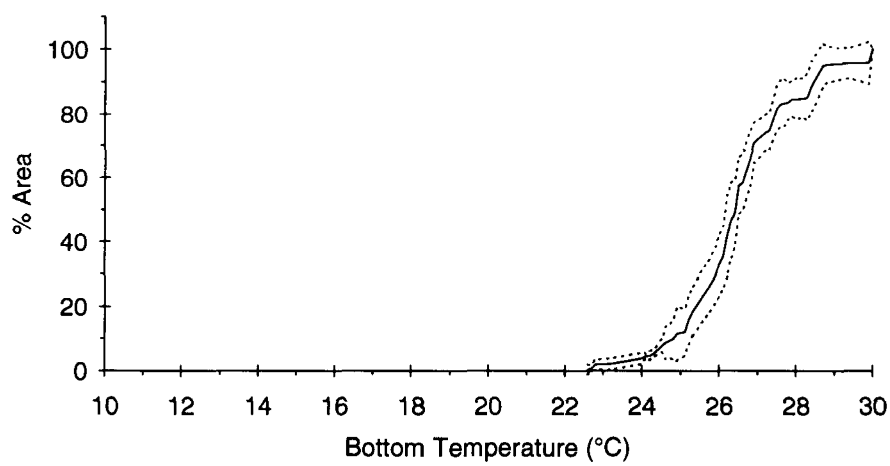


Figure 3-32. Cumulative distribution of bottom water temperature as a percent of area by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

Quality Assurance

Valid temperature data exist for 415 of the 446 Base Sampling Sites in the database (93%). The 415 sites sampled represent 92% of the area of the Virginian Province. The process of quality assuring water quality data is lengthy, and includes a review of the CTD profiles and QA data, automated checks, splitting of profiles into multiple files, and determining the appropriate values to report for surface and bottom measurements. The current water quality database contains numerous QA qualifier flags resulting from this process. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

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 3-33) reflects the different salinity characteristics of the large estuarine systems (Figure 3-34).

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 33 and 0.1 to 22‰, respectively (Figure 3-35).

The data show 21 ± 10% of the large tidal river area to be fresh water (salinity < 0.5‰). Large tidal rivers also contain the largest oligohaline area (35 ± 10% < 5‰) compared to 9 ± 3% for small estuaries and 1 ± 1% for the large estuaries (Figure 3-35).

Quality Assurance

Valid salinity data exist for 420 of the 446 Base Sampling Sites in the database (94%). The 420 sites sampled represent 92% of the area of the Virginian Province. The process of quality assuring water quality data is lengthy, and includes a review of the CTD profiles and QA data, automated checks, splitting of profiles into multiple files, and determining the appropriate values to report for surface and bottom measurements. The current water quality database contains numerous QA qualifier flags resulting from this process. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

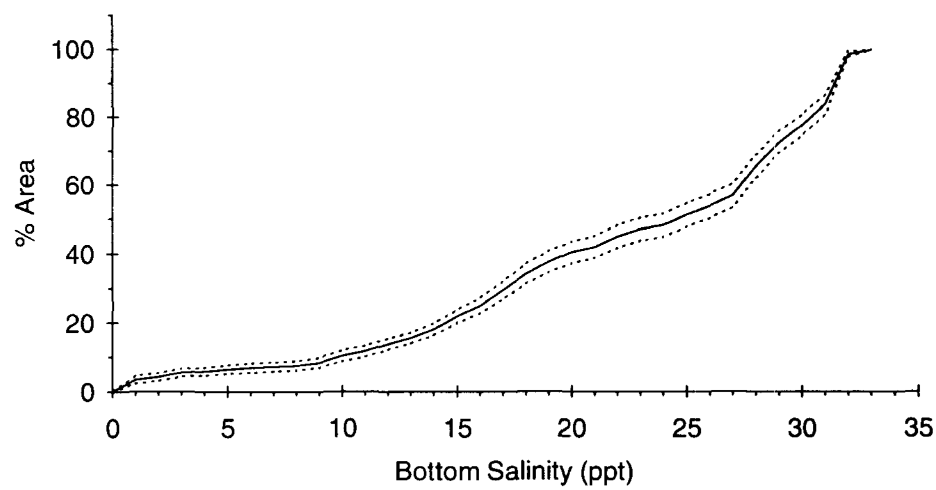


Figure 3-33. Cumulative distribution of bottom water salinity as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

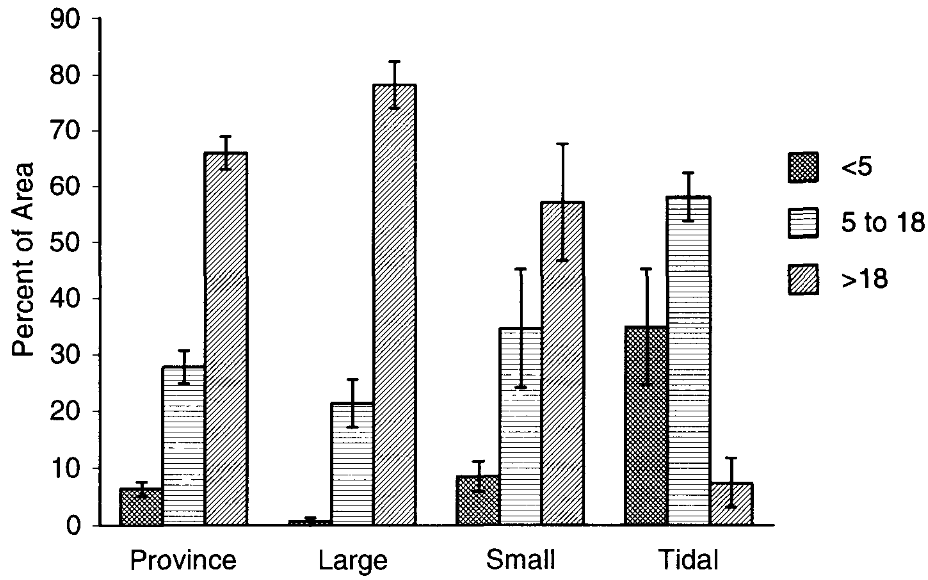


Figure 3-34. The percent of area by estuarine class classified as oligohaline (<5‰), mesohaline (5 to 18‰), or polyhaline (>18‰). (Error bars represent 95% confidence intervals).

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 6.3 to 9.2. The range for large estuaries was 7.1 to 8.6. This range also accounted for 97 ± 1% of the area of the Province. The lowest pH values occurred in the freshwater portions of the large tidal rivers with the lowest values measured in the Rappahannock River. 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, and the second highest in upper Chesapeake Bay (Northeast River). High pH values can be caused by algal blooms resulting from eutrophication.

Quality Assurance

Valid pH data exist for 410 of the 446 Base Sampling Sites in the database (92%). The 410 sites sampled represent 92% of the area of the Virginian Province. The process of quality assuring water quality data is lengthy, and includes a review of the CTD profiles and QA data, automated checks, splitting of profiles into multiple files, and determining the appropriate values to report for surface and bottom measurements. The current water quality database contains numerous QA qualifier flags resulting from this process. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

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.

a) Large Estuaries

b) Small Estuaries

c) Large Tidal Rivers

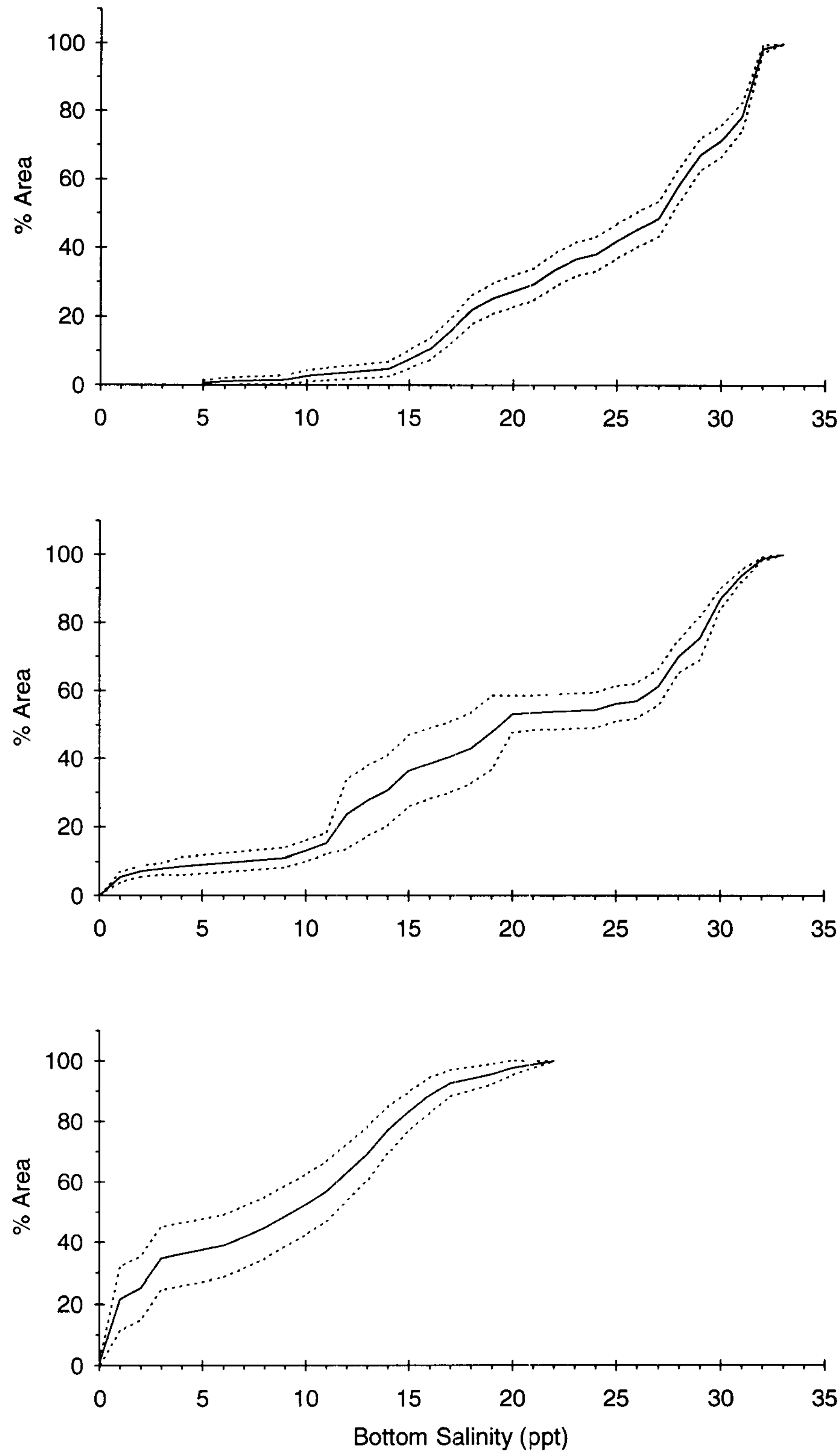


Figure 3-35. Cumulative distribution of bottom water salinity as a percent of area by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

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. 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. 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.

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 3-36). 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.*, at atmospheric pressure), and is presented as:

(density - 1) x 1000

The CDF for all estuaries shows that 72 ± 3% of the Province area had a $\Delta\sigma_t$ of ≤1 unit, with 41 ± 4% being ≤ 0.2; thus the majority of the water in the Virginian Province was well-mixed. Thirteen ± 3% of the Province area was stratified ($\Delta\sigma_t$ >2). The bar chart for stratification by class (Figure 3-37) shows that small estuaries were least stratified (2 ± 2% with $\Delta\sigma_t$ >2) and best mixed (95 ± 3% with $\Delta\sigma_t$ ≤ 1.0). Large estuaries had the greatest range of $\Delta\sigma_t$ (0 to 9.5).

Quality Assurance

Valid surface and bottom salinity and temperature (and therefore, stratification) data exist for 413 of the 446 Base Sampling Sites in the database (93%). The 413 sites sampled represent 92% of the area of the Virginian Province. The process of quality assuring water quality data is lengthy, and includes a review of the CTD profiles and QA data, automated checks, splitting of profiles into multiple files, and determining the appropriate values to report for surface and bottom measurements. The current water quality database contains numerous QA qualifier flags resulting from this process.

When multiple visits were made to a station, the data utilized in the generation of this report are from the first visit with valid surface **AND** bottom density measurements. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

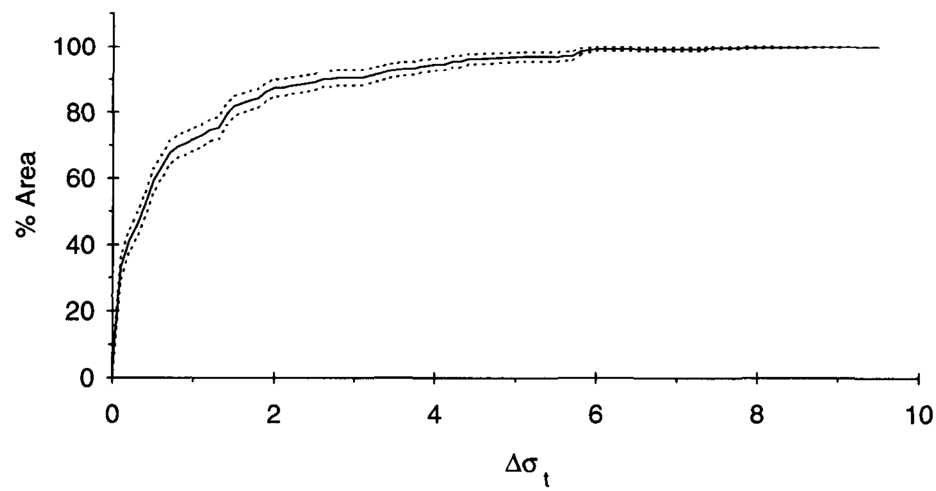


Figure 3-36. Cumulative distribution of the surface to bottom sigma-t density difference as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

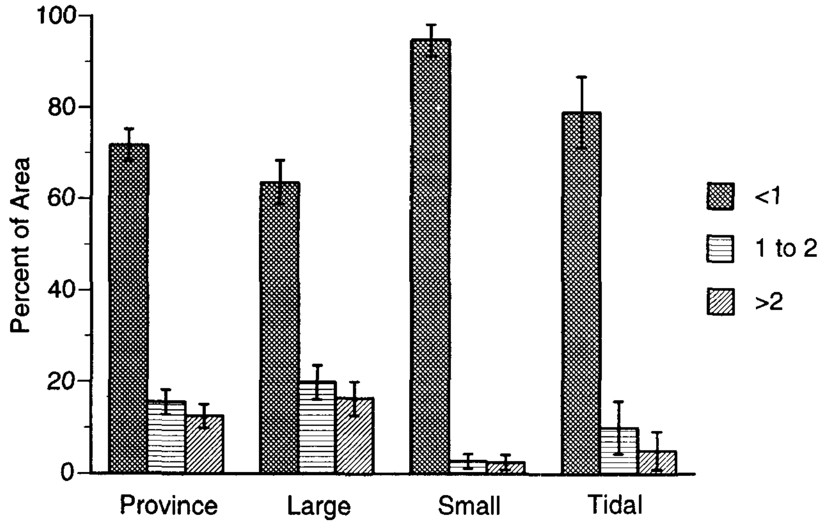


Figure 3-37. The percent of the area by estuarine class that had a low (<1), medium (1 to 2), or high (>2) degree of stratification ($\Delta\ \sigma_t$ as kg/m^3). (Error bars represent 95% confidence intervals).

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 71 mg/L (Figure 3-38). The relative condition of Virginian Province waters in large estuary, small estuary, and large tidal river classes are similar (Figure 3-39).

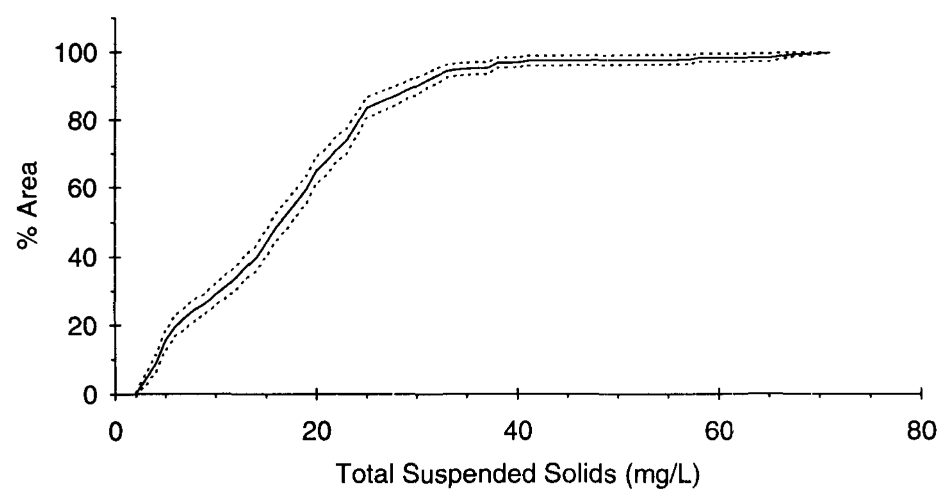


Figure 3-38. Cumulative distribution of total suspended solids concentration as a percent of area in the Virginian Province, 1991-1993. (Dashed lines are the 95% confidence intervals).

a) Large Estuaries

b) Small Estuaries

c) Large Tidal Rivers

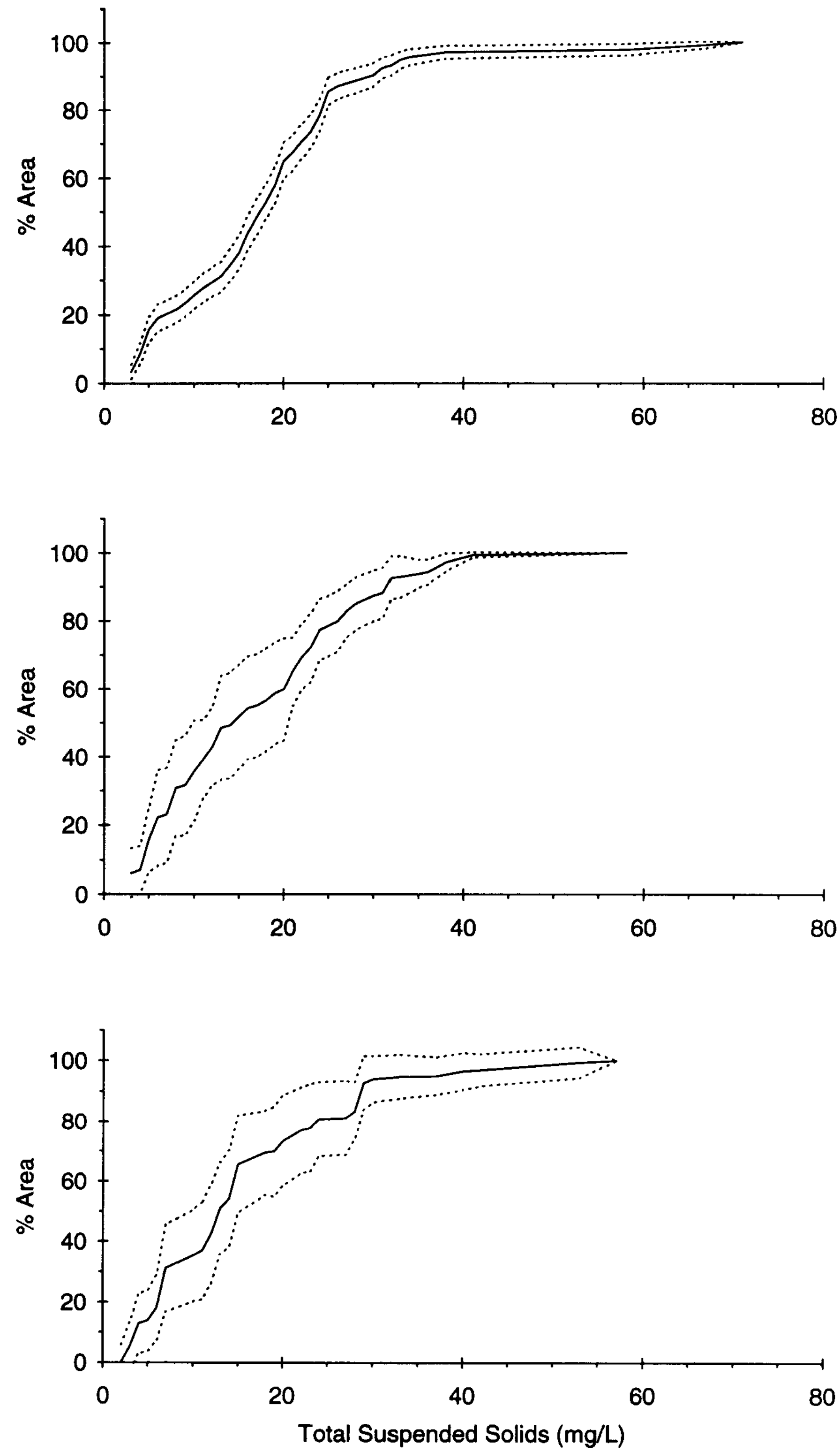


Figure 3-39. Cumulative distribution of total suspended solids concentration as a percent of area by estuarine class (1991-1993 only): a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

Quality Assurance

Valid suspended solids data exist for 298 of the 446 Base Sampling Sites in the database (67%). The 298 sites sampled represent 67% of the area of the Virginian Province. Samples for total suspended solids were collected at all Base Sampling Sites beginning in 1991. In 1990 they were collected only at Indicator Testing and Evaluation Sites, and those data are not included in this report.

In 1992 three samples were accidentally destroyed when dust fell in the dried sample pan (and there was insufficient sample for reanalysis). Overall in 1992, 44% of the TSS results were flagged in the database as being of questionable quality because of inadequate QA. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

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 a 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 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. Good 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 good clarity would be able to see his/her feet in waist-deep water.

Water clarity was good in 81 ± 3% of the sampled area of the Virginian Province (Figure 3-40). Water of low clarity was found in 6 ± 2% of the Province and an additional 13 ± 2% of the Province had water of moderate clarity. Thus, in 19 ± 2% 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 ± 2% of the large estuarine area, 11 ± 11% of the small estuarine area, and in 15 ± 13% of the large tidal river area (Figure 3-41). 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 (91 ± 3%).

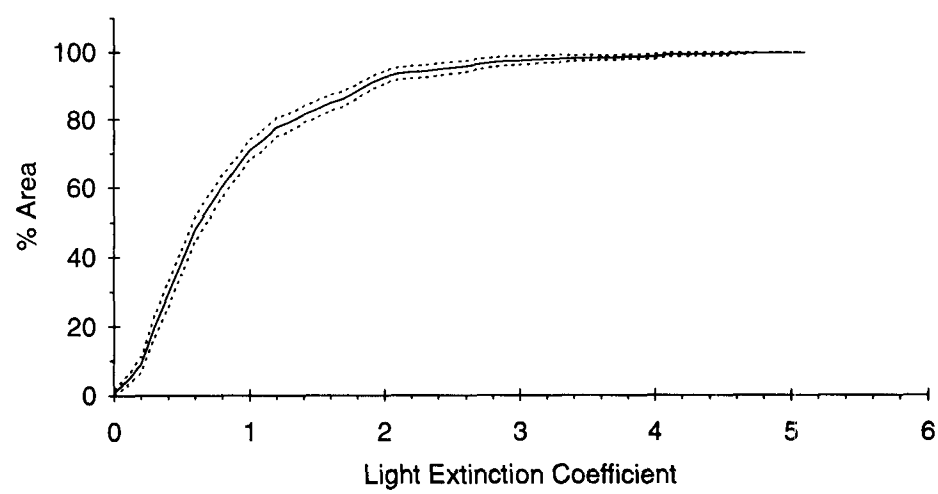


Figure 3-40. Cumulative distribution of light extinction coefficient as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

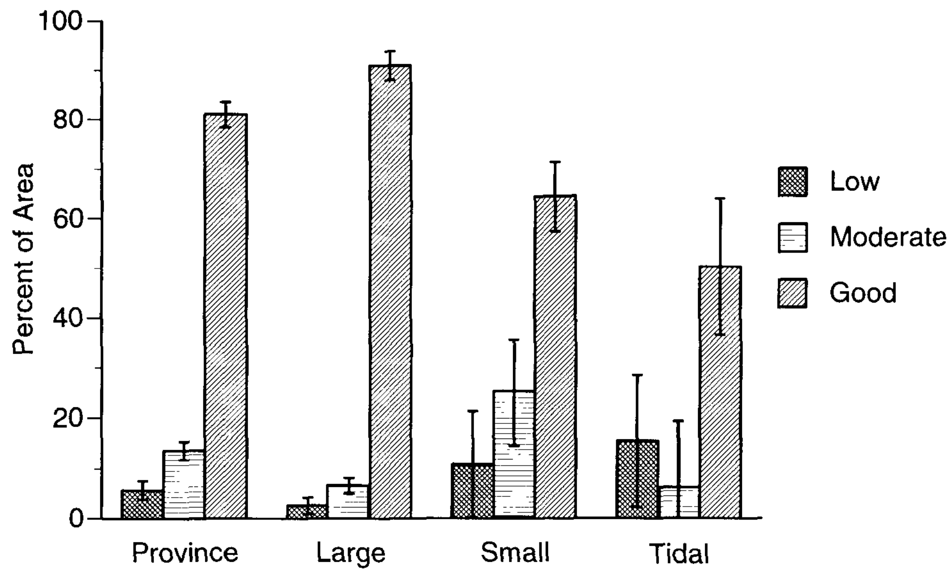


Figure 3-41. The percent of area by estuarine class where water clarity was poor, moderate, or good. (Error bars represent 95% confidence intervals).

Quality Assurance

Valid water clarity data exist for 408 of the 446 Base Sampling Sites in the database (91%). The 408 sites sampled represent 91% of the area of the Virginian Province. The process of quality assuring water quality data is lengthy, and includes a review of the CTD profiles and QA data, automated checks, splitting of profiles into multiple files, and determining the appropriate values to report for surface and bottom measurements. The current water quality database contains numerous QA qualifier flags resulting from this process.

When multiple visits were made to a station, the data utilized in the generation of this report are from the first visit with a valid PAR profile. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

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 3-42. Forty-six (± 4) percent of the area contained sandy sediments (<20% silt-clay), and 26 ± 3% 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 3-43).

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

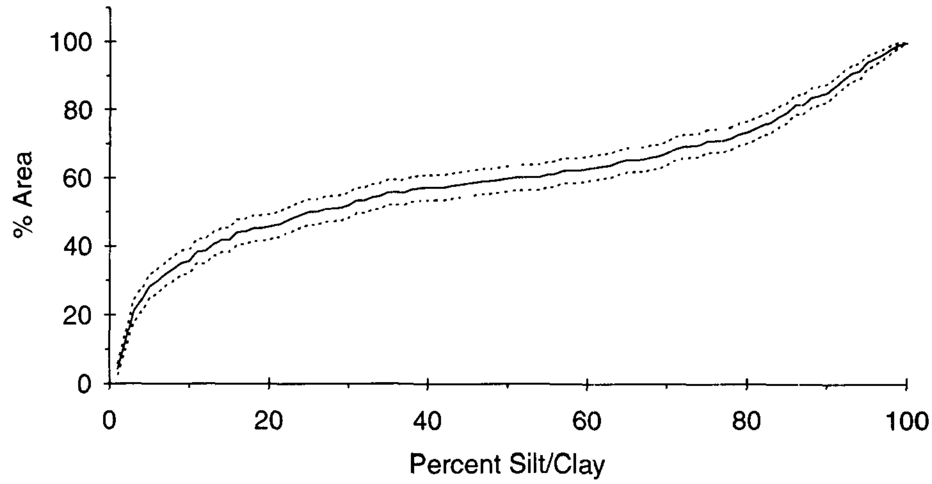


Figure 3-42. Cumulative distribution of the percentage of silt/clay in sediments as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

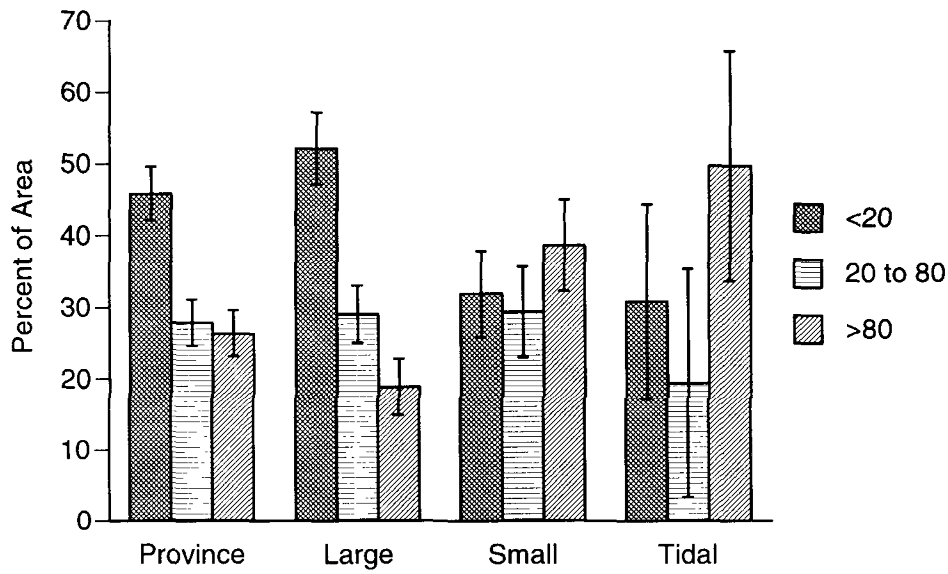


Figure 3-43. The percent of area by estuarine class with a low (<20), medium (20 to 80), or high (>80) percent silt/clay in the sediments. (Error bars represent 95% confidence intervals).

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).

Quality Assurance

Valid sediment grain size data exist for 394 of the 446 Base Sampling Sites in the database (88%). The 394 sites sampled represent 88% of the area of the Virginian Province. The current sediment grain size database contains no QA qualifier flags. Additional QA information can be found in the 1990-1993 Virginian Province Quality Assurance Report (Strobel *et al.*, 1995).

SECTION 4

SUMMARY OF FINDINGS

Thousands of pieces of information on the condition of estuarine resources in the Virginian Province were collected and analyzed. The major findings of the four-year Virginian Province Demonstration Project 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, Delaware Bay, Long Island Sound, Block Island Sound, Buzzards 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.

4.2 Findings of the Virginian Province Demonstration Project

- Of the 446 Base Sampling Sites initially selected, all but 21 (4.7%) were successfully sampled. The majority of the data collected at these stations met the quality control standards set by the Program. Overall six percent of the area of the Province could not be sampled because of inadequate water depth (< 2m) or inaccessibility. Because all samples could not be collected from all sampled sites (*e.g.*, sediment could not be collected when the bottom was rocky), this value is higher for selected indicators.

- A benthic index was developed to discriminate between good and poor environmental conditions. Based on this index, approximately 25 ± 3% 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 ± 2% of the Province area. Concentrations ≤5 mg/L were measured in 25 ±3% 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 exceeded (for PAHs) at three small estuary stations representing 0.07 percent of the area of the Virginian Province. The SQC for dieldrin was not exceeded at any station.

- Sediments collected from stations representing approximately 46 ± 5% of the Province area were determined to contain elevated levels of metals; however, metals concentrations high enough to potentially result in ecological effects were measured in only 4 ± 2% of the area of the Province based on exceedence of ER-M values.

- Table 4-1 summarizes the data presented in Section 3 for selected Biotic Condition, Abiotic Condition, and Habitat indicators.

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

	Percent area			
Estuarine Condition	Province	Large Estuary	Large Tidal River	Small Estuary
Benthic Index				
<0	23 ± 3	18 ± 4	33 ± 14	35 ± 6
Total Benthic Abundance				
≤200 / m^2	7 ± 2	5 ± 2	15 ± 9	8 ± 3
≤500 / m^2	9 ± 2	7 ± 3	24 ± 11	10 ± 3
Bottom DO				
<2 mg/L	5 ± 2	6 ± 2	10 ± 6	0.2 ± 1.3
<5 mg/L	25 ± 3	28 ± 5	18 ± 6	21 ± 11
Sediment Toxicity (% control survival)				
<80%	10 ± 2	10 ± 3	3 ± 4	12 ± 6
<60%	2 ± 1	2 ± 1	1 ± 1	3 ± 4
Enriched metals				
any metal above background	46 ± 5	37 ± 7	69 ± 16	64 ± 3
Marine Debris				
presence	20 ± 3	15 ± 4	28 ± 13	35 ± 9
Salinity				
Polyhaline (>18‰)	66 ± 3	78 ± 4	7 ± 4	57 ± 10
Mesohaline (5 to 18‰)	28 ± 3	21 ± 4	58 ± 4	34 ± 10
Oligohaline (< 5‰)	6 ± 1	1 ± 1	35 ± 10	9 ± 3

SECTION 5

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APPENDIX A

SAMPLING DESIGN, ECOLOGICAL INDICATORS, AND METHODS

A.1 Region and Estuarine Classification

EMAP-E monitoring is conducted on regional and national scales. Standardized methods are employed, and the entire Virginian Province is sampled synoptically within a defined "index" time period to ensure comparability of data within and among sampling years. EMAP-E identified boundaries for 12 estuarine regions (Holland, 1990) based on biogeographic provinces defined previously by NOAA and the U.S. Fish and Wildlife Service using major climatic zones and prevailing major ocean currents (Terrell, 1979) (Figure A-1). The 1990-1993 Virginian Province Demonstration Project included the estuarine resources located along the irregular coastline of the mid-Atlantic coast between Cape Cod, MA and Cape Henry, VA, including: Buzzards Bay, Narragansett Bay, Long Island Sound, New York/New Jersey Harbors, Delaware Bay, and Chesapeake Bay. Five major rivers within the Province were monitored: the Hudson, the Delaware, the Rappahannock, the Potomac, and the James.

A review of the literature identified potential classification variables that reduced within-class variability. These variables included physical attributes (salinity, sediment type, depth), and extent of pollutant loadings. The use of salinity, sediment type, and pollutant loadings as classification variables (*i.e., a priori* strata) would result in the definition of classes for which areal extents could vary dramatically from year-to-year or even over the index sampling period of EMAP-E. This stratification process requires establishment of a sampling frame prior to sampling; thus misclassification of sample sites within a class should be minimized. Stratification by sediment type, depth, or salinity was considered to be difficult because detailed maps of sediment and water column characteristics were not available or are often unreliable for much of the Virginian Province. These attributes were not used.

A simple classification scheme based on the physical dimensions of an estuary was used to develop three classes -- 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, 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 designations excluded estuarine water bodies less than 2.6 km^2 in surface area. These resources were included in the sampling frame by incorporating them into the adjacent water body, but they were not sampled separately.

Application of the classification scheme based upon geometric dimensions (criteria unlikely to change in reasonable time frames) to the Virginian Province estuarine resources resulted in the identification of 12 large estuaries; 5 large tidal rivers; and 144 small estuaries / small tidal rivers.

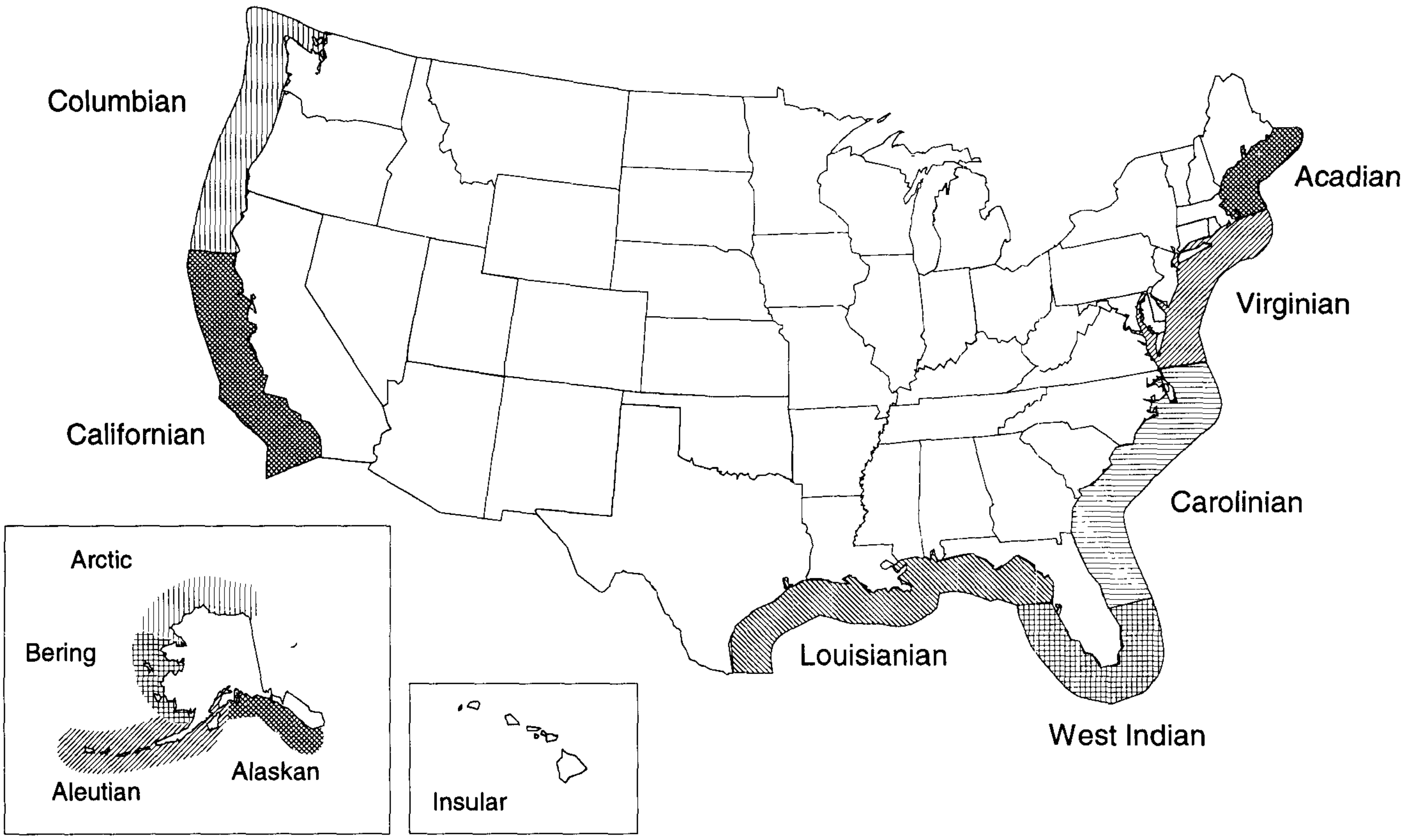

Figure A-1. EMAP-Estuaries biogeographical provinces.

A.2 Sampling Design

Sample collection in the Virginian Province focused on ecological indicators (see Section A.3) during the index sampling period (late July through September), the period when many estuarine responses to anthropogenic and natural stresses are anticipated to be most severe. The sampling design employed 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. In addition, some special-study sites were sampled to collect information for specific hypothesis testing and other specific study objectives. This resulted in sampling seven types of sampling sites (stations) for the Virginian Province survey.

- 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 preliminary status assessment. There were 446 BSS to be sampled during the four-year project.

- Index Sites (IND) were a continuation of a special study initiated in 1990. They are associated with the base sampling sites in small estuarine systems and large tidal rivers and are located in depositional environments where there is a high probability of sediment contamination or low dissolved oxygen conditions. A total of 86 IND sites were monitored.

- Long-term Trend Sites (LTT) were a select number of 1990 BSS that were revisited in 1991 through 1993. They were sampled each year to investigate the within-station annual variability. Twelve LTT sites were monitored (only 11 in 1991).

- Long-term Trends Spatial Transect (LTS) sites were located along a transect originating at selected large-estuary LTT stations. Twelve (12) LTS sites were associated with four transects in 1991 and were all located in the Chesapeake Bay. Three LTS sites were placed along each transect at 0.25, 0.5, and 1.0 statute miles from the associated LTT station to evaluate the spatial variability within a sampling cell. LTS sites were monitored only in 1991.

- Indicator Testing and Evaluation (ITE) sites were sampled to determine the reliability, sensitivity, and replicability of indicator responses for discriminating between sites with "known" environmental conditions. These sites were selected on the basis of historical information concerning dissolved oxygen concentration and sediment contamination. These sites were used to develop indices and test the discriminatory power of specific indicators. The number of ITE sites varied with year with some being revisited over multiple years. A total of 22 sampling events at ITE stations were conducted over the four-year period.

- Replicate sampling sites (REP) were randomly located in small estuarine systems. Replicate stations were designed to provide information on within-system spatial variability. Twenty-nine REP sites were sampled as part of the Demonstration Project.

- Supplemental sites (SUPP) were sites located in the Delaware Bay (large estuary) in 1990. These sites were selected using the same design used to locate large estuary sites, but on a smaller scale. The purpose of supplemental sites was to investigate the effect of scale on the design. A total of 24 supplemental sites were sampled in 1990.

A.3 Indicators

EMAP monitoring focuses on indicators of biological response to stress, and uses measures of exposure to stress or contamination as a means for interpreting that response. Traditionally, estuarine monitoring has focused on measures of exposure (*e.g.*, concentrations of contaminants in sediments) and attempted to infer ecological impacts based on laboratory bioassays. The advantage of the ecologically-based approach emphasized in EMAP is that it can be applied to situations where multiple stressors exist, and where natural processes cannot be modeled easily. This is certainly the case in estuarine systems, which are subject to an array of anthropogenic inputs and exhibit a great biotic diversity and complex physical, chemical, and biological interactions.

The implementation plan for the Virginian Province (Schimmel, 1990) listed three general indicator categories for the Demonstration Project: core, developmental and research. Table A-1 lists the EMAP-Virginian Province indicators.

Table A-1. Ecological indicators used in the Virginian Province Survey.

Category	Indicator
Core	Benthic Species Composition & Biomass Habitat Indicators (Salinity, pH, Temperature,Water Depth, % Silt-Clay)
Developmental	Sediment Contaminants Sediment Toxicity Dissolved Oxygen Concentration Gross Pathology of Fish Marine Debris Fish Community Composition & Lengths Water Clarity
Research	Histopathology of Fish Fish Biomarkers (1990 and 1991) Contaminants is Fish Tissue (1991 only)

A.4 Indicator Sampling Methods

The EMAP indicator strategy involves four types of ecological indicators (Hunsaker and Carpenter, 1990; Knapp *et al.*, 1990): Biotic condition, abiotic condition, habitat, and stressor. Biotic condition indicators are ecological characteristics that integrate the responses of living resources to specific or multiple pollutants and other stresses, and are used by EMAP to assess overall estuarine condition. Abiotic condition indicators quantify pollutant exposure and habitat degradation and are used mainly to identify associations between stresses on the environment and degradation in biotic condition indicators. Habitat indicators provide basic information about the natural environmental gradients. Stressor indicators are used to quantify pollution inputs or stresses and identify the probable sources of pollution exposure. Tables A-2 and A-3 list individual indicators.

Table A-2. Ecological indicators categorized as biotic condition, abiotic condition, and habitat indicators.

Indicator Type	Indicator
Biotic Condition	Benthic Community Composition
	Benthic Abundance
	Benthic Biomass
	Fish Community Composition
	Fish Lengths
	Pathology in Fish
Abiotic Condition	Sediment Contaminants
	Sediment Toxicity
	Dissolved Oxygen Concentrations
	Marine Debris
Habitat	Water Clarity
	Salinity
	Temperature
	Percent Silt-Clay
	pH
	Water Depth

Table A-3. Subcomponents of ecological indicators.

Primary Indicator	Subcomponents
Benthos	Total abundance
	Species composition
	Species diversity
	Abundance by species
	Percentage by taxonomic group
	Biomass
	Biomass by taxonomic group
Fish	Total abundance
	Species composition
	Species diversity
	Abundance by species
	Percentage by taxonomic group
	Mean length by species
Gross Pathology	Type of disorder
Dissolved Oxygen	Instantaneous at sampling
	Continuous for 24-hr (15-min intervals)
Sediment Toxicity	*Ampelisca abdita* 10-day test
Sediment Contaminants	23 polycyclic aromatic hydrocarbons
	15 metals
	15 pesticides
	18 PCB congeners
	Butyltins
Sediment Characters	Percent silt-clay
	Acid Volatile Sulfides (AVS: 1991-1993)
	Total organic carbon (TOC)

Descriptions of the methods used for individual indicators have been taken from the Near Coastal Program Plan (Holland, 1990), the Virginian Province Implementation Plan (Schimmel, 1990), the 1993 Virginian Province Field Operations and Safety Manual (Reifsteck *et al.*, 1993), and the EMAP-E Laboratory Methods Manual (USEPA, 1995).

A.4.1 Biotic Condition Indicators

A.4.1.1 Benthos

Benthic invertebrate assemblages are composed of diverse taxa with a variety of reproductive modes, feeding guilds, life history characteristics, and physiological tolerances to environmental conditions (Warwick, 1980; Bilyard, 1987). As a result, benthic populations respond to changes in conditions, both natural and anthropogenic, in a variety of ways (Pearson and Rosenberg, 1978; Rhoads *et al.*, 1978; Boesch and Rosenberg, 1981). Responses of some benthic organisms indicate changes in water quality while others indicate changes in sediment quality. Most benthic organisms have limited mobility. They are not as able to avoid exposure to pollution stress as many other estuarine organisms (*e.g.*, fish). Benthic communities have proven to be a reasonable and effective indicator of the extent and magnitude of pollution impacts in estuarine environments (Bilyard, 1987; Holland *et al.*, 1988 and 1989).

Benthic samples for evaluation of species composition, abundance, and biomass were collected at all sampling sites. Samples were collected with a Young-modified van Veen grab that samples a surface area of 440 cm^2. Three (3) grabs were collected at each base, index, or long-term site. A small core (60 cc) was taken from each grab for sediment characterization. The remaining sample was sieved through a 0.5 mm screen using a backwash technique that minimized damage to soft-bodied animals. Samples were preserved in 10% formalin-rose bengal solution and stored for at least 30 days prior to processing to assure proper fixation.

In the laboratory, macrobenthos were transferred from formalin to an ethanol solution and sorted, identified to lowest practical taxonomic level, and counted. Biomass was measured for key taxa and all other taxa were grouped according to taxonomic type (*e.g.*, polychaetes, amphipods, decapods). Shell-free dry weight was determined using an analytical balance with an accuracy of 0.1 mg after drying at 60°C. Large bivalves were shucked prior to determining biomass. Smaller shells were removed by acidification using a 10% HCl solution.

A.4.1.2 Fish

There are several advantages to using fish as a potential indicator of estuarine condition. Because of their dominant position at the upper end of the estuarine food web, fish responses integrate many short-term and small-scale environmental perturbations. Fish are known to respond to most environmental problems of concern in estuaries, including eutrophication, habitat modification, and pathogenic or toxic contamination.

Fish were collected by trawling with a 15 m, high-rise otter trawl with a 2.5-cm mesh cod end. The net was towed for 10 minutes against the tide (if significant tidal current existed) between 0.5 and 1.5 m/s (1-3 knots). All fish caught in the trawl were identified to species and counted; up to 30 fish of a species from each collection were measured to the nearest millimeter.

Individuals collected in standard trawls were inspected for gross external pathological disorders at all stations where fish were collected. This inspection included checking body surface and fins for lumps, growths, ulcers and fin erosion. In 1991 only target species (Table A-4) were examined. Specimens with observed gross pathologies were preserved in Dietrich's solution for subsequent laboratory verification and histological examination. At indicator testing sites, all specimens exhibiting gross pathologies, and up to 25 pathology-free specimens of each target species (and 10 of non-target species), were preserved for quality control checks of field observations. These fish also received histopathological examinations related to liver lesions, spleen macrophage aggregates, and gill or kidney disfunction (research indicator).

Table A-4. 1991 target species examined for external pathology and saved for chemical residue analysis.

Common Name	Scientific Name
Atlantic Croaker	*Micropogonias undulatus*
Bluefish	*Pomatomus saltatrix*
Channel Catfish	*Ictalurus punctatus*
Scup	*Stenotomus chrysops*
Spot	*Leiostomus xanthurus*
Summer Flounder	*Paralichthys dentatus*
Weakfish	*Cynoscion regalis*
White Catfish	*Ameiurus catus*
White Perch	*Morone americana*
Winter Flounder	*Pleuronectes americanus*

A.4.2 Abiotic Condition Indicators

A.4.2.1 Sediment Collection Procedures

Sediments were collected using the same Young-modified van Veen grab used for benthic invertebrate sampling. The top 2 cm of 6 to 10 grabs were placed in a mixing bowl and homogenized. After approximately 2,000 cc of sediment were collected and completely homogenized, the sediment was distributed among containers for sediment characterization, sediment chemistry, and sediment toxicity testing.

A.4.2.2 Sediment Characterization

The physical characteristics of estuarine sediments (*e.g.*, grain size) and certain chemical aspects of sediments (*e.g.*, acid volatile sulfide [AVS] content, total organic carbon [TOC] content) influence the distribution of benthic fauna and the accumulation of contaminants in sediments (Rhoads, 1974; Plumb, 1981; DiToro *et al.*, 1991). Sediment silt-clay content was determined to help interpret biotic condition indicator data and sediment contaminant concentrations. AVS and TOC were collected not only as interpretive aids but also as potential covariates for toxic contaminant concentrations.

Subsamples from each benthic grab and contaminant/ toxicity homogenate were retained for grain size determination. A sample for determination of AVS content was removed from the homogenate (1991) or directly from each grab being composited (1992-1993). Samples were shipped on ice to their respective processing laboratory. Samples for the determination of silt/clay content were sieved using a 63μm mesh sieve. Both an aliquot of the filtrate and the fraction retained on the sieve were dried in an oven at 60°C and weighed to calculate the proportion of silt/clay in the sample.

The AVS collection method employed in the 1991 Survey permitted the potential release of sulfides when the materials where processed on-board the sampling vessel and in subsequent shipping. The sample was collected from a homogenized composite (*i.e.*, allowing maximal exposure to oxygen). As a result, the accuracy of the 1991 AVS measurements could be in doubt although the precision may remain reliable as all samples were treated similarly. Modifications to the collection methods were incorporated into the 1992 sampling program to prevent a recurrence of these problems. Beginning in 1992 a two-cm deep core was removed from each grab included in the homogenate. These "plugs" were placed in the AVS container without mixing, thereby reducing the oxidation of the sample. The container was filled to the top to further reduce the probability of oxidation.

A.4.2.3 Sediment Contaminants

Metals, organic chemicals, and fine-grained sediments entering estuaries from freshwater inflows, point sources of pollution, and various non-point sources including atmospheric deposition, generally are retained within estuaries and accumulate in the sediments (Turekian, 1977; Forstner and Wittmann, 1981; Schubel and Carter, 1984; Nixon *et al.*, 1986; Hinga, 1988). Samples were collected from a homogenate created during sampling by combining the top 2 cm of sediment from 6-10 sediment grabs. The sediment was placed in clean glass jars with teflon liners or polypropylene containers (for organics and metals analyses, respectively), shipped on ice, and stored frozen in the laboratory prior to analysis for contaminants. Sediments were analyzed for the NOAA Status and Trends suite of contaminants (Table A-5).

A.4.2.4 Sediment Toxicity

Sediment toxicity testing is the most direct measure available for determining the toxicity of contaminants in sediments to indigenous biota. It improves upon direct measurement of sediment contaminants because many contaminants are tightly bound to sediment particles or are chemically complexed and, therefore, are not biologically available (U.S. EPA, 1989). Sediment toxicity testing, however, cannot be used to replace direct measurement of the concentrations of contaminants in sediment because such measurements are an important part of interpreting the results of toxicity tests.

Toxicity tests were performed on the composite sediment samples from each station. Tests were conducted using the standard 10-day acute test method (Swartz *et al.*, 1985; ASTM 1991) and the tube-dwelling amphipod *Ampelisca abdita*.

A.4.2.5 Dissolved Oxygen

Dissolved oxygen (DO) is a fundamental requirement for maintenance of populations of benthos, fish, shellfish, and other estuarine biota. DO concentrations are affected by environmental stresses, such as point and non-point discharges of nutrients or oxygen-demanding materials (*e.g.*, particulates, dissolved organic matter). In addition, stresses that occur in conjunction with low DO concentrations may be even more detrimental to biota (*e.g.*, exposure to hydrogen sulfide, decreased resistance to disease and contaminants). DO levels are highly variable over time, fluctuating widely due to tidal action, wind stress, and biological activity (Kemp and Boynton, 1980; Welsh and Eller, 1991).

Dissolved oxygen was sampled in three ways during the Virginian Province survey: 1) instantaneous water column profiles using a SeaBird model SBE 25 CTD, (2) point-in-time bottom oxygen conditions with a YSI (model 58) oxygen meter and the SeaBird CTD, and 3) continuous 24-72 hr measurements of bottom concentrations using a Hydrolab DataSonde 3 data logging array (1991 only). The first two measurements were taken at all sites, and the continuous measurements were taken at base stations (BSS) only, and only in 1991.

The Hydrolab DataSonde 3 data logger deployed at each 1991 Base site for 24-72 hours collected continuous DO data at 15-min intervals. The DataSonde 3 also collected salinity, temperature, water depth, and pH data. The instruments were calibrated prior to every deployment, and were checked on-board ship immediately prior to deployment and following retrieval by comparison to the YSI oxygen meter. These instruments were deployed

Table A-5. EMAP Virginian Province: Sediment Chemistry Analytes

Analyte Code	Definition
TOC	Total Organic Carbon Concentration in µg/g Dry Weight
AG	Silver Concentration in µg/g Dry Weight
AL	Aluminum Concentration in µg/g Dry Weight
AS	Arsenic Concentration in µg/g Dry Weight
CD	Cadmium Concentration in µg/g Dry Weight
CR	Chromium Concentration in µg/g Dry Weight
CU	Copper Concentration in µg/g Dry Weight
FE	Iron Concentration in µg/g Dry Weight
HG	Mercury Concentration in µg/g Dry Weight
MN	Manganese Concentration in µg/g Dry Weight
NI	Nickel Concentration in µg/g Dry Weight
PB	Lead Concentration in µg/g Dry Weight
SB	Antimony Concentration in µg/g Dry Weight
SE	Selenium Concentration in µg/g Dry Weight
SN	Tin Concentration in µg/g Dry Weight
ZN	Zinc Concentration in µg/g Dry Weight
PCB8	2,4'-dichlorobiphenyl in ng/gram
PCB18	2,2',5-trichlorobiphenyl in ng/gram
PCB28	2,4,4'-trichlorobiphenyl in ng/gram
PCB44	2,2',3,5'-tetrachlorobiphenyl in ng/gram
PCB52	2,2',5,5'-tetrachlorobiphenyl in ng/gram
PCB66	2,3',4,4'-tetrachlorobiphenyl in ng/gram
PCB101	3,3',4,4',5-pentachlorobiphenyl in ng/gram
PCB105	2,2',4,4',5-pentachlorobiphenyl in ng/gram
PCB118	2,3,3',4,4'-pentachlorobiphenyl in ng/gram
PCB128	2,2',3,3',4,4'-hexachlorobiphenyl in ng/gram
PCB138	2,2',3,4,4',5'-hexachlorobiphenyl in ng/gram
PCB153	2,2',4,4',5,5'-hexachlorobiphenyl in ng/gram
PCB170	2,2',3,3',4,4',5-heptachlorobiphenyl in ng/gram
PCB180	2,2',3,4,4',5,5'-heptachlorobiphenyl in ng/gram
PCB187	2,2',3,4',5,5',6-heptachlorobiphenyl in ng/gram
PCB195	2,2',3,3',4,4',5,6-octachlorobiphenyl in ng/gram
PCB206	2,2',3,3',4,4',5,5',6-nonachlorobiphenyl in ng/gram
PCB209	Decachlorobiphenyl in ng/gram
MBT	Mono-butyl Tin in ng/gram
DBT	Di-butyl Tin in ng/gram
TBT	Tri-butyl Tin in ng/gram
OPDDE	2,4'-DDE DDT and metabolites in ng/gram
PPDDE	4,4'-DDE DDT and metabolites in ng/gram
OPDDD	2,4'-DDD DDT and metabolites in ng/gram
PPDDD	4,4'-DDD DDT and metabolites in ng/gram
OPDDT	2,4'-DDT DDT and metabolites in ng/gram
PPDDT	2,4'-DDT DDT and metabolites in ng/gram

(Continued)

Table A-5 (continued).

Analyte Code	Definition
ALDRIN	Aldrin in ng/gram
ALPHACHL	Alpha-Chlordane in ng/gram
TNONCHL	Trans-Nonachlor in ng/gram
DIELDRIN	Dieldrin in ng/gram
HEPTACHL	Heptachlor in ng/gram
HEPTAEPO	Heptachlor epoxide in ng/gram
HEXACHL	Hexachlorobenzene in ng/gram
LINDANE	Lindane (gamma-BHC) in ng/gram
MIREX	Mirex in ng/gram
NAPH	Naphthalene in ng/gram
MENAP2	2-methylnaphthalene in ng/gram
MENAP1	1-methylnaphthalene in ng/gram
BIPHENYL	Biphenyl in ng/gram
DIMETH	2,6-dimethylnaphthalene in ng/gram
ACENTHY	Acenaphthlylene in ng/gram
ACENTHE	Acenaphthene in ng/gram
TRIMETH	2,3,5-trimethylnaphthalene in ng/gram
FLUORENE	Fluorene in ng/gram
PHENANTH	Phenanthrene in ng/gram
ANTHRA	Anthracene in ng/gram
MEPHEN1	1-methylphenanthrene in ng/gram
FLUORANT	Fluoranthene in ng/gram
PYRENE	Pyrene in ng/gram
BENANTH	Benz(a)anthracene in ng/gram
CHRYSENE	Chrysene in ng/gram
BENZOBFL	Benzo(b)fluoranthene in ng/gram
BENZOKFL	Benzo(k)fluoranthene in ng/gram
BENAPY	Benzo(a)pyrene in ng/gram
BENEPY	Benzo(e)pyrene in ng/gram
PERYLENE	Perylene in ng/gram
INDENO	Ideno(1,2,3-c,d)pyrene in ng/gram
DIBENZ	Dibenz(a,h)anthracene in ng/gram
BENZOP	Benzo(g,h,i)perylene in ng/gram
SAND_PC	Sand Content (%)
SICL_PC	Silt-Clay Content (%)

approximately 1 m from the bottom. The stored data were downloaded to a computer and the unit was serviced and recalibrated for subsequent deployment at another site. Dataloggers were also deployed in 1990 for the entire summer (*ca.* 60 days) at selected sites (Long-Term Dissolved Oxygen [LTDO] sites) to evaluate variability. Units deployed in 1990 were set to log at 30-minute intervals. The results of this special study are discussed in the 1990 Demonstration Project Report (Weisberg *et al.,* 1993).

Water column profiles for dissolved oxygen were collected at each station using a SeaBird SBE-25 SeaLogger CTD. This unit was equipped with probes to measure salinity, temperature, depth, pH, DO, light transmission, fluorescence, and PAR. The unit was equilibrated at the sea surface, and then lowered through the water column at *ca.* ¼ m/s until it reached a depth of one meter above the bottom where it was allowed to equilibrate. It was then returned to the surface and all CTD data were downloaded to an on-board computer for review and storage. If the cast appeared unusual or failed QC it was repeated. Beginning in 1991 a bottom water sample was collected using a *Go-Flo* water sampling bottle, and the dissolved oxygen concentration of the sample determined with a YSI Model 58 DO meter. This measurement served as a check on the CTD probe as well as a back-up in case the CTD failed.

A.4.2.6 Marine Debris

The kinds and amounts of floating and submerged (*i.e.*, collected in trawls) marine debris were noted at all stations. Debris was categorized as paper, plastics, metal, glass, wood, and other wastes. Only debris of anthropogenic origin was included. Wastes that were comprised of composited materials (*e.g.*, metal, wood, and plastic) were categorized based on their dominant component.

A.4.3 Habitat Indicators

Habitat indicators provide basic information about the natural environmental setting. Habitat indicator data discussed in this report include water depth, salinity, temperature, pH, water clarity, and sediment silt/clay content.

All water quality measurements were made using the Seabird model SBE 25 CTD (described earlier). This unit was equipped with probes to measure salinity, temperature, depth, pH, DO, light transmission, fluorescence, and PAR.

Measurements of water clarity are incorporated into the CTD casts that were performed at each station. Included in the CTD instrumentation package are a SeaTech transmissometer and a Biospherical PAR (Photosynthetically Active Radiation) sensor. As the CTD is lowered through the water column, transmissivity and PAR data are continually logged.

Surficial water samples were collected at all stations for determination of Total Suspended Solids (TSS). Samples were refrigerated, returned to the laboratory, filtered through a glass-fiber filter, dried and weighed.

Sediment silt/clay content was measured on samples taken from the surficial sediment (top two cm) homogenate from which chemistry and toxicity samples were also removed.

A.5 Data Collection and Sample Tracking

Each field crew was supplied with two portable computers and appropriate software to facilitate electronic recording of the data, data transfer, and sample tracking. All samples, shipments, and equipment were labelled with bar-coded labels to facilitate sample tracking and reduce transcription errors. Field computers were equipped with bar code readers to record sample identification numbers. Receiving laboratories were also equipped with bar code readers to facilitate the receiving process and to rapidly convey information concerning lost or damaged shipments.

Copies of all data entered into the field computer were stored on the hard disk and copied to diskettes. Information on the hard disk was transferred daily via modem to the Information Management Center at AED-Narragansett (RI). Backup diskettes and hard-copy data sheets were shipped weekly to the Center.

All transferred data were examined within 24-48 hours of collection by EMAP-E personnel. Errors were brought to the attention of the field crews for correction and resampling, if required. All electronic data were checked against paper data forms for verification. Further information on the details of the Near Coastal data management systems are presented in Rosen *et al.* (1990).

A.6 Analytical Methods For This Statistical Summary

Three types of analyses were conducted for this report: 1) direct descriptions of measured indicators, 2) development of modified or adjusted indicators (*e.g.*, metal contaminants in sediments), and 3) development of indices based on directly measured indicators. These analyses are documented in a Virginian Province 1990 Demonstration Report (Weisberg *et al.*, 1993) and Appendix C of this document.

A.6.1 Cumulative Distribution Functions (CDFs)

All ecological indicators collected during the Virginian Province survey were characterized using Cumulative Distribution Functions (CDFs). These functions describe the full distribution of indicators in relation to their areal extent within the Province. All observations are weighted based upon surface area associated with each sampling site. The area associated with each sampling unit in large estuaries was equal to the hexagonal spaces created by the EMAP grid (70 km^2). For tidal river and small estuary classes, the area associated with each station was determined using the ARC/INFO data model which produces areal and perimeter estimates. For the tidal river class ARC/INFO was used to delineate the extent of 25 km-long segments beginning at the mouth of the river on a 1:100,000 digital line graph. The area of a large tidal river station is equal to the area of the segment containing the station. For small estuarine systems, the station area is equal to the area of the system in which it was randomly located. The total areas associated with the three classes is: large estuaries - 16,097 km^2; large tidal rivers - 2,602 km^2; and small estuaries - 4,875 km^2.

To generate estimates across classes (strata), weights for stations within each class were adjusted so that the total of the weights for that class was equal to the total area represented by all stations (including unsampleable stations) within that class. The equations used in the generation of CDFs are described in Appendix B.

A.6.2 Adjustment To Known Covariates

In several cases, variability in observed indicators might reflect relationships to known habitat or control variables. Examples of these relationships are: variation in estuarine biota resulting from sampling throughout the salinity gradient; variation in sediment toxicity tests with different mortalities associated with the controls; and variation in sediment metals observed at a site resulting from variations in the amount of natural crustal materials at the site. In all these cases, the observed data must be adjusted in order to construct CDFs or to compare observations from different locations.

A.6.2.1 Adjustment for Natural Habitat Gradients

Estuarine biota are largely controlled by their environmental settings, both natural and anthropogenic. Natural gradients, particularly in salinity and silt-clay content, are common in estuaries. Many estuarine organisms may represent overlapping discrete distributions along these gradients. Thus, normalization of ecological measures over habitat gradients is a common tool used to interpret information when such normalization is necessary. Such relationships were examined; however, no data were normalized in the production of this report.

A.6.2.2 Adjustment for Experimental Controls

Estimates of the area in the Virginian Province containing toxic sediments were based on the results of toxicity tests using the amphipod, *Ampelisca abdita*. For this summary, a relative measure of toxicity was created to facilitate comparisons between sites over a series of bioassays. This adjustment is necessary because control mortalities vary among test series. Sediments were determined to be toxic if: survival of the test organism in test sediments was less than or equal to 80% of the survival observed in clean, control sediments; survival in test and control sediments were significantly different ($p < 0.05$); and survival in control sediments was ≥ 85%. This results in an adjustment to the observed survival rates in test sediments that accounts for variability due to differences in the controls for individual bioassays. These criteria are consistent with those established in U.S. EPA/ACE (1991).

A.6.2.3 Adjustment for Natural Crustal Properties

The extent to which anthropogenic activities have affected concentrations of metals in sediments is complicated by the natural variation of concentrations due to differing particle size distributions in sediments. Because of surface adsorptive and complexation processes, fine-grained sediments will naturally have higher trace metal concentrations than coarse sediments. In some studies, *e.g.*, the National Status and Trends program, reported concentrations are adjusted for this variation by normalizing the concentrations by the fine-grained fraction determined separately. As an alterative to actual size-fractionation measurements, a number of authors (Windom *et al.*, 1989; and Schropp *et al.*, 1990) have determined relationships between sediment concentrations of trace metals and other elements indicative of fine-grained crustally-derived material, *e.g.*, aluminum, iron and manganese. The most commonly used of these indicator elements is aluminum, due to its large natural abundance, freedom from common anthropogenic contaminant sources and significant correlation with both the fine-grained fraction and trace metal concentrations in clean, un-impacted sediments. The correlation between aluminum and trace metals in fine-grained sedimentary material has a geochemical basis related to the composition of crustal material from which the fine particles are derived and the natural adsorption and complexation processes occurring during "weathering" of the crustal material. Once background sediment metal-aluminum relationships have been determined, concentrations of metals expected from background material can be subtracted from total metal concentrations, allowing residual, presumably anthropogenic, contributions to be assessed.

Background metal-aluminum relationships are derived by linear regression of sediment concentrations of each element against aluminum concentrations in the same sediment. Some investigators have used log-transformed metals concentrations in the regression analyses. Such transformations do not improve correlation of the metals-aluminum concentrations of this data set. Furthermore, linear regressions provide direct correlation with the physical mixing and geochemical factors noted above which affect the overall concentration of metals in sediments. This correlation is lost when the concentrations are transformed. Consequently, no data transformations were performed prior to regression analysis.

Use of linear regression to determine metal-aluminum relationships in background sedimentary material can only be successful if the sediments do not include contributions from sources other than natural background sediments. The data sets used in this study were statistically screened to eliminate samples which might contain additional source materials. This was accomplished by performing linear regressions of concentrations of aluminum against each metal. The residuals (the differences between the measured concentrations and those predicted from the regression) were then tested for normal distribution. If the residuals were found not to be normally distributed, samples which had studentized residual values greater than 2 were eliminated from the data set. Regression of the reduced data set was repeated and the residuals tested again for normal distribution. This process was repeated for each metal until residuals from the regressions were all normally distributed, at which point the remaining samples were assumed to represent natural, background sediments.

The regression relationships derived for the background sediments were then applied to the original data set. Samples with trace metal concentrations exceeding the upper 95% confidence limit for that metal's regression against aluminum were designated as enriched. It should be noted that no assessment was made as to the magnitude of enriched; metal concentrations might be only slightly above the 95% confidence limit or might exceed the limit by factors of 10-100. The categorization "enriched" was applied to any sediment with a metal concentration higher than that expected from the background sediment aluminum metal relationship at the 95% confidence level.

A.6.3 The Benthic Index

A benthic index, which uses individual measures of the benthic community, was utilized to report on the condition of the benthic biological resources of the Virginian Province. The index, as used in this report, was developed from a subset of the data collected over all four years of sampling and was constructed to represent a combination of individual benthic measures that best discriminates between good and poor benthic conditions. This current index is EMAP's continued attempt to reduce many individual indicators into a single value that has a high level of discriminatory power between good and poor ecological conditions. The reader should note that the index as used in this report is a revision to prior ones used in earlier EMAP-VP reports. It has always been the intent of the program to continually revise the benthic index as more data became available (Weisberg *et al.*, 1993), and the current index represents the effort using four years of available EMAP data (Paul *et al.*, in preparation).

The process for developing an index of benthic community condition has been documented for the 1990 (Weisberg *et al.*, 1993) and, separately, for the 1990-91 (Schimmel *et al.*, 1994) data sets. This process entails several discrete steps: identification of a set of benthic parameters to define conditions that include components of faunal and functional diversity and structure; determination of the statistical relationships between these benthic parameters and habitat variables; normalization of those benthic parameters that are strongly associated with habitat condition; identification of a test data set that clearly distinguishes relatively pristine sites from those exhibiting toxic contamination, hypoxia, or both; and application of discriminant analysis to the test data set to determine those benthic parameters whose variation is most closely associated with differences in reference and impacted condition. This same process was used with the 1990-93 data set.

The benthic index developed using the 1990-91 data set suffered from poor representation of impacted and reference conditions in low salinity (< 5 ppt) in the test data set. This benthic index was highly correlated with salinity and appeared to misclassify good sites in the oligohaline and impacted sites in the meso- and polyhaline. This led to the refinement of the candidate benthic parameters, utilization of more stringent criteria for assignment of sites to the reference and impacted categories in the test data set, and revision of the benthic index based upon the four-year data set (1990-93). Statistical analyses indicated that most measures of diversity and abundance of low salinity tubificids were highly correlated with salinity and required normalization (Weisberg *et al.*, 1993).

The test data set was constructed to contain an equal number of impacted and reference sites, and equal number of sites exhibiting each condition in each of the three salinity zones (< 5, 5-18, > 18 ppt), and a relative balance of muddy and sandy sites in each condition/salinity category. For a site to be included in the reference condition test data set, all of the following were met: bottom dissolved oxygen > 7 mg/l; no more than three sediment contaminant concentrations exceeding Long *et al.* (1995) ER-L values, and none exceeding ER-M concentration; and survival in a sediment toxicity test 90% or better and not significantly different from control survival. Ten sites in each of the oligo-, meso-, and polyhaline zones were selected. Thirty impacted sites were selected based on criteria that included: low bottom dissolved oxygen (< 2 mg/l); low survival in the toxicity test and multiple concentration exceedances of ER-M values. The test data set contained 60 cases; 30 were categorized as impacted and 30 were reference.

The discriminant analyses identified a series of highly correlated benthic indices that correctly classified reference and impacted sites in the test data set. The benthic parameter common to the candidate indices that accounted for the greatest degree of variability was a measure of species richness, Gleason's D (Washington, 1984). The benthic index that was chosen (1) maximized classification efficiency using the test data set (goal of ca. 90% correct classification), (2) provided a good degree of cross-validation with the test data set (goal of ca. 80% cross-validation), (3) produced a good classification efficiency with a validation data set (goal of ca. 80% correct classification), and (4) had the individual parameters contribute to the overall score consistently with our understanding of benthic communities. The stations that met the reference and impacted site criteria, but were not used in the test data set for the discriminant analysis, were used as a validation data set (52 cases).

The three benthic parameters of the index were: salinity-normalized expected Gleason's D for infaunal and epifaunal species; salinity-normalized expected number of tubificids and abundance of spionids. The richness measure is associated with reference conditions (positive contribution) and the latter two measure are associated with impacted conditions (negative contribution).

The discriminant score calculation normalizes the individual parameters based on the mean and standard deviation for the parameter in the test data set. The critical value for discriminating between reference and impacted sites was determined to be zero using the following equation:

Benthic Index Score =

1.389 (pct expect Gleason - 51.5) / 28.4
- 0.651 (normalized tubificid abundance - 28.2) / 119.5
- 0.375 (spionid abundance - 20.0) / 45.4

Where:

Percent Expected Gleason diversity index value =

$$\text{Gleason} / (4.283 - 0.498 \cdot \text{bottom salinity} + 0.0542 \cdot \text{bottom salinity}^2 - 0.00103 \cdot \text{bottom salinity}^3) \cdot 100$$

Normalized Tubificid Abundance =

$$\text{Tubificids} - 500 \cdot e^{-15 \cdot \text{bottom salinity}}$$

APPENDIX B

ESTIMATION FORMULAE FOR EMAP SAMPLING IN THE LOUISIANIAN AND VIRGINIAN PROVINCES

Acknowledgements: The equations described in this section for large estuary, large tidal river, and whole province estimates were formulated by Douglas Heimbuch and Harold Wilson of Coastal Environmental Services Inc., Linthicum, MD and Stephen Weisberg of Versar Inc., Columbia, MD

B.1 INTRODUCTION

This appendix describes the equations used for making the four-year estimates of the areal extent of conditions of interest (and estimates of variances for these estimates) reported in this document. Equations were formulated using data from the first four years of EMAP-Estuaries (EMAP-E) sampling conducted in the Virginian and Louisianian Provinces. The recommended methods were chosen to be consistent with the sampling designs employed in each of the estuarine system classes (large estuaries, large tidal rivers, and small estuaries). This appendix describes the generic equations for each class, followed by specific instructions for application to Virginian Province data. The equations and associated SAS programs were provided to the EMAP-Virginian Province team by EMAP-Estuaries.

The reader should note that the large estuary and large tidal river equations differ from those used for generating single-year estimates in the 1991 and 1992 Statistical Summaries. These equations represent a refinement of the earlier equations. It should be noted that these equations are still under review and may be further refined in the future to address additional measurements of variability. Any alterations to the equations should result in only minor changes. A comparison of the confidence intervals generated using the "old" equations with those reported in this section shows only small changes result.

The 95% confidence intervals reported in this document are calculated as 1.96 times the standard error of the estimate, with the standard error (of the estimate) being the square root of the variance of the estimate.

B.2 LARGE SYSTEM RECOMMENDED METHODS

The recommended method for large system estimation is based on a sampling design in which sampling stations are selected within hexagons of a randomly overlaid grid. If a station within a hexagon is on land, then no sample is obtained from that hexagon. The estimated subnominal (*i.e.*, impacted) area for one year of the survey is based on Horvitz-Thompson estimation methods and is given by:

$$\hat{Y}_t = A\frac{\sum_{i=1}^{n} z_{ti}x_{ti}}{\sum_{i=1}^{n} x_{ti}} = A\frac{N}{D}$$

where,

$\hat{Y}_t =$ the estimated subnominal area in year t

$A =$ the known total area of large systems in the province

$N = \sum_{i=1}^{n} z_{ti}x_{ti}$

$D = \sum_{i=1}^{n} x_{ti}$

$n =$ the total number of hexagons subject to sampling in the province

$z_{ti} =$ the response from hexagon i in year t (=1 if subnominal, 0 otherwise)

$x_{ti} =$ 1 if a sample is obtained from hexagon i, 0 otherwise.

The indicator variable X_{ti} can also be defined in a manner to estimate the subnominal area of a particular subpopulation of the province (*e.g.*, Delaware Bay as a subpopulation within the Virginian Province). In this case, X_{ti} would be defined as 1 if the sample was obtained in the subpopulation of interest, and zero otherwise. The total area used in this calculation (A) would be the known area of the subpopulation of interest.

The variance of the estimated subnominal area is estimated using a formula based on the Yates-Grundy formula for the variance of the Horvitz-Thompson estimator, and the Taylor series expansion formula for the variance of a quotient:

$$v\hat{a}r(\hat{Y}_t) = v\hat{a}r\left(A\frac{N}{D}\right) = \left(A\frac{N}{D}\right)^2\left[\frac{v\hat{a}r(N)}{N^2} + \frac{v\hat{a}r(D)}{D^2} - \frac{2c\hat{o}v(N,D)}{ND}\right]$$

where,

$$v\hat{a}r(N) = \sum_{i=1}^{n}\sum_{j>i}^{n} W_{ij}(z_{ti}x_{ti} - z_{tj}x_{tj})^2$$

$$v\hat{a}r(D) = \sum_{i=1}^{n}\sum_{j>i}^{n} W_{ij}(x_{ti} - x_{tj})^2$$

$$c\hat{o}v(N,D) = \sum_{i=1}^{n}\sum_{j\neq i}^{n} W_{ij}x_{ti}(x_{ti}z_{ti} - x_{tj}z_{tj}) \quad ,$$

[which is equivalent to, $c\hat{o}v(N,D) = \sum_{i=1}^{n}\sum_{j>i}^{n} W_{ij}(x_{ti} - x_{tj})(x_{ti}z_{ti} - x_{tj}z_{tj})$]

$$W_{ij} = \frac{V_{ij}}{1 - V_{ij}}$$, and

V_{ij} = the proportion of random placements of the grid which result in points i and j lying in the same hexagon.

Two stations can be jointly selected for sampling in the same year only if they are located in separate hexagons. The probability of joint inclusion is therefore related to the complement of the probability that the random placement of the grid causes the two points to be included in the same hexagon. For stations that are sufficiently distant, the probability of being included in the same hexagon is equal to zero.

The recommended method for estimating the subnominal area is based on the ratio of two random quantities: the number of actual samples associated with a subnominal response, and the total number of actual samples. The total number of actual samples is a random quantity due to the edge effect of hexagons that include both land and water area. An alternative method could be used for estimation that is based only on the product of the number of hexagons with a subnominal response and the area of a hexagon. However, this method could produce estimates of subnominal area that are greater than the total known area due to a greater than expected number of sample stations falling in water. The ratio method is recommended to insure that estimates of subnominal area are not adversely affected by actual sample size in this manner.

To estimate the four-year average subnominal area in large systems, the average of the annual estimates is calculated:

$$\hat{Y} = \frac{\sum_{t=1}^{4} \hat{Y}_t}{4}$$

where,

$\hat{Y}$ = the estimated average response over four years.

The estimated variance of the four-year average is given by:

$$var(\hat{Y}) = \frac{1}{16} \sum_{t=1}^{4} var(\hat{Y}_t)$$

The recommended method for estimating the four-year average subnominal area employs years as independent strata. An alternative method could have been used which combines data from all years into one procedure without stratifying by year. In this method, years that received more effort due to random sample sizes would receive more weight in the calculation of the four year average. By treating years as strata, each year receives equal weight in the estimation of the four-year average. The recommended method also insures that the year to year variation in the response variable will not affect the variance of the four year average estimate. This is consistent with the view of interannual variability as a fixed effect (rather than a random effect) when characterizing a specified set of years.

Application to the Virginian Province

The recommended method for estimating the subnominal area for one year can be applied to large system data from the Virginian Province. However, sampling stations in the Virginian Province were not randomly selected within hexagons, but were obtained at the center point of each hexagon. For this reason, the recommended method for the estimation of the variance of the subnominal area estimate in one year cannot be directly applied. An approximate estimate of this variance can be calculated by redefining V_{ij} as :

$V_{ij}=\frac{1}{\beta n}$ for i and j in adjacent hexagons, 0 otherwise,

where β is the proportion of all pairs of samples that are from adjacent hexagons. This approximation is based on the following relationships:

$$\pi_{ij}=(1-V_{ij})\frac{1}{a^2}$$

and,

$$\sum_i \sum_{j\neq i} \pi_{ij}=n(n-1)$$

where,

$n=$ number of hexagons in the grid

$a=$ area of each hexagon (in appropriate units)

$\pi_{ij}=$ joint inclusion probability for station locations i and j.

Therefore,

$$na(na-1)\beta(1-\bar{V})\frac{1}{a^2}+na(na-1)(1-\beta)\frac{1}{a^2}=n(n-1)$$

where,

$\bar{V}=$ average of non-zero V_{ij} values

$\beta=$ proportion of i,j pairs that are no farther apart than the distance between centers of adjacent hexagons,

and,

$\bar{V}=\frac{1}{\beta n}$ for large "a" (relative to the size of a sampling station).

The recommended method for estimating the variance of the four-year average can be applied to the approximate variances of the one year estimates. This approach does not account for any gain in precision that may be caused by the four-year interpenetrating design which was implemented in the Virginian Province. The potential gain in precision is due to negative covariance among the annual estimates. The magnitude of the negative covariance depends on the degree of spatial autocorrelation of distances less than the size of a hexagonal cell. Analyses of the data suggest that spatial autocorrelation in the response variables is insignificant at distances as small as 2.5 km. Therefore, little increase in precision is anticipated and the recommended method is likely to provide an adequate approximation.

B.3 TIDAL RIVER RECOMMENDED METHODS

The recommended methods for tidal rivers estimation is based on a stratified random sampling design. Each river is stratified into areas of river length equal to 25 kilometers. In each year, at least one sample is obtained in each stratum with some strata providing two samples (Lousinian Province only: see notes on Application to Virginian Province). Each 25-km segment was divided into four subsegments, with one being sampled each year. The statistical area applied to each station was equal to the area of the subsegment the station resided in plus the area of the next three upstream subsegments. The recommended method for estimating subnominal area for tidal rivers is:

$$\hat{Y}_t = A\frac{\sum_{i=1}^{n} W_i \bar{z}_{ti}}{\sum_{i=1}^{n} W_i}$$

where,

$\hat{Y}_t$ = estimated subnominal area in year t

A = the total known area of tidal river systems in the province

n = the number of sampled tidal river strata in the province

W_i = the area of stratum i

$\bar{z}_{ti} = \frac{\sum_{j=1}^{m_{ti}} z_{tij}}{m_{ti}}$ = the average response in year t and stratum i

z_{tij} = the response in year t, stratum i, sample j (1 if subnominal, 0 otherwise)

m_{ti} = the number of observations in year t and stratum i.

The recommended method can be applied to estimate the subnominal area in a particular tidal river within the province. In this application, only data from the strata of interest would be utilized, and the total area (A) would be that of only the selected tidal river.

The variance of the estimated subnominal area is calculated as:

$$v\hat{a}r(\hat{Y}_t) = \frac{A^2 \bar{S}_t^2}{\left(\sum_{i=1}^{n} W_i\right)^2} \left[\sum_{i=1}^{n} W_i^2 \left(\frac{1}{m_{ti}}\right)\right]$$

where,

$v\hat{a}r(\hat{Y}_t)$ = the estimated variance of the subnominal area estimate in year t,

$$\bar{S}_t^2 = \frac{\sum_{i=1}^{n^*} \sum_{j=1}^{m_{ti}} (z_{tij} - \bar{z}_{ti})^2}{\sum_{i=1}^{n^*} (m_{ti} - 1)}$$ (the pooled estimate of within stratum variance)

n^* = the number of strata with replicate samples ($m_{ti} \geq 2$).

The variance of the estimated subnominal area is based on the estimate of within-strata variance pooled across strata which contain at least two observations. The estimation of variance requires that at least one stratum contains two or more observations (see note on application to Virginian Province).

The estimate of the four-year average subnominal area is calculated as the average of the annual estimates:

$$\hat{Y} = \frac{1}{4} \sum_{t=1}^{4} \hat{Y}_t$$

where,

$\hat{Y}$ = the estimated four-year average subnominal area.

The estimated variance of the four-year average estimate is:

$$v\hat{a}r(\hat{Y}) = \frac{1}{16} \sum_{t=1}^{4} v\hat{a}r(\hat{Y}_t)$$

Application to the Virginian Province

The recommended method for estimating tidal river subnominal area can be applied to Virginian Province data. However, the area subject to sampling in each tidal river changed over the four-year period because the statistical area applied to each station was equal to the area of the subsegment the station resided in plus the area of the next three upstream subsegments. Stations in the first subsegment were sampled in 1990, third subsegment in 1991, second subsegment in 1992, and fourth subsegment in 1993. Therefore, in year 1 the reach from 0 km to 125 km was subject to sampling, in year 2 the reach from 12 km to 125 km was subject to sampling, in year 3 the reach from 6.25 km to 125 km, and in year 4 the reach from 18.75 km to 125 km was subject to sampling.

The tidal river sampling in the Virginian Province consisted of one sample per stratum. Since replicate observations were not obtained in any stratum, the approximate estimate of within-stratum variance applied to Louisianian Province data can also be applied to data from the Virginian Province. In this application, approximations of within-stratum variances can be calculated separately for each tidal river.

The recommended methods for the estimate of the four-year average subnominal area and corresponding variance can be directly applied to tidal river data from the Virginian Province. This approach does not account for any gain in precision that may be caused by the four-year interpenetrating design which was implemented in the Virginian Province. Similarly to the approach for large systems, the potential gain in precision is a function of the degree of spatial autocorrelation in the response variables. Since studies have suggested that the degree of spatial autocorrelation is small, little increase in precision from the interpenetrating design is anticipated, and the recommended approach is likely to produce an adequate approximation.

B.4 SMALL SYSTEM RECOMMENDED METHODS

For small estuarine systems, estimates of CDFs and associated variances were computed based on a random selection of small systems within the Province, with replicate samples taken from a subset of the selected systems (Cochran, 1977). Unlike large estuaries and large tidal rivers, only a portion of the area of this class is sampled each year; therefore, a single four-year estimate is produced from the entire dataset as opposed to pooling individual yearly estimates. This method is directly applicable to Virginian Province data without modification The resulting CDF estimate is:

$$\hat{P}_{Sx} = \frac{\sum_{i=1}^{n} A_i \bar{y}_i}{\sum_{i=1}^{n} A_i}$$

where,

$\hat{P}_{Sx}$ = CDF estimate for value x

$\bar{y}_i = \frac{1}{m_i} \sum_{j=1}^{m_i} y_{ij}$

m_i = number of samples at small system i

A_i = area of small system i

$y_{ij} = \begin{cases} 1 \text{ if response is less than } x \\ 0 \text{ otherwise} \end{cases}$

n = number of small systems sampled

Since replicate samples were only obtained at a subset of the sampled small estuarine systems, the formula for the estimated variance taken from Cochran (1977 eq. 11.30) was modified to produce the following estimate of the approximate mean squared error (MSE) of the CDF estimate:

$$MSE(\hat{P}_{sx}) = \frac{\frac{N^2}{n}(1-f_1)\frac{\sum_{i=1}^{n} A_i^2(\bar{y}_i-\hat{P}_{sx})^2}{n-1} + \frac{N}{n*}\sum_{i=1}^{n*}\frac{A_i^2 S_{2i}^2}{m_i}}{A^2}$$

where,

$f_1 = n/N$

$n*$ = number small systems with replicate samples

$$S_{2i}^2 = \frac{\sum_{j=1}^{m_i}(y_{ij}-\bar{y}_i)^2}{m_i-1}$$

A = the total area of small systems in the Province (4,875 km^2)

N = number small systems in Province (144)

B.5 ENTIRE PROVINCE RECOMMENDED METHODS

The recommended estimate for the subnominal area for the entire province (*i.e.*, across all system classes) is the sum of the subnominal area estimates of the large systems, tidal rivers, and small systems:

$$\hat{U}_t = \sum_{i=l,t,s} \hat{Y}_{ti}$$

where,

$\hat{U}_t$ = the estimated subnominal area for the entire province in year t

$\hat{Y}_{ti}$ = the estimated subnominal area in year t for system class i, (i=large, tidal, small).

The estimated variance for the subnominal area in the entire province is the sum of the component variances:

$$v\hat{a}r(\hat{U}_t) = \sum_{i=l,t,s} v\hat{a}r(\hat{Y}_{ti})$$

where,

$v\hat{a}r(\hat{U}_t)$ = the estimated variance of the subnominal area in the entire province,

$v\hat{a}r(\hat{Y}_{ti})$ = the estimated variance of the subnominal area in year t, system class i.

The recommended methods for estimation in the entire province are based on the assumption of the system classes as being independent strata. The methods can be directly applied to one-year and four-year average estimates, and to data from both the Louisianian and Virginian Provinces.

APPENDIX C

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

As discussed in Section 3.2.3.5, 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.6.2.3). For each metal, a regression and an upper 95% confidence interval was determined and plotted (Figures C-1 to C-8). Stations with concentrations falling above the upper 95% confidence interval were classified as enriched for that metal. This process was inefficient for several metals, but performed well for As, Cr, Fe, Hg, Mn, Ni, Sb, and Zn. Regressions and regression parameters (slope, intercept, and correlation coefficient: Table C-1) for only these metals are included in this report.

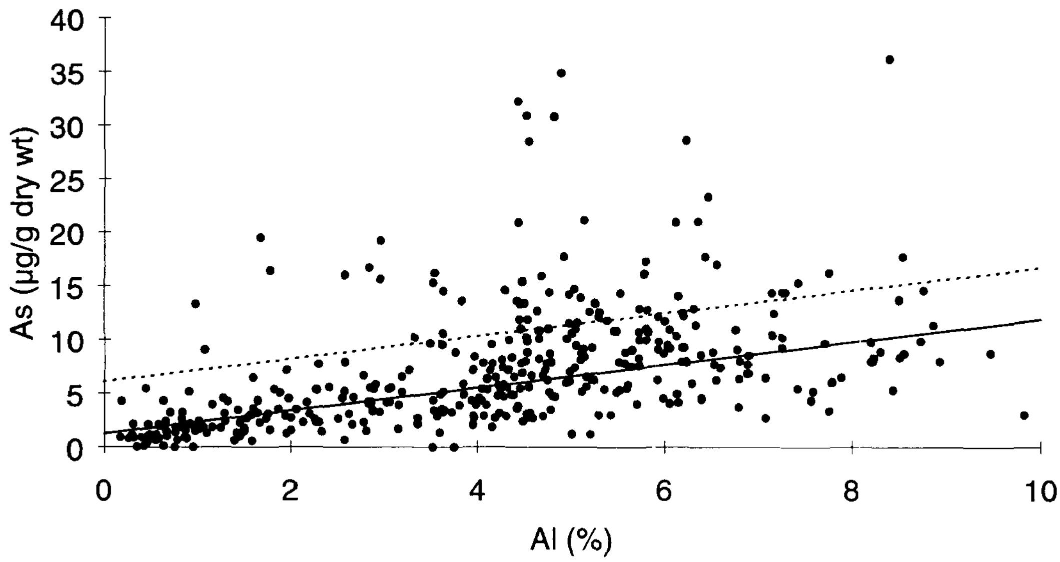

Figure C-1. Linear regression of Arsenic against aluminum. (Dashed line is the upper 95% confidence interval).

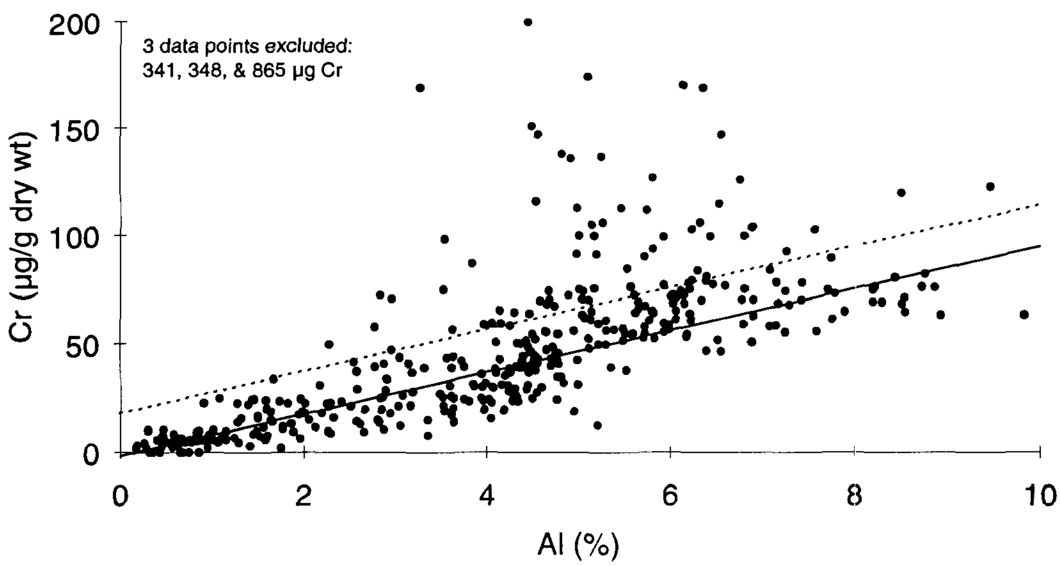

Figure C-2. Linear regression of Chromium against aluminum. (Dashed line is the upper 95% confidence interval). NOTE: Three data points were excluded for clarity.

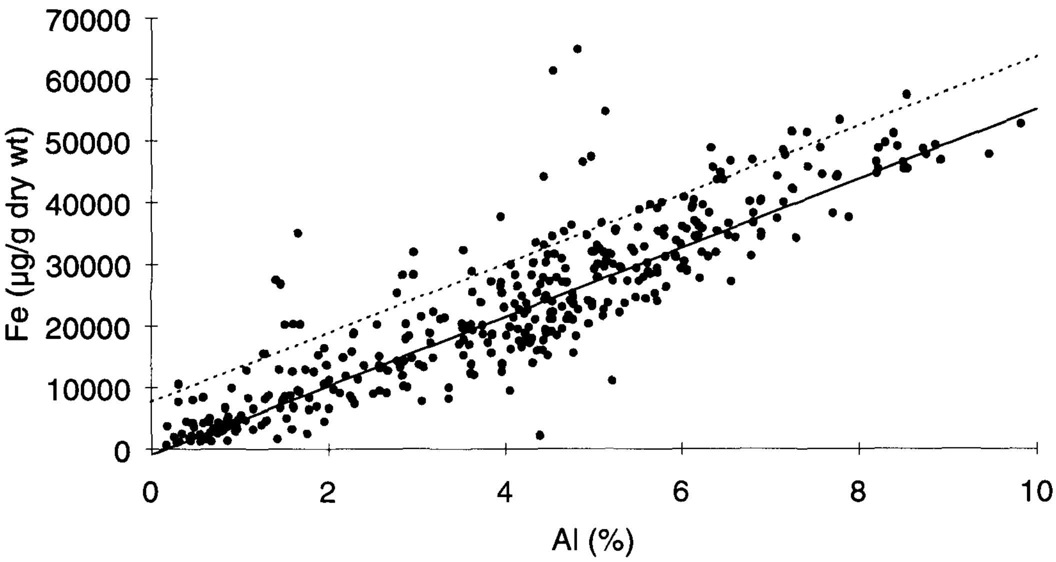

Figure C-3. Linear regression of Iron against aluminum. (Dashed line is the upper 95% confidence interval).

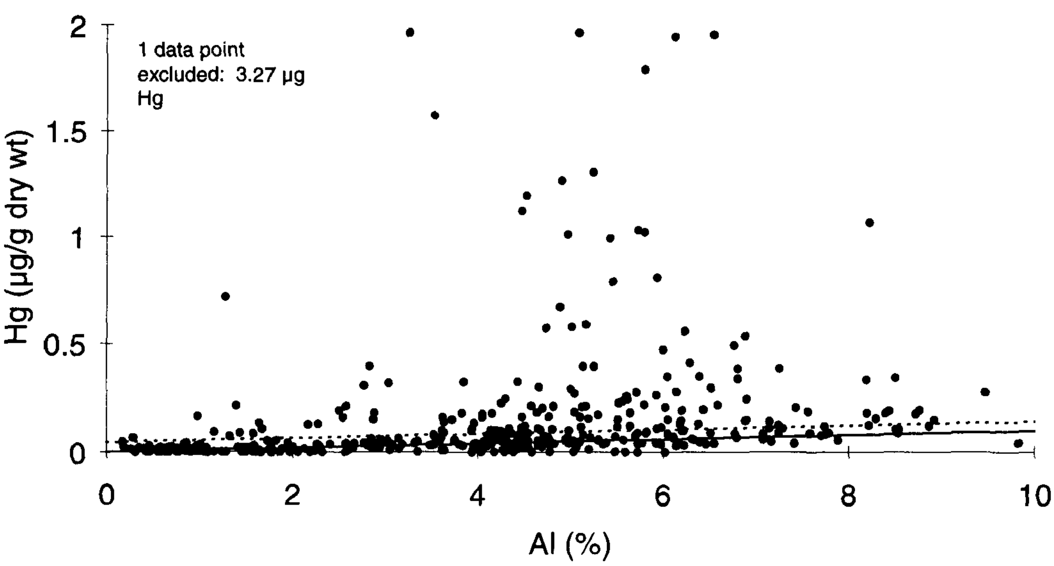

Figure C-4. Linear regression of Mercury against aluminum. (Dashed line is the upper 95% confidence interval). NOTE: One data point was excluded for clarity.

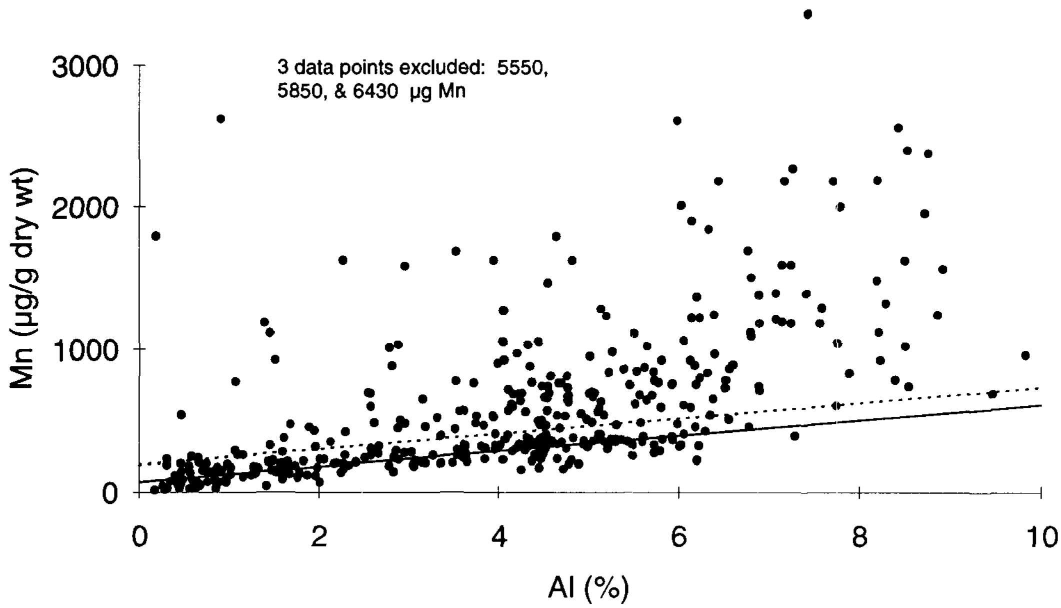

Figure C-5. Linear regression of Manganese against aluminum. (Dashed line is the upper 95% confidence interval). NOTE: Three data points were excluded for clarity.

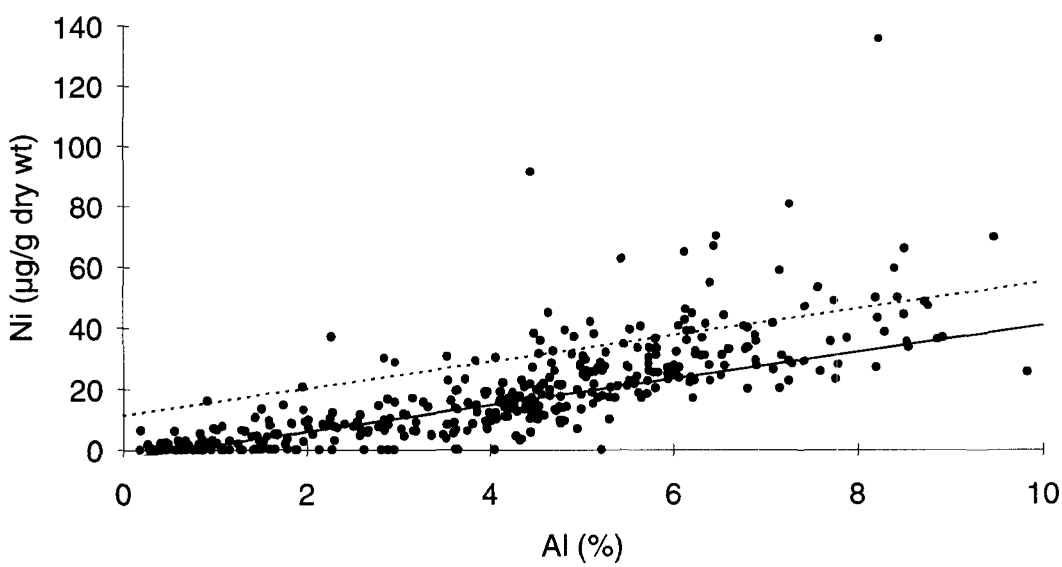

Figure C-6. Linear regression of Nickel against aluminum. (Dashed line is the upper 95% confidence interval).

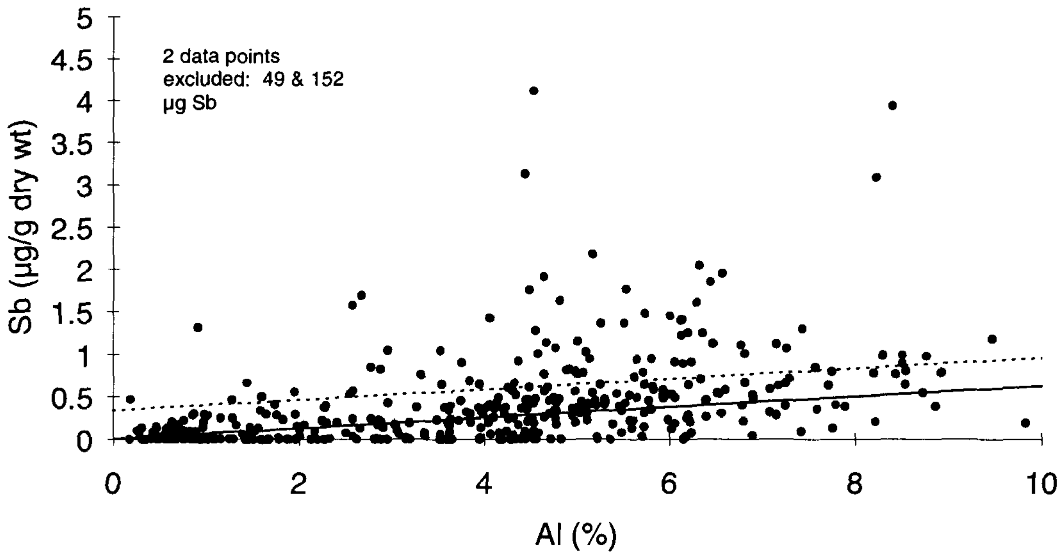

Figure C-7. Linear regression of Antimony against aluminum. (Dashed line is the upper 95% confidence interval). NOTE: Two data points were excluded for clarity.

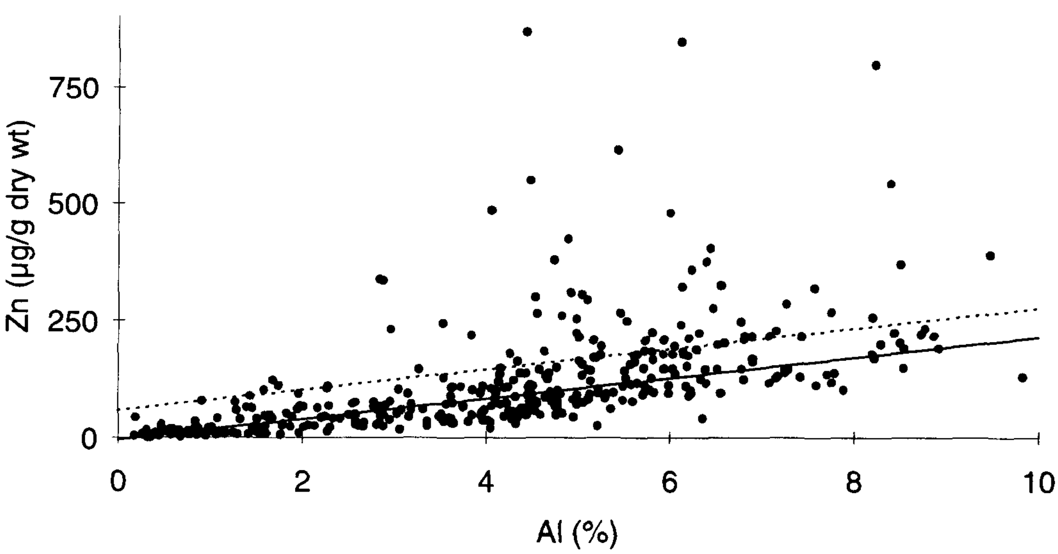

Figure C-8. Linear regression of Zinc against aluminum. (Dashed line is the upper 95% confidence interval).

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

Element	Regression parameters		
	m	b	r^2
As	1.06	1.28	0.49
Cr	9.64	-1.55	0.82
Fe	5,581	-953	0.89
Hg	0.010	0.002	0.48
Mn	54.22	69.05	0.74
Ni	4.66	-3.40	0.76
Sb	0.006	0.006	0.39
Zn	21.83	-5.43	0.69

*U.S. GOVERNMENT PRINTING OFFICE:1995-650-006/22053