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Statistical Summary
EMAP-Estuaries
Virginian Province - 1991

by

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ABSTRACT

Annual monitoring of indicators of the ecological condition of bays and estuaries within the Virginian Province (Cape Cod, MA to Cape Henry, VA) was conducted by the U.S. EPA's Environmental Monitoring and Assessment Program (EMAP) during July, August, and September, 1991. Data were collected at 154 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, fish gross external pathology, and fish tissue contamination. Data are used to estimate the current status of the ecological condition of Virginian Province estuarine resources, and provide a baseline for identifying future trends. Cumulative distribution functions (CDFs) and bar charts are utilized to graphically display data. Estimates, with 95% confidence intervals, are provided of the areal extent of degraded resources within the Province for those indicators where "degradation" can be defined. Data are also presented by estuarine class: Large estuaries, small estuarine systems, and large tidal rivers. Included, as an appendix, are sub-population estimates for Chesapeake Bay and Long Island Sound.

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

DISCLAIMER

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

This report represents data from a single year of field operations of the Environmental Monitoring and Assessment Program (EMAP). Because the probability-based scientific design used by the EMAP necessitates multiple years of sampling, there may be significant levels of uncertainty associated with some of these data. This uncertainty will decrease as the full power of the approach is realized by the collection of data over several years. Similarly, temporal changes and trends cannot be reported, as these require multiple years of observation. Please note that this report contains data from research studies in only one biogeographical region (Virginian Province) collected in a short index period (July to September) during a single year (1991). Appropriate precautions should be exercised when using this information for policy, regulatory or legislative purposes.

PREFACE

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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 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 indicators of ecological condition. Specific issues investigated include:

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

In 1990, EMAP-E initiated a demonstration project in the estuaries of the Virginian Province. The 1991 field season represents the second year of sampling in the Province, which includes the coastal region of the Northeast United States from Cape Cod south to the mouth of Chesapeake Bay. It is composed of 23,574 km^2 of estuarine resources including 11,469 km^2 in Chesapeake Bay and 3,344 km^2 in Long Island Sound.

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

Three field crews sampled 154 of the scheduled 155 sites in the Virginian Province during the seven-week sampling period beginning on July 22, 1991. Of these, 102 were "Base Sampling Sites" (BSS) which were the probability-based sites selected according to the EMAP-E design for assessing the condition of the estuarine resources of the Province (see Appendix A). Only data collected at these sites were used in the generation of this report.

Field crews collected data and samples for three categories of "ecological indicators": Biotic condition, abiotic condition, and habitat which are described in Appendix A.

The 1991 data reported in this document represent only one year of sampling of a four-year cycle; *i.e.*, the total number of samples needed by EMAP to characterize the Province are sampled over a four-year period (Holland, 1990). Therefore, the reader must use these data carefully, and be aware that the proportion of degraded area calculated for 1991 may differ somewhat from the regional assessment to be generated following the completion of the four-year cycle.

All EMAP-Virginian Province (EMAP-VP) data used in the generation of this report were subjected to rigorous quality assurance measures as described in the 1991 Quality Assurance Project Plan (Valente and Schoenherr, 1991).

Biotic Condition Indicators

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

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

A benthic index critical value of zero was determined from the combined 1990/1991 Virginian Province dataset. Fourteen (± 6) percent of the bottom area of the Virginian Province sampled in 1991 had an index value of < 0, indicating likely impacts on the benthic community (Figure 1). The lowest incidence was found in the large estuaries (6 ± 7%), and the highest in small estuaries (32 ± 17%).

"Standard" fish trawls (trawling at a specified speed for a specified time) were 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 31 ± 10% of the Province, and "high" catches (>100 fish/trawl) were experience in approximately 18 ± 9% (Figure 2). Tidal rivers produced the greatest percent area with "high" catches.

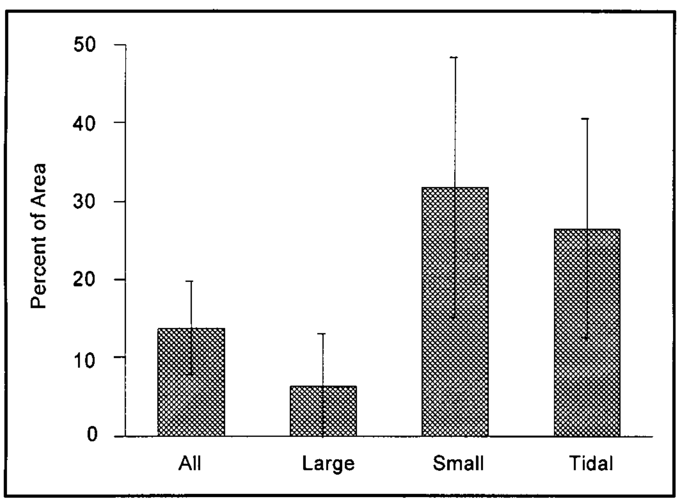


Figure 1. Percent area of the Virginian Province by estuarine class with a benthic index value below 0 in 1991. (Error bars represent 95% confidence intervals).

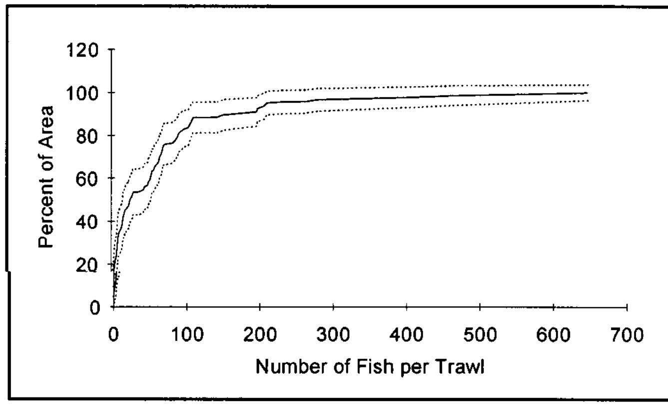


Figure 2. Cumulative distribution of fish abundance in numbers per standard trawl as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

The incidence of the gross external pathologies; growths, lumps, ulcers, and fin erosion, among "target" species in the Virginian Province in 1991 was 0.6%. Of the 2,513 fish examined, 16 were identified as having one or more of these pathologies. These individuals were collected at six of the 101 base stations sampled during the index period (one additional station could not be sampled). It should be noted that fewer than half of these pathologies were verified by an expert pathologist.

Eighty-four composites of up to five individuals of target species were analyzed for contaminants in muscle. No sample exceeded FDA action limits (or, where FDA action limits were not available, international limits) for any of the organic analytes for which criteria were available (see Table 3-2). Several metals (arsenic, chromium and selenium) exceeded criteria values, with the highest incidence of exceedences being measured for arsenic. Fourteen of the 82 composite samples analyzed for metals (two samples were lost) exceeded the mean of international criteria values for As (2 μg/g wet weight).

Abiotic Condition Indicators

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

One potential stress to aquatic organisms is a low concentration of dissolved oxygen (DO). Two and five mg/L are values employed by EMAP to define severe and moderate hypoxia, respectively. Approximately 18 ± 8% of the sampled area of the Province lies in waters with bottom DO concentrations less than or equal to 5 mg/L (Figure 3). "Bottom" is defined as one meter above the sediment-water interface. Approximately 5 ± 5% of the sampled area exhibited bottom DO conditions ≤2 mg/L. Dissolved oxygen conditions ≤ 2 mg/l were evident in 4 ± 6, 1 ± 2, and 15 ± 28% of the area of the large estuaries, small estuaries, and large tidal rivers sampled within the Province, respectively.

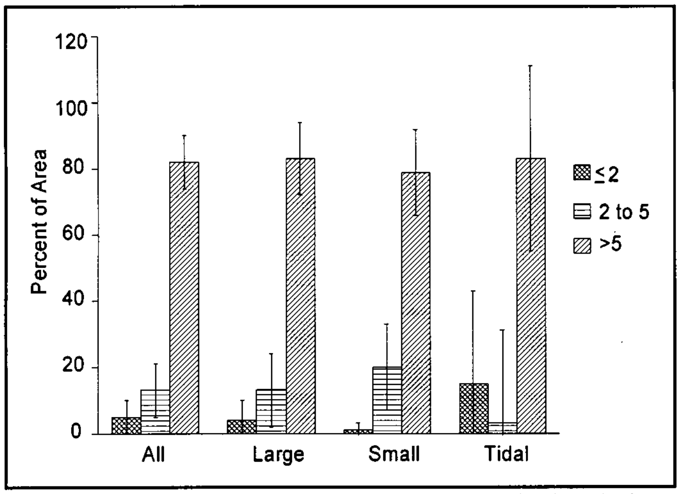


Figure 3. The percent of area by class that had a low (≤ 2 mg/L), medium (2 to 5 mg/L), or high (>5 mg/L) oxygen concentration in the bottom waters. (Error bars represent 95% confidence intervals).

In addition to measuring individual stressors (*i.e.*, individual chemical analytes) sediment toxicity tests were performed on sediments collected at each site to determine if they were toxic to the tube-dwelling amphipod, *Ampelisca abdita*. Sediments were classified as toxic if amphipod survival in the test sediment was less than 80% of that in the control sediment. Approximately 21 ± 10% of the sampled area of the Virginian Province contained sediments which were toxic to the amphipod during 10-day exposures (Figure 4).

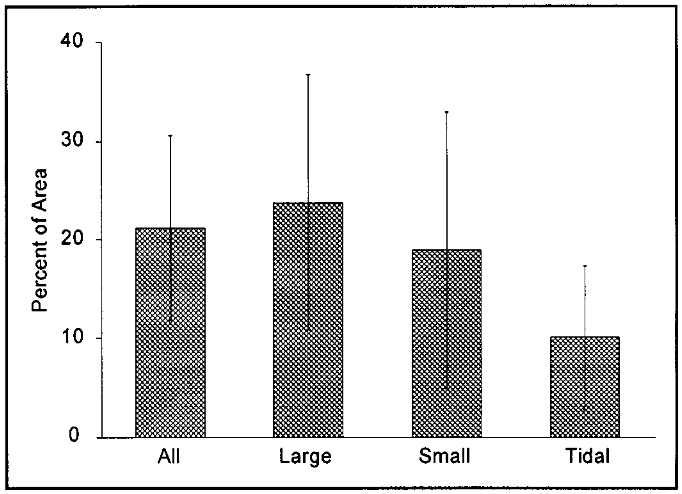


Figure 4. Percent of area in the Virginian Province in 1991, by estuarine class, with low amphipod survival (<80% of control) in sediment toxicity tests. (Error bars represent 95% confidence intervals).

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

Figure 5 shows the distribution of the sum of measured polycyclic aromatic hydrocarbons (PAHs) in the Virginian Province. The complete list of analytes included in this summation can be found in Section 3. Approximately 94 ± 6% of the Province has concentrations of PAHs below 4,000 ng/g dry weight, with a maximum measured concentration at any station of 80,100 ng/g.

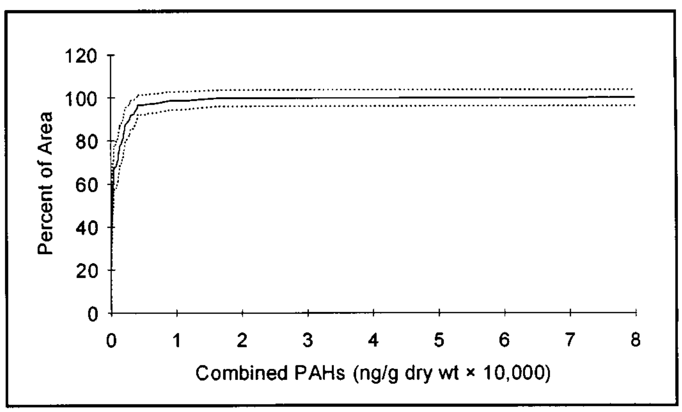


Figure 5. Cumulative distribution of combined PAHs in sediments as percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

Draft EPA Sediment Quality Criteria (SQC) are currently available for the PAHs acenaphthene, phenanthrene, and fluoranthene; and the pesticide dieldrin. Exceedences of the PAH criteria were measured at only three stations within the Province (2 ± 5% of the area). The station representing the largest area was located in a shipping channel at the mouth of Chesapeake Bay in a sandy environment. Sediments from this station did not show any toxicity, and the benthic community was indicative of a healthy 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. Eliminating this station results in 0 ± 0%, 0.3 ± 5% (one station) and 0.4 ± 4% (two stations) of the sampled area of the Province exceeding SQC for acenaphthene, phenanthrene and fluoranthene, respectively. No station sampled in 1991 exceeded the SQC for dieldrin.

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 (see Appendix A for a description of the normalization process). Figure 6 presents the results of this normalization. Approximately 41 ± 10% of the area of the Province showed enrichment of sediments with at least one metal. Thirty five (± 14), 53 ± 22, and 51 ±23 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, *i.e.*, this does not imply concentrations are elevated to the point where biological effects might be expected.

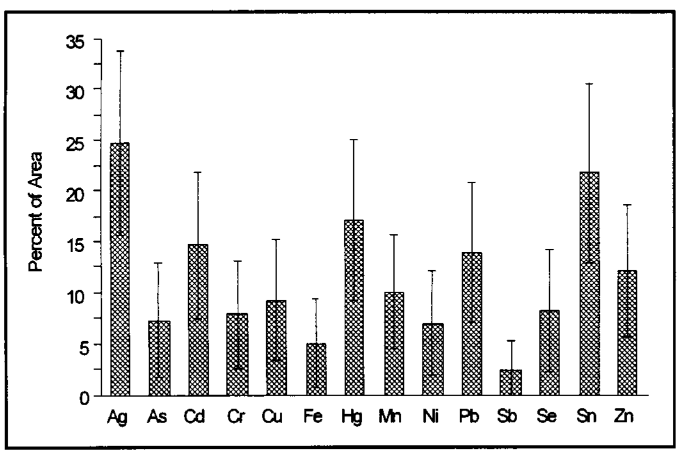


Figure 6. Percent area of the Virginian Province with enriched concentrations of individual metals in sediments in 1991. (Error bars represent 95% confidence intervals).

Presence of marine debris in fish trawls was documented by field crews as being encountered at stations representing 18 ± 8% of the Virginian Province area (Figure 7). The small estuary class had the largest percent area (35 ± 17%) where trash was found.

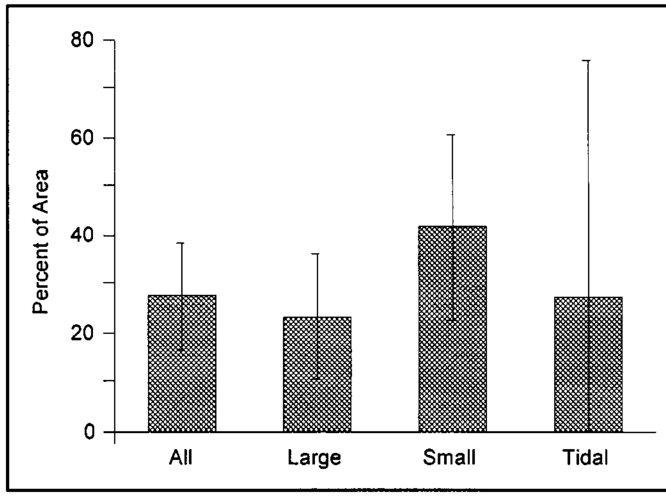


Figure 7. The percent of area of the Virginian Province by estuarine class where anthropogenic debris was collected in fish trawls, 1991.

Habitat Characterization

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

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

Based on the sampling design where a single station represents a statistical area (*e.g.*, 70 km^2 for large estuary sites), 12% of the area of large estuaries of the Province to be sampled in 1991 was unsampleable due to inadequate water depth. Small systems were considered unsampleable if the water depth did not exceed 2 m anywhere in the system. Such systems account for approximately 1.5% of the area of small systems in the Virginian Province. No large tidal river stations were unsampleable due to water depth in

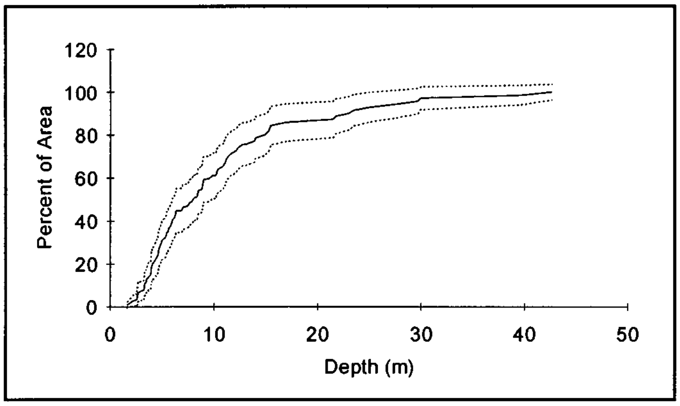


Figure 8. Cumulative distribution of water depth as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

1991. Overall, 9% of the area of the Province to be sampled in 1991 was deemed unsampleable due to water depth.

Bottom water temperature in the Virginian Province ranged from 16.2°C to 30.0°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 estuary class.

Vertical density differences (a function of both salinity and temperature) in the waters of the Virginian Province can be large enough to result in a reduction in mixing between surface and bottom waters, potentially allowing the bottom waters to become hypoxic. Degree of stratification in the Virginian Province was measured as the delta (Δ) σ_t, which is the σ_t (sigma-t density) difference between surface and bottom waters. Approximately 76 ± 10% 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 7 ± 7% of the Province area was strongly stratified ($\Delta\sigma_t$ >2).

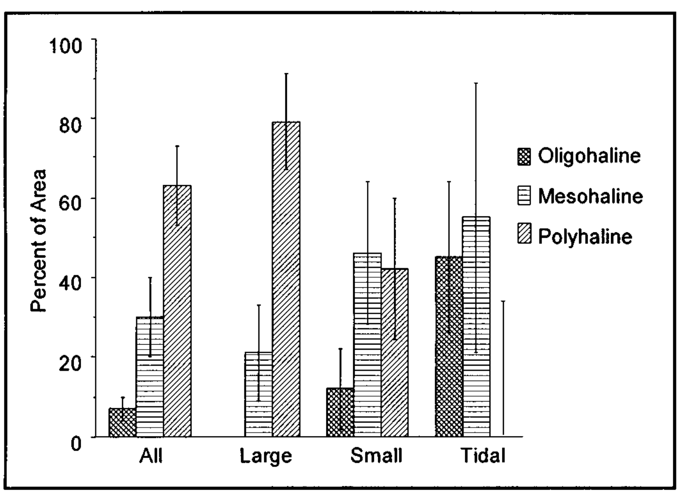


Figure 9. The percent of area by estuarine class classified as oligohaline (<5 ppt), mesohaline (5 to 18 ppt), and polyhaline (>18 ppt). (Error bars represent 95% confidence intervals).

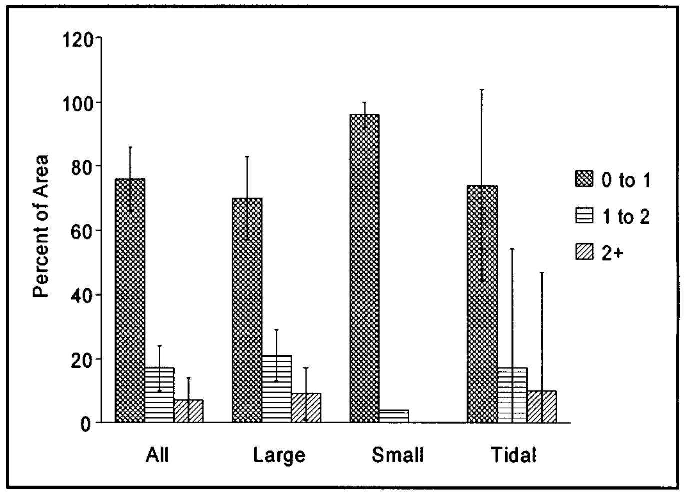


Figure 10. The percent of the area by estuarine class that had a low (<1), medium (1 to 2), or high (>2) degree of stratification ($\Delta\ \sigma_t$). (Error bars represent 95% confidence intervals).

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

Water clarity was good in 80 ± 7% of the area of the Virginian Province (Figure 11). Water of low clarity was found in 8 ± 6% of the Province and an additional 12 ± 7% 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.

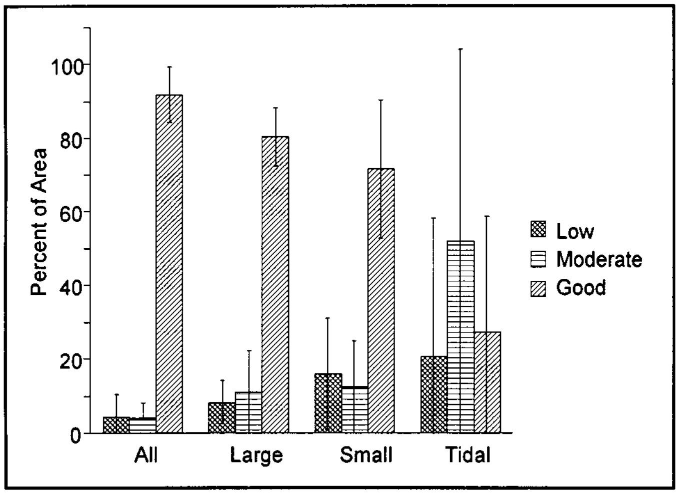


Figure 11. The percent of area by estuarine class where water clarity was poor, moderate, or good. (Error bars represent 95% confidence intervals).

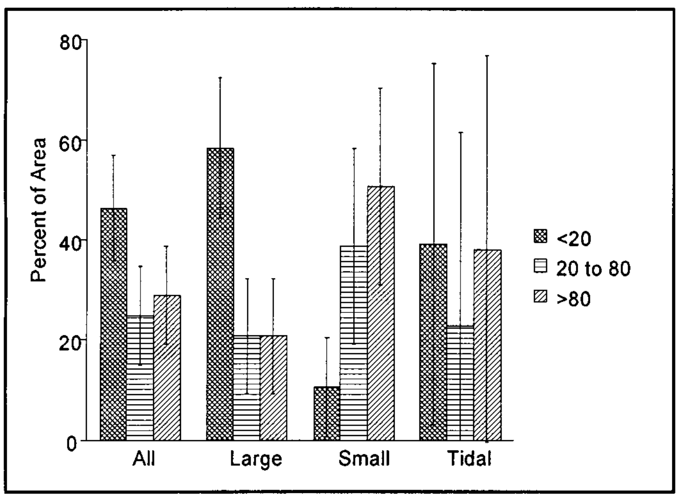


Figure 12. The percent of area by estuarine class with a low (<20), medium (20 to 80), or high (>80) percent silt-clay in the sediments. (Error bars represent 95% confidence intervals).

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 it 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 issues including:

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

In 1990, EMAP-E initiated a demonstration project in the estuaries of the Virginian Province (*i.e.*, estuaries, bays and sounds between Cape Cod, MA and Cape Henry, VA: Weisberg *et. al.*, 1993). One of the objectives of the Demonstration Project was to test the EMAP design, logistical approach and various ecological condition indicators. Based on the experience of the 1990 Demonstration Project, EMAP-E modified minor aspects of the logistical plan for 1991.

1.1 Objectives of 1991 Virginian Province Monitoring Activities

The specifics of the planning activities of the 1991 Virginian Province sampling effort are documented in the 1991 Virginian Province Logistics Plan (Strobel and Schimmel, 1991a), the 1991 Field Readiness Report (Strobel, 1991), and the 1991 Virginian Province Field Operations and Safety Manual (Strobel and Schimmel, 1991b). Sampling was conducted from 22 July through 8 September 1991, spanning 154 sites (stations). Approximately 30 field personnel and three extramural contracts were utilized.

The objectives of the 1991 Virginian Province monitoring were to:

- implement, for the first time, the routine monitoring of the Province using selected indicators from the 1990 Demonstration Project;
- incorporate EMAP-E design changes based on the 1990 experience;
- obtain data on Virginian Province-specific variability in ecological parameters;
- develop and refine assessment procedures for the ecological status of estuaries and apply these procedures to establish the baseline conditions in the Virginian Province; and

- identify and resolve remaining logistical problems associated with sampling estuarine resources in the Province within a 4-6 week sampling period.

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 (*i.e.*, dissolved oxygen concentrations < 2mg/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 target fish species in the Virginian Province?

- What proportion of estuarine sediments in the Virginian Province contain anthropogenic marine debris?

- What proportion of estuarine sediments in the Virginian Province contain elevated levels of anthropogenic chemical contaminants?

1.2 Data Limitations

The 1991 data represent only one year of sampling of a four year cycle; *i.e.*, the total number of samples needed to characterize the Province with the degree of confidence required by EMAP are sampled over a four-year period (Holland, 1990). Therefore, the reader must use these data carefully, and be aware that single-year results may differ from those reported following the completion of the four-year cycle (*i.e.*, 1990 - 1993).

EMAP is designed to provide data on a "provincial" scale. This design creates an additional limitation for those interested in smaller scale studies. For example, each of the 144 small systems (*i.e.*, 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.

Lastly, a benthic index is currently under development to aid in the interpretation of benthic community data (described in Appendix B). This index has been developed using combined 1990/1991 data and cross-validated using a test dataset. Additional validation using independent data is necessary, and will be conducted using 1992 and 1993 data as they become available. Therefore, the benthic index that appears in the four-year assessment report may differ from the one presented here, however, the estimated percent area degraded is not expected to change significantly.

1.3 Purpose and Organization of This Report

The purpose of this report is to provide estimates of the ecological condition (and environmental exposures) of the estuarine resources of the Virginian Province for 1991.

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

This report is organized into sections addressing the objectives and results of the 1991 Virginian Province survey. Section 1 describes the objectives of the Program and limitations on the use of the data presented in this report.

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

Section 3 is the statistical summary of the data collected during the 1991 survey.

Section 4 summarizes the quality assurance/quality control results of the 1991 survey.

Section 5 summarizes the findings of the 1991 survey in the Virginian Province.

Section 6 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 the survey.

Appendix B presents the statistical methods used in the calculation of the benthic index presented in Section 3.

Appendix C provides sub-population estimates for Chesapeake Bay and Long Island Sound.

Appendix D 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 1991 Virginian Province survey was conducted during late July through early September, 1991. 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. A more detailed discussion of the sampling design can be found in Appendix A.

One hundred and fifty four (154) of the scheduled 155 sites in the Virginian Province between Nantucket Sound (MA) and Cape Henry (VA) were sampled during the seven-week sampling period. Sample collection in the Virginian Province focused on ecological indicators (see Appendix A) during the index sampling period (July 1 - September 30), when responses of estuarine resources to anthropogenic and natural stresses are anticipated to be most severe. 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). This design resulted in five types of sampling sites for the Virginian Province survey, which are described 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. There were 102 BSS to be sampled during the 1991 index period, representing approximately ¼ of the total number of base sites that will be sampled over the four-year cycle. Fifty three special study sites were also scheduled for sampling.

The 155 stations were divided among three sampling teams, each covering a specific area of responsibility (Figure 2-1). Each team was comprised of two, four-person alternating crews which sampled for six consecutive days. During the six-day period, the crew was assigned responsibility for sampling a cluster of stations. The crew shift in which each cluster was to be sampled was randomized to assure stations were not sampled across the Province in a north-south series. Each BSS station was normally visited twice during the 6-day period to accommodate the deployment and retrieval of continuous water quality monitoring instruments. Figures 2-2, 2-3, and 2-4 present maps of all the base sampling sites (BSS) scheduled for sampling in the 1991 Virginian Province survey.

The 1991 Virginian Province Survey was successful in its attempt to collect large amounts of information and samples over a relatively short time period. The overall effectiveness of the 1991 sampling plan is reflected in the high percentage of stations for which usable data were obtained for the variety of parameters measured (Table 2-1). While all but one station were sampled as planned, not every site was sampled for every parameter, and not every sample was successfully processed. Overall, 9% of the area of the Province originally scheduled for sampling in 1991 could not be sampled due to inadequate water depth, or, in the case of the one station mentioned above, logistical difficulties.

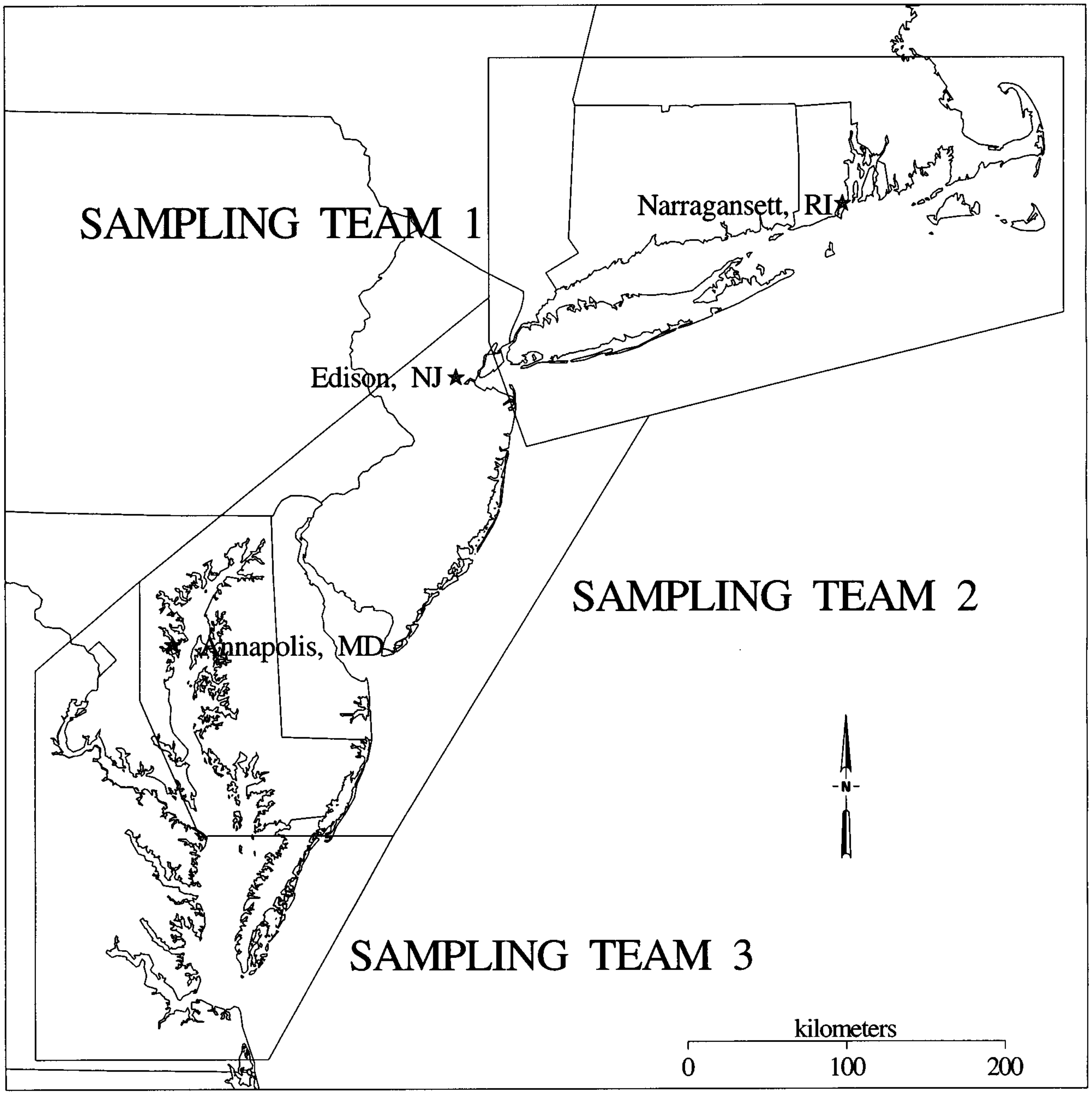


Figure 2-1. Areas of Responsibility of the EMAP-VP Sampling Teams.

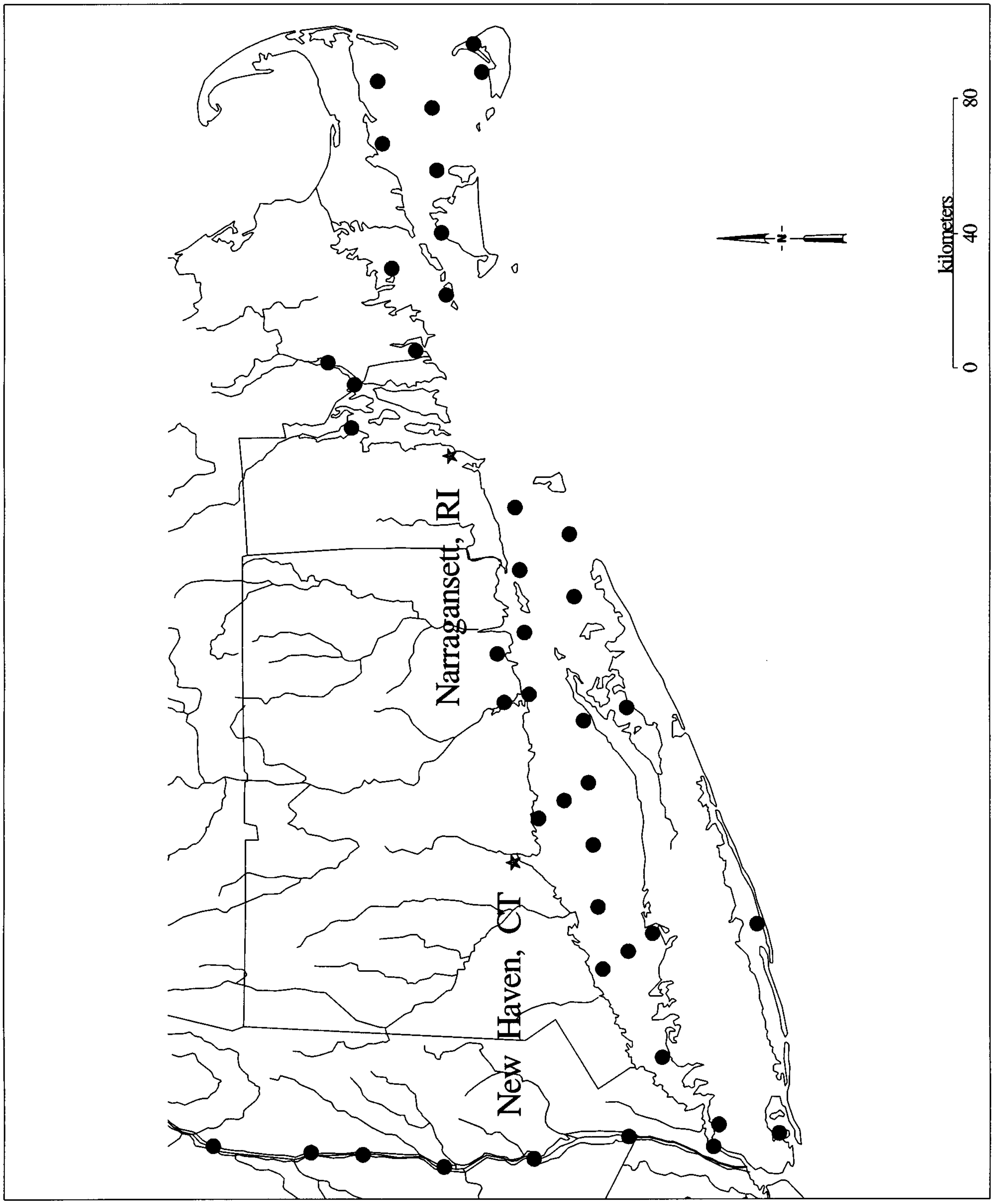


Figure 2-2. Team 1 Base Sampling Stations.

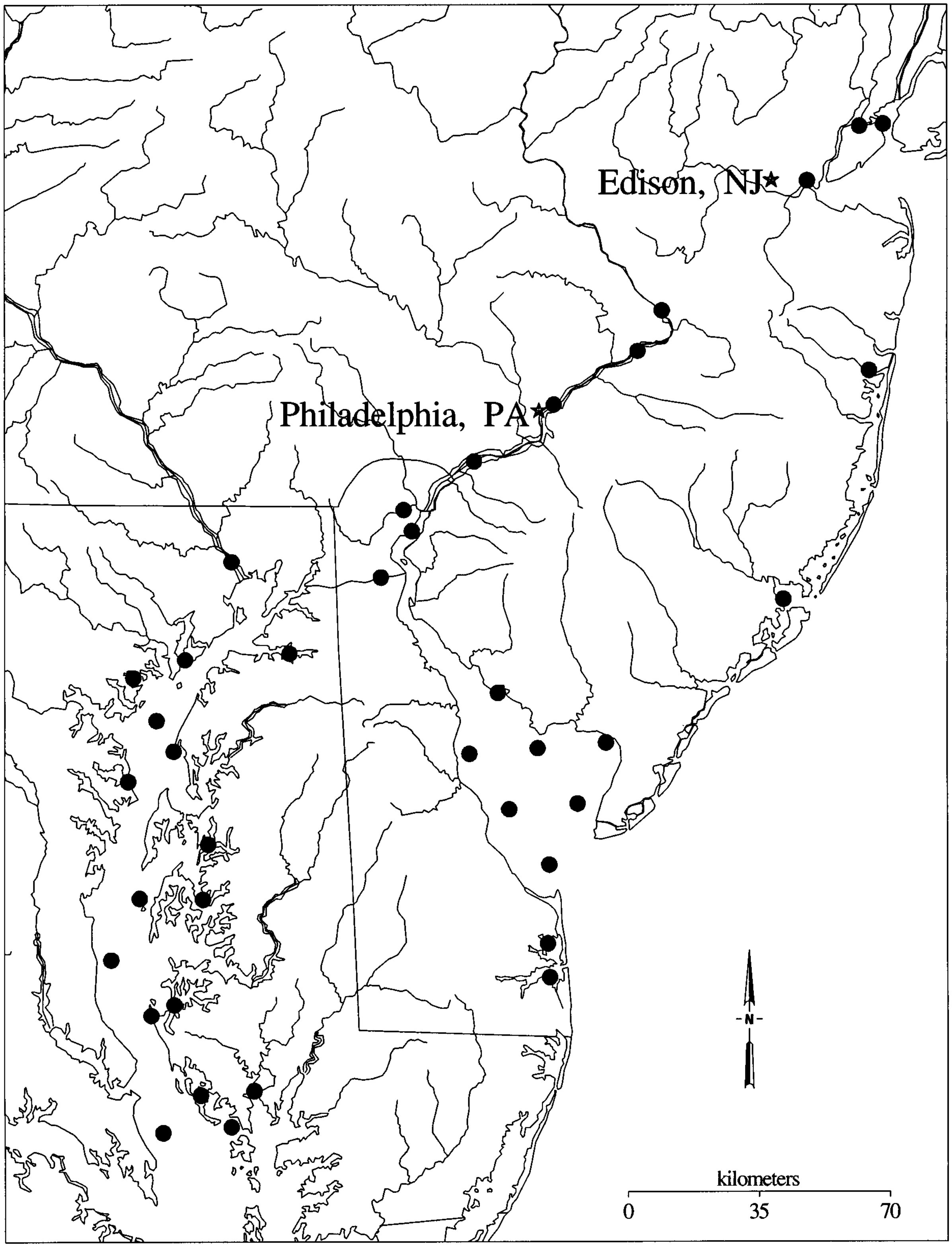


Figure 2-3. Team 2 Base Sampling Stations.

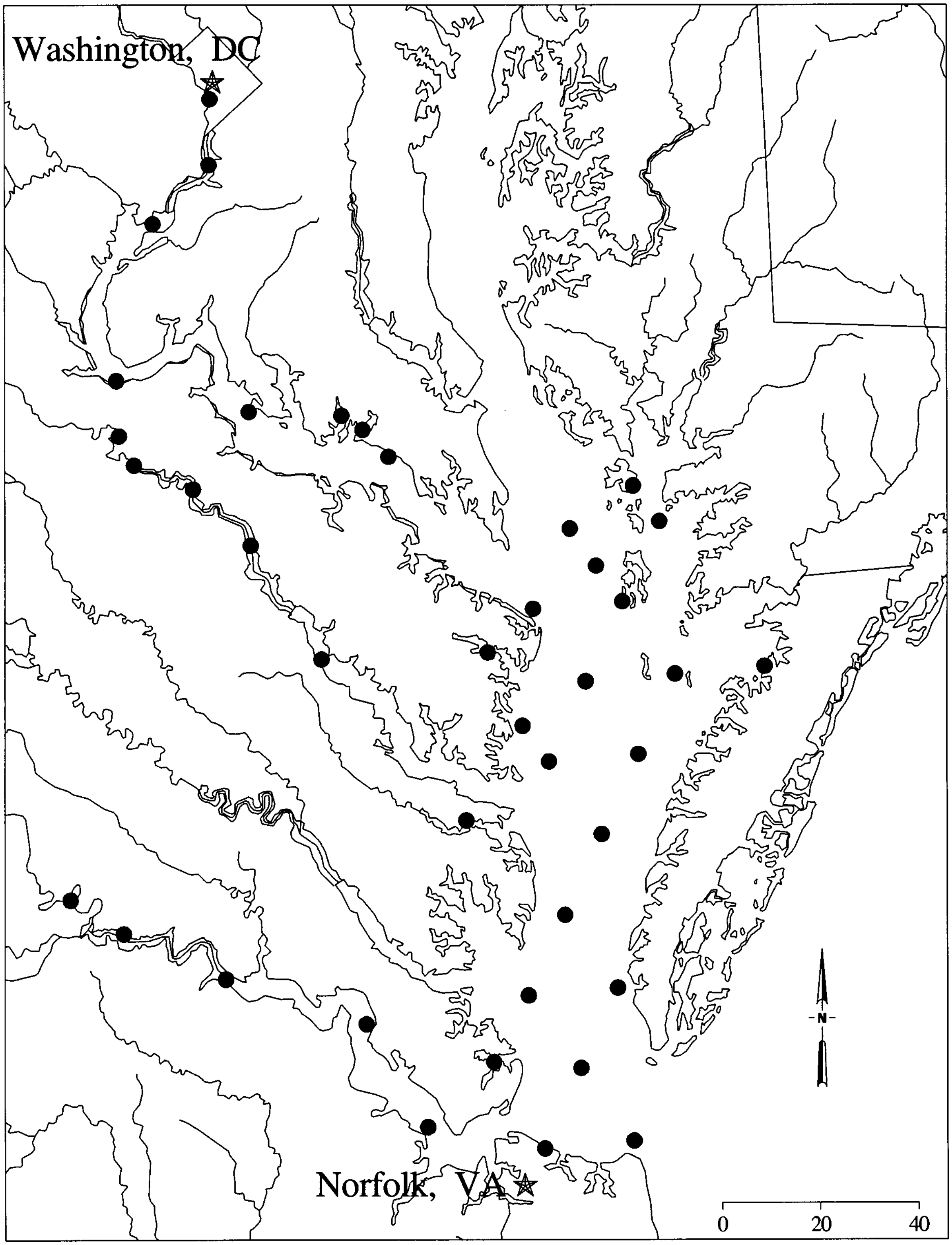


Figure 2-4. Team 3 Base Sampling Stations.

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

Sample Type	# Stations Expected to be Sampled[a]	# Stations Sampled (% of Expected Stations)	Percent Stations With Data Passing Final QC[b]
Water Quality (DO, Temp., Salinity)			
BSS Only	102	101 (99.0%)	99.0%
All Station Classes	155	146 (94.2%)	94.2%
Light Attenuation Coefficient (CTD cast)			
BSS Only	102	96 (94.1%)	94.1%
All Station Classes	155	144 (92.9%)	92.9%
Suspended Solids			
BSS Only	102	101 (99.0%)	99.0%
All Station Classes	155	153 (98.7%)	98.1%
Hydrolab Deployment			
BSS Only	102	93 (91.2%)	91.2%
All Station Classes	114	105 (92.1%)	85.6%
Sediment Chemistry			
BSS Only	102	100 (98.0%)	97.1%
All Station Classes	155	152 (98.1%)	98.1%
Sediment Toxicity			
BSS Only	102	100 (98.0%)	86.3%[c]
All Station Classes	155	152 (98.1%)	87.8%[c]
Sediment Grain Size			
BSS Only	102	100 (98.0%)	95.1%
All Station Classes	155	152 (98.1%)	91.0%
Benthic Infauna			
BSS Only	102	100 (98.0%)	98.0%
All Station Classes	155	152 (98.1%)	98.1%
Fish Community Data (successful trawl)			
BSS Only	102	98 (96.1%)	96.1%
All Station Classes	114	111 (97.4%)	97.4%
Anthropogenic Marine Debris			
BSS Only	102	98 (96.1%)	96.1%
All Station Classes	114	111 (97.4%)	97.4%

[a] Number of stations expected to be sampled excludes all stations determined to be too shallow to sample prior to the start of field operations. Activities differed at different station classes resulting in the inconsistency in Expected Station Numbers for "All Station Classes" between indicators. For example, trawling and Hydrolab deployments were not conducted at Index Stations, resulting in a reduced number of stations expected to be sampled. Station classes are described in Appendix A.

[b] This value takes into account samples not collected, damaged or lost during shipping or processing, or failing to pass final QC. The value for "BSS Only" represents the data utilized in the assessment of conditions within the Province.

[c] Low percentage was due to poor survival of control organisms in both original and repeated tests. This is below the completeness goal of 90%; however, this target is expected to be met over the four-year period.

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 1991 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 into Biotic Condition, Abiotic Condition, and Habitat sections. The indicators will be briefly described, and in most cases the Cumulative Distribution Function (CDF) will be shown to delineate the frequency of occurrence of observations within the Province. Bar graphs and other figures are also presented, where appropriate, to delineate the proportions of the Province or class resources degraded, or falling above or below values of interest.

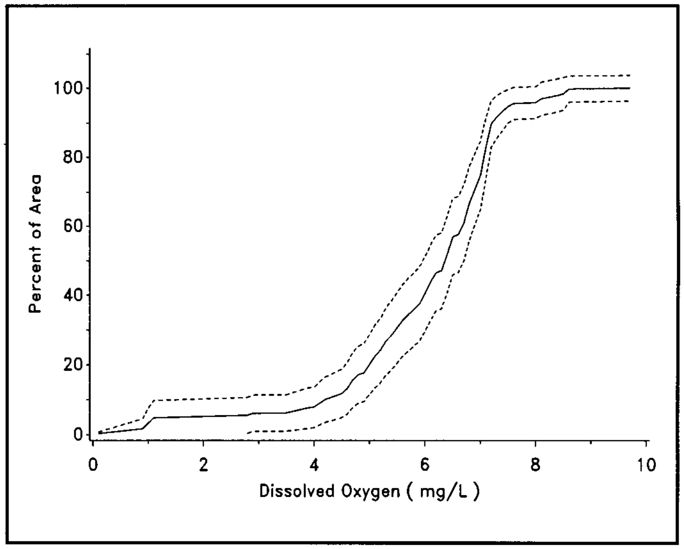


Figure 3-1. Example CDF of instantaneous bottom dissolved oxygen concentrations as a percent of area in the Virginian Province.

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

The x-axis represents DO concentrations observed in 1991 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 (see Appendix A). 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 criteria. This concentration intersects with the cumulative area in the Province at 5 ± 5%. The reader might also be interested in a state regulatory criteria of 5 mg/L, and the CDF shows that, based on the 1991 sampling, 18 ± 8% 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 in 1991 approximately 25 ± 10% of the bottom waters in the Province were observed to be at or above 7 mg/L DO, based on instantaneous daytime values.

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

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

3.1 BIOTIC CONDITION INDICATORS

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

3.1.1 Benthic Index

An index of benthic community condition was developed following the 1990 Demonstration Project. When applied to the 1991 benthic dataset, the original index failed to validate, resulting in the need to develop a new index. This new benthic index, which uses measures of individual health, functionality, and community condition to evaluate the condition of the benthic assemblage, was utilized in the assessment of biological resources of the Virginian Province. It was determined from the combined 1990/1991 data and is assumed to represent a combination of ecological measurements that best discriminates between good and poor ecological conditions. This index represents EMAP-E's attempt to reduce many individual indicators into a simple value that has a high level of discriminatory power between good and poor environmental conditions. The reader should be cautioned that this index has not yet been validated with an independent dataset, and therefore, should be used with caution.

It should be noted that applying the new index to the 1990 dataset does not significantly affect the percent area degraded reported in the 1990 Demonstration Project Report (Weisberg *et al.*, 1993). Details on the validation attempt on the 1990 index and the calculation of the 1991 benthic index can be found in Appendix B.

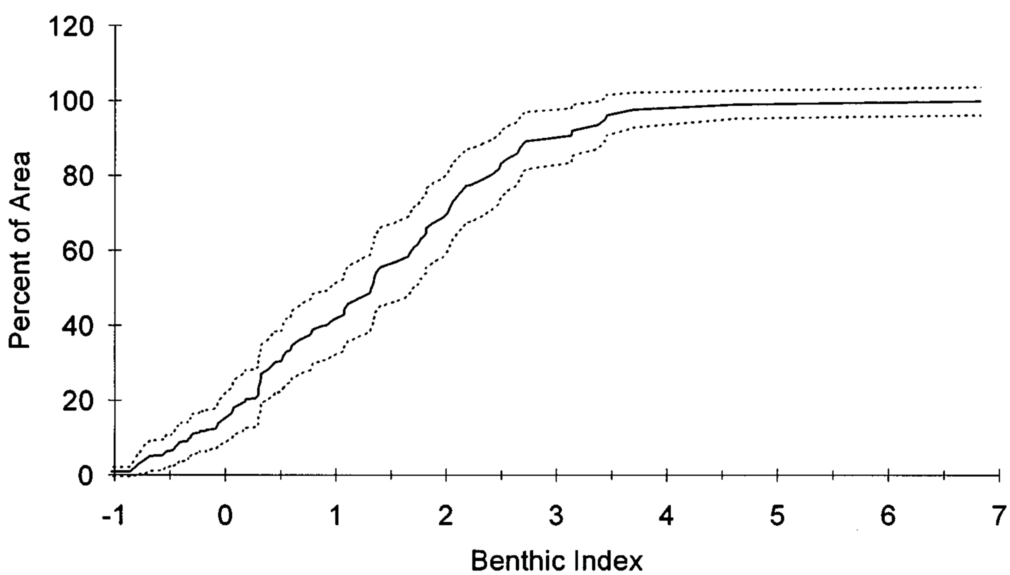


Figure 3-2. Cumulative distribution of benthic index values as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

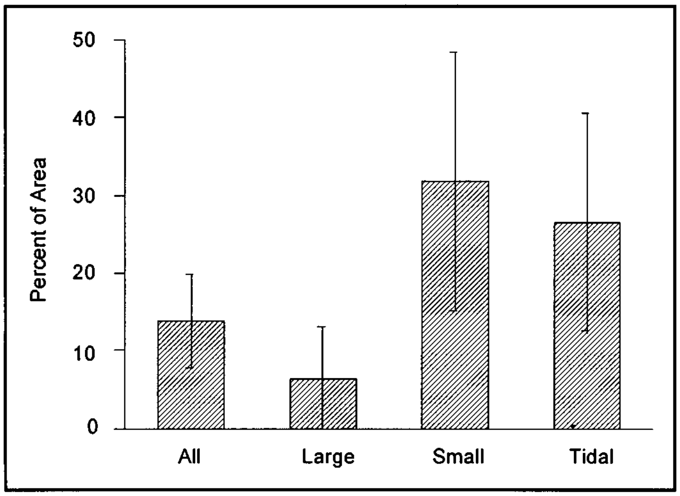


Figure 3-3. Percent area of the Virginian Province by estuarine class with a benthic index value below 0 in 1991. (Error bars represent 95% confidence intervals).

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

A benthic index critical value of zero was determined from the combined 1990/1991 Virginian Province dataset. Fourteen (± 6) percent of the bottom area of the Virginian Province sampled in 1991 had an index value of < 0, indicating likely impacts on the benthic community (Figure 3-2).

The percent area classified as degraded among the three classes of estuaries are 6 ± 7 %, 32 ± 17 %, and 27 ± 14 % for large estuaries, small estuarine systems, and large tidal rivers, respectively (Figure 3-3).

3.1.2 Number of Benthic Species

Number of benthic species has been used to characterize the environmental condition of estuarine habitats for specific salinity and grain size conditions. The mean number of infaunal species per grab from three replicate 440 cm^2 grabs collected at each station resulted in numbers of benthic species ranging from 0 to 54 (Figure 3-4), with the maximum number of species encountered per station being 54, 42, and 15 in the large estuaries, small estuaries, and large tidal rivers respectively (Figure 3-5). Because community composition is

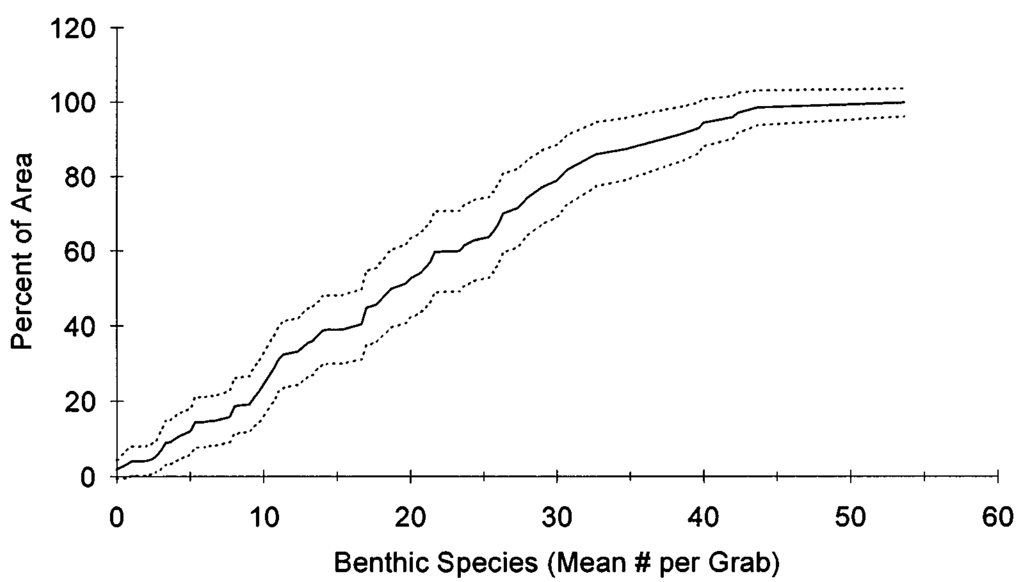


Figure 3-4. Cumulative distribution of the mean number of benthic species per grab as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

a) Large Estuaries

b) Small Estuaries

c) Tidal Rivers

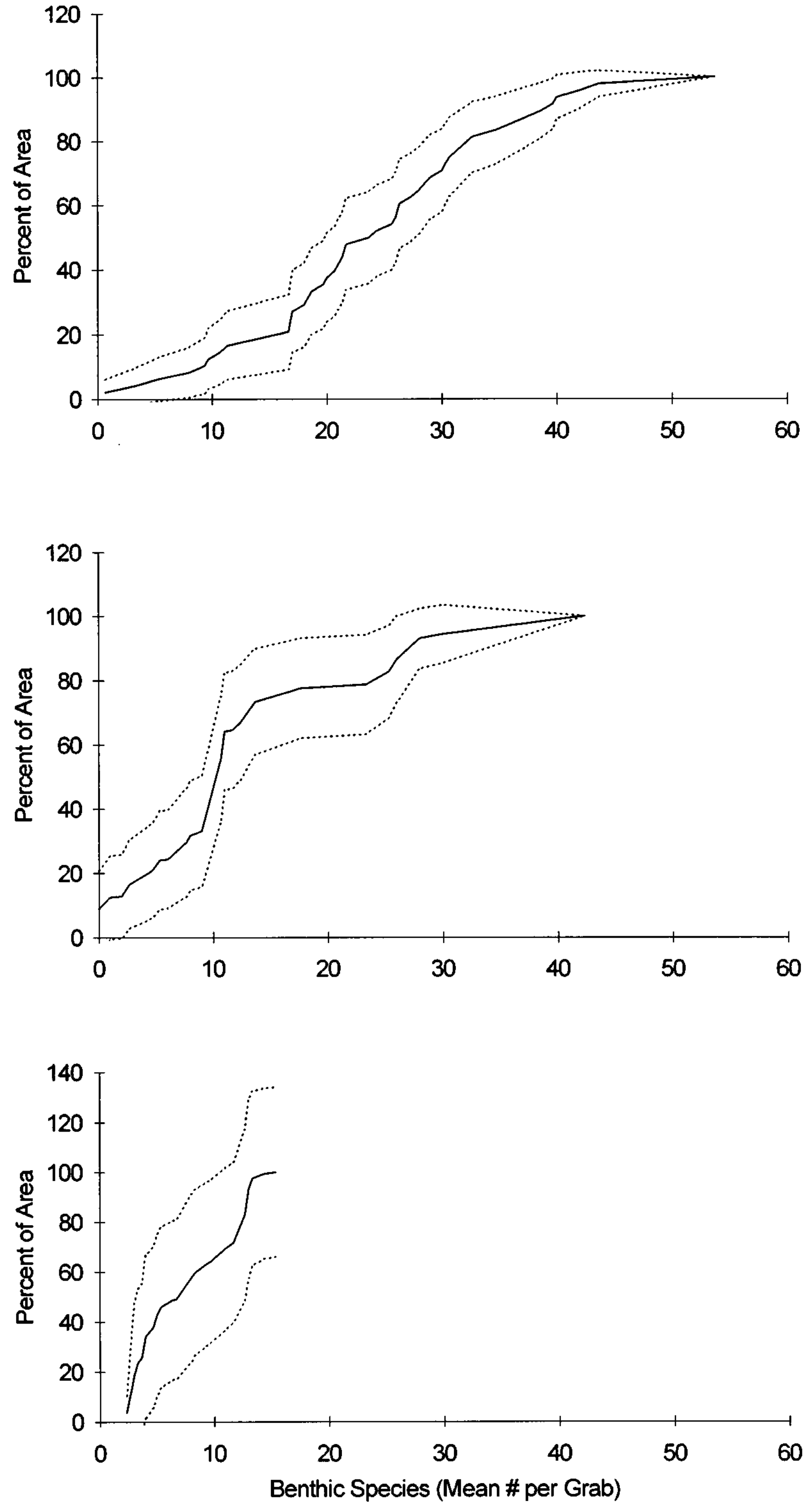


Figure 3-5. Cumulative distribution functions of the number of benthic species by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

strongly influenced by factors other than environmental "health" (*i.e.*, salinity and grain size), we cannot infer a low number of species necessarily represents an impacted community. However, the CDFs presented provide baseline information and can be a useful tool in assessing future trends in community structure.

3.1.3 Benthic Infaunal Abundance

Abundant benthic organisms, particularly in communities characterized by multiple species and feeding types, suggest a productive estuarine environment. Infaunal abundances ranged from 0 to over 114,000 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, 6 ± 5% of the Virginian Province had low abundances, and an additional 3 ± 6% had moderate abundances. Because of natural variation in benthic populations and modifying factors such as salinity and grain size, low abundance, as defined above, does not necessarily imply degraded communities, however, this information can be useful in detecting trends.

Areas of low abundance were primarily associated with the lower salinity waters of the small estuary and large tidal river classes, in which 13 ± 13% and 15 ± 28% of the area, respectively, had benthic infaunal abundances less than 200 organisms per square meter (Figure 3-7). Approximately 2 ± 4% of the sampled large estuary area showed low abundances. The highest number of individuals (114,674 per m^2) was found in the large estuary class, with maximums of 62,970 and 12,530 found in the small estuary and large tidal river classes, respectively.

3.1.4 Number of Fish Species

Zero to 15 species of fish were collected from single standardized, 10-min trawls performed at each base station in the Virginian Province (Figure 3-8). A total of 69 species were collected in standard trawls throughout the Province in 1991. Catch statistics for target species are shown in Table 3-1.

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

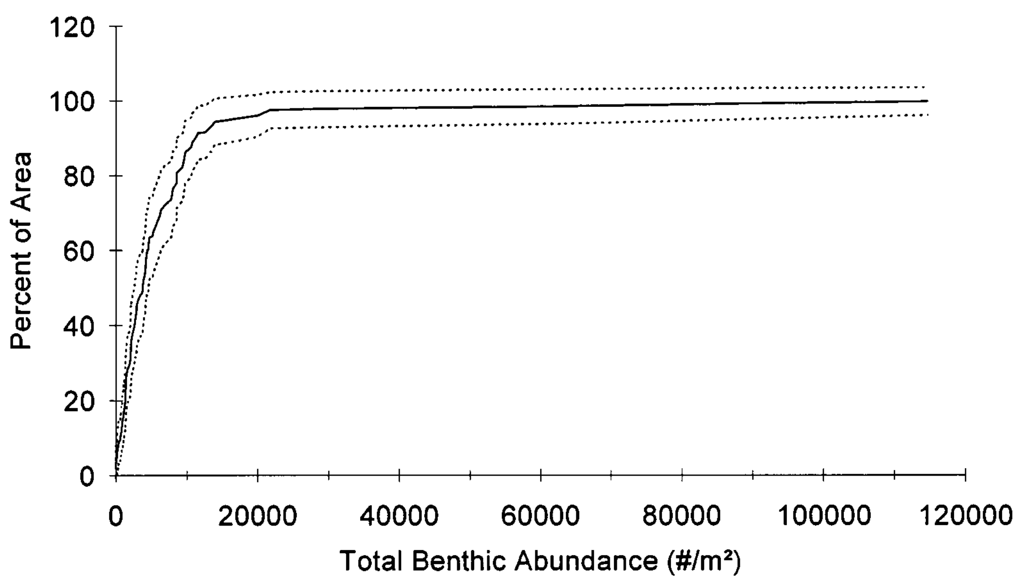


Figure 3-6. Cumulative distribution of the number of benthic organisms per m^2 as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

a) Large Estuaries

b) Small Estuaries

c) Tidal Rivers

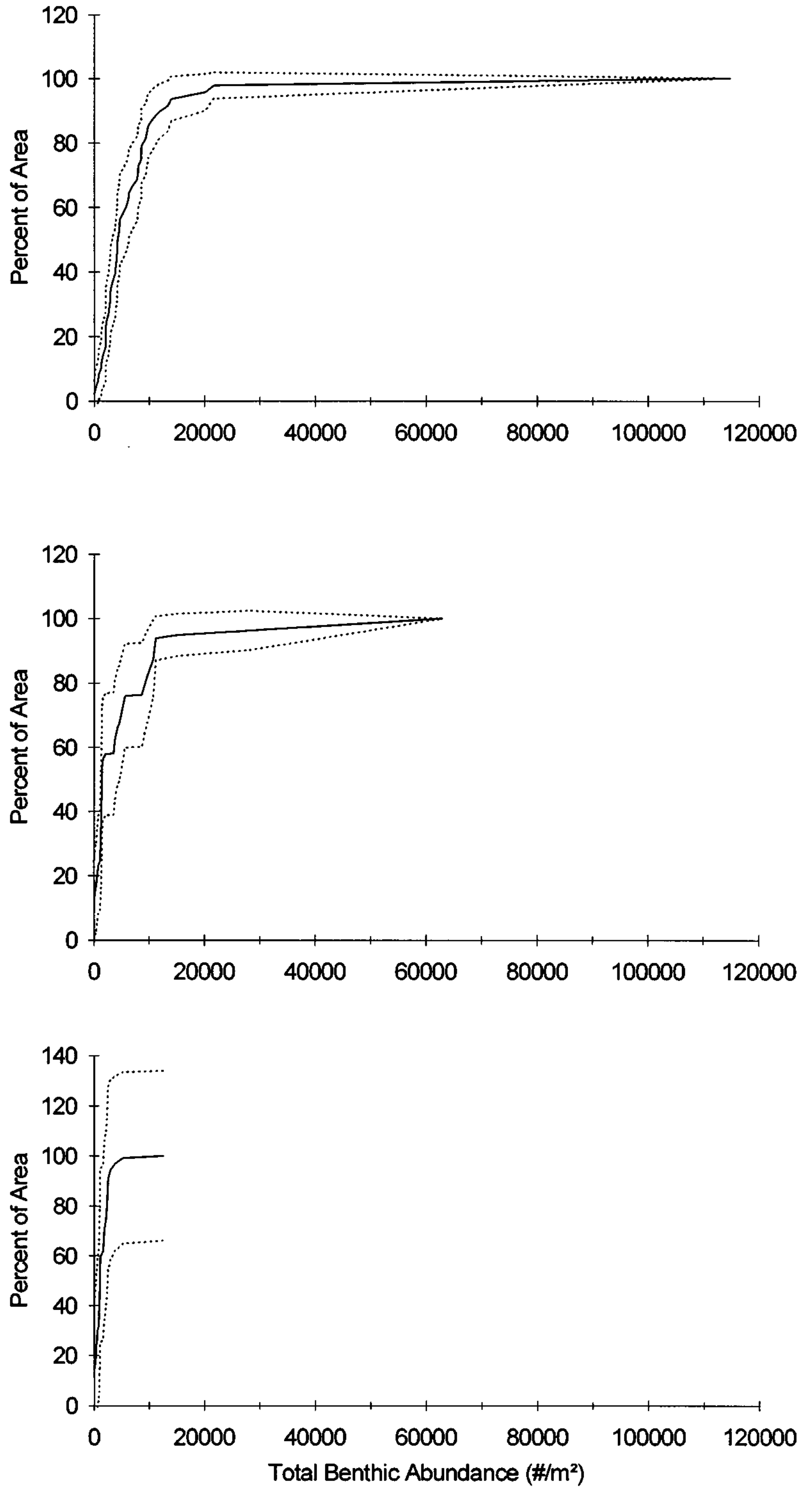


Figure 3-7. Cumulative distribution functions of the number of benthic organisms per m² by class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

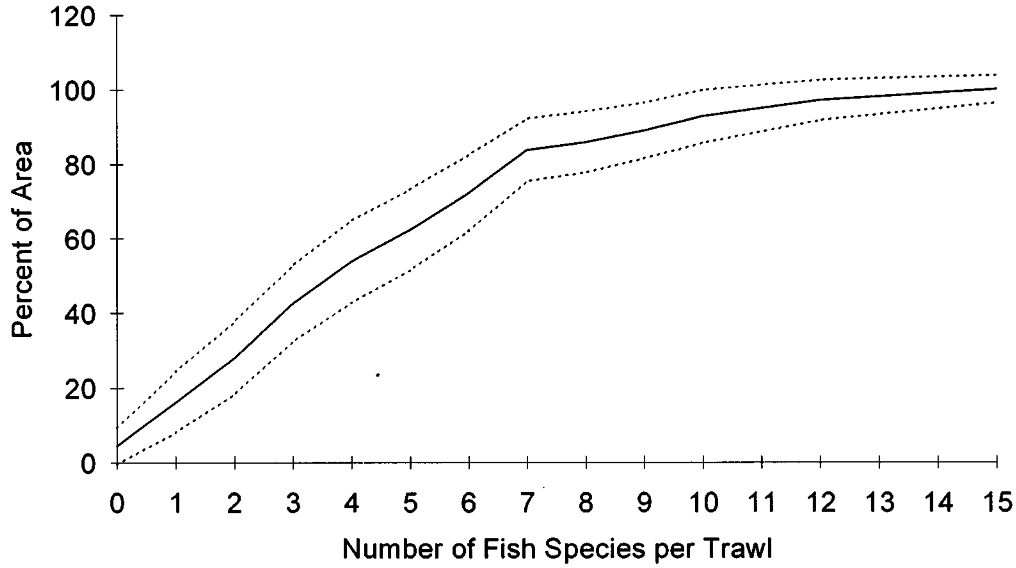


Figure 3-8. Cumulative distribution of the number of fish species per standard trawl as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

Table 3-1. Target Fish Species Summary. Only data from the 102 Base Stations are included. The total number of individuals caught at Base Stations was 6,563 fish.

Common Name	Scientific Name	# Stations Where Caught	Total Fish of Species Caught
Atlantic Croaker	*Micropogonias undulatus*	35	1,025
Bluefish	*Pomatomus saltatrix*	8	13
Channel Catfish	*Ictalurus punctatus*	15	286
Scup	*Stenotomus chrysops*	27	742
Spot	*Leiostomus xanthurus*	44	925
Summer Flounder	*Paralichthys dentatus*	32	92
Weakfish	*Cynoscion regalis*	25	813
White Catfish	*Ameiurus catus*	8	44
White Perch	*Morone americana*	22	540
Winter Flounder	*Pleuronectes americanus*	9	129

Two or fewer species were caught in a standard trawl in approximately 28 ± 10% of the Virginian Province. Alternatively, at least five fish species were collected throughout approximately 38 ± 11% of the sampled area of the Province. No fish were collected at 4 stations, representing 4 ± 5% of the area of the Province. The areas producing no fish catch were located primarily in large estuaries (Figure 3-9). Fish were collected in all but one small estuary station (0.3 ± 0.6% of the area) and at all stations in the large tidal river class (Figure 3-9).

a) Large Estuaries

b) Small Estuaries

c) Tidal Rivers

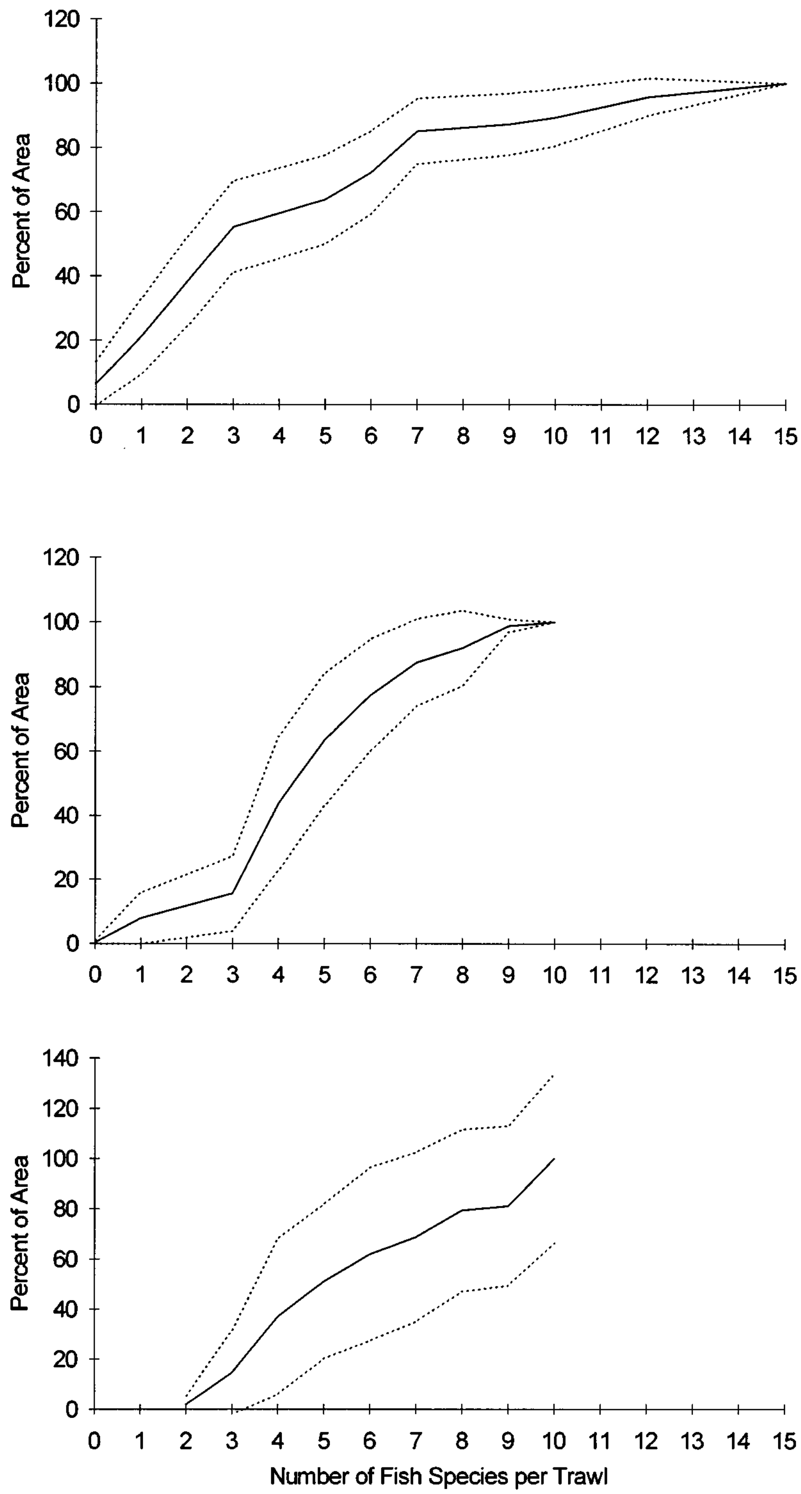


Figure 3-9. Cumulative distribution functions of the number of fish species per trawl by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

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 650 fish per trawl throughout the Province (Figure 3-10). A total of 7,134 fish was collected in standard trawls, of which approximately 70% were target species.

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

No striking differences occur by class except the high percentage of area in large systems with low fish catch (36 ± 14% with <10 fish collected per trawl), and the high catch of over 100 fish per trawl in 33 ± 33% of the area represented by large tidal river systems. Small estuaries were characterized by moderate fish catch (10 to 100 fish) in 60 ± 18% of the area. As with the fish species indicator, only high versus low catches can be reported with no inference made on the quality of the area relative to this indicator.

3.1.6 *Fish Gross External Pathology*

Field crews examined the first 30 individuals of each target fish species for evidence of external pathology. As stated in Section 4, crews were generally conservative, and many fish identified as having a pathology, in fact, did not. The pathologies reported are growths, lumps, ulcers, and fin erosion. Of the 2,513 fish examined, 16 (0.6%) were identified as having one or more of these pathologies. These individuals were collected at six of the 101 base stations sampled during the index period. All but one of the individuals with a pathology was a channel or white catfish, species which live and feed on the bottom.

Of the four categories, five lumps, nine ulcers, and three cases of fin erosion were reported (17 pathologies identified on 16 fish).

3.1.7 *Fish Tissue Contaminants*

As part of the suite of fish indicators, field crews collected up to five individuals of each target species present at each station for chemical residue analysis. Samples analyzed in the laboratory were composites of these individuals by species. In the laboratory, the individual fish were filleted and a composite sample

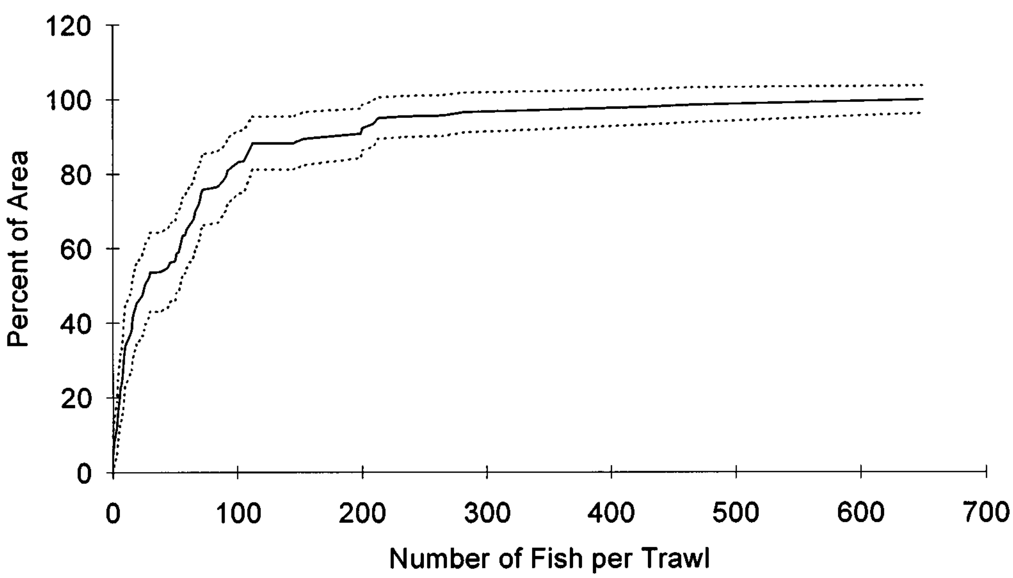


Figure 3-10. Cumulative distribution of fish abundance in numbers per standard trawl as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

a) Large Estuaries

b) Small Estuaries

c) Tidal Rivers

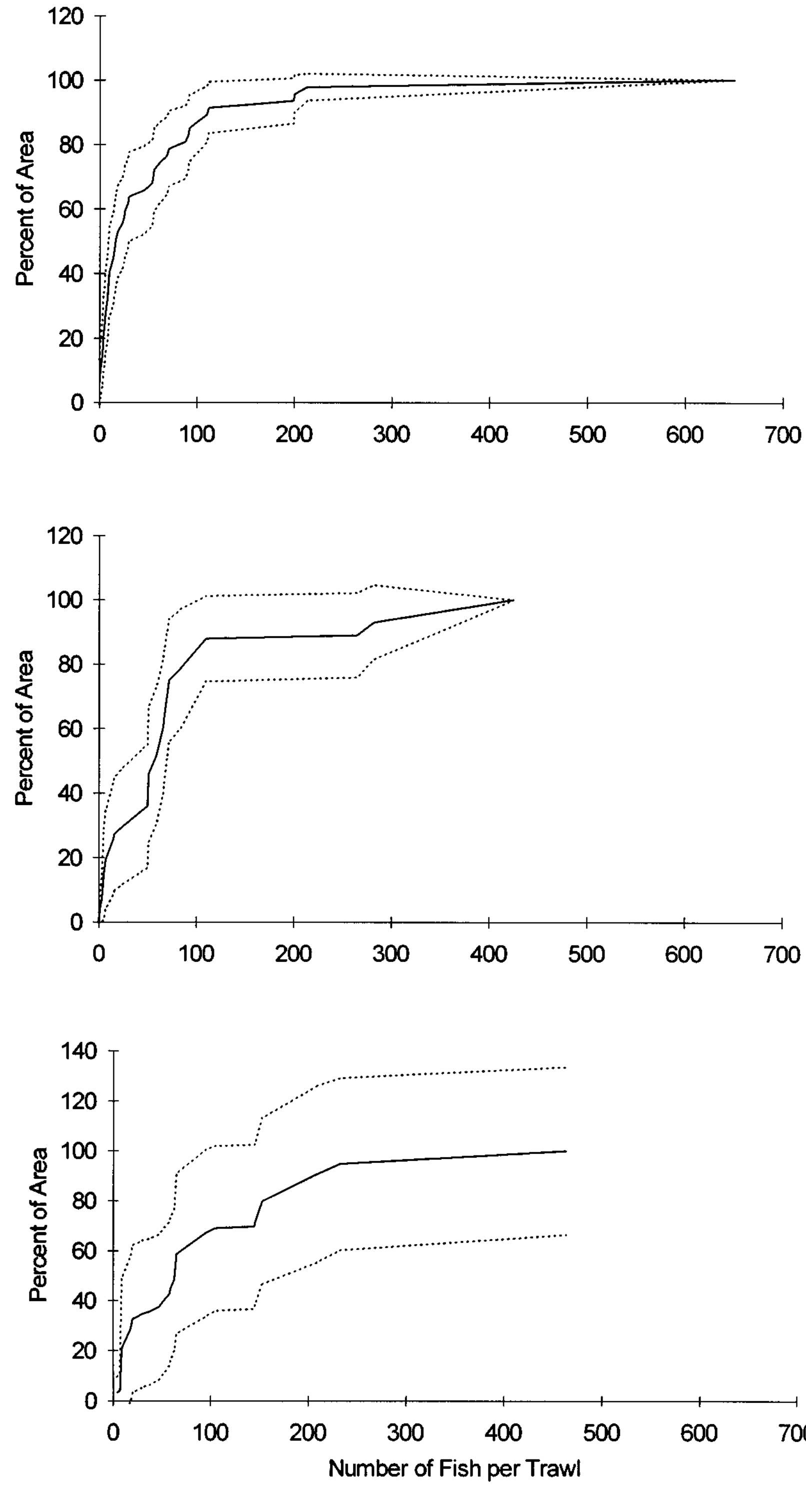


Figure 3-11. Cumulative distribution functions of fish abundance in numbers per trawl by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

created from the muscle tissue. A total of 84 composites of 3-5 individuals per composite were analyzed for the list of contaminants presented in Appendix A. No sample exceeded FDA action limits (or, where FDA action limits were not available, the mean of international limits) for any of the organic analytes measured Table 3-2). White perch generally contained the highest levels of organic contaminants among the samples analyzed. Several metals (arsenic, chromium and selenium) exceeded criteria values (shown as bold type in Table 3-2), with the highest incidence of exceedences being measured for arsenic. Fourteen of the 82 composite samples analyzed for metals (two samples were lost) exceeded the criteria value (2 µg/g wet weight). Six of these were winter flounder, whereas none of the summer flounder composites analyzed contained levels above 2 µg/g. Four of the six winter flounder collection sites were in mid-Long Island Sound, one was in Nantucket Sound, and one in Peconic Bay. Summer flounder samples were not collected at these stations.

3.2 ABIOTIC CONDITION INDICATORS

Abiotic condition indicators provide information on the potential exposure of organisms to environmental stresses, and have historically been the mainstay of environmental monitoring programs. Indicators of exposure measured during the 1991 Virginian Province Survey were dissolved oxygen concentration (instantaneous and 24-hr continuous), 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 during the 1991 survey of the Virginian Province: instantaneous point measurements, and continuous measurements (from deployed instruments) at base stations for a minimum of 24 hours. "Bottom" relative to dissolved oxygen and other water quality measurements is defined as one meter above the sediment/water interface.

3.2.1.1 Bottom Dissolved Oxygen -Instantaneous

Data collected in 1991 indicate that approximately 18 ± 8% of the sampled area of the Province contains bottom waters with a dissolved oxygen concentration less than or equal to 5 mg/L (Figure 3-12). Approximately 5 ± 5% of the Province exhibited bottom DO conditions ≤2 mg/L, defined by EMAP-E as severely hypoxic.

Dissolved oxygen conditions ≤2 mg/L were evident in all classes of estuaries sampled within the Province (Figures 3-13 and 3-14). Approximately 4 ± 6%, 1 ± 2%, and 15 ± 28% of the areas of large estuaries, small estuaries, and large tidal rivers, respectively, contained measured concentrations of bottom DO of ≤ 2.0 mg/L. An additional 13 ± 10%, 20 ± 13%, and 3 ± 28% of the area of large estuaries, small estuaries, and large tidal rivers, respectively, fell within the range of 2 to 5 mg/L DO.

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

3.2.1.2 Bottom Dissolved Oxygen - Continuous

In addition to single point measurements of DO at a station at a specific time, 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 (Figure 3-15). These 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.

Table 3-2. Results of chemical analysis of fish muscle tissue. Maximum concentration measured and percent composite samples exceeding criteria values (in parentheses) are presented.

Analyte	Criteria Value[*]	Atlantic Croaker	Bluefish	Channel Catfish	Scup	Spot	Weakfish	White Perch	Summer & Winter Flounder	All Species[‡]
Number of composites organics/metals[&]		*10/9*	*1/1*	*5/5*	*11/10*	*20/20*	*8/8*	*18/18*	*11/11*	*84/82*
					Maximum concentration (% exceeding criteria)					
Organic Contaminants (ng/g wet weight)										
Aldrin	300	0.06 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.02 (0%)	0.00 (0%)	0.15 (0%)	0.00 (0%)	0.15 (0%)
Dieldrin	300	5.05 (0%)	3.42 (0%)	10.5 (0%)	4.37 (0%)	8.43 (0%)	2.85 (0%)	52.8 (0%)	1.09 (0%)	52.8 (0%)
Heptachlor	300	0.09 (0%)	0.00 (0%)	0.23 (0%)	0.00 (0%)	0.03 (0%)	0.00 (0%)	0.14 (0%)	0.00 (0%)	0.23 (0%)
Heptachlor Epoxide	300	0.88 (0%)	0.12 (0%)	4.89 (0%)	0.09 (0%)	0.45 (0%)	0.29 (0%)	5.29 (0%)	0.10 (0%)	5.29 (0%)
Hexachloro-benzene	200	0.47 (0%)	0.10 (0%)	0.36 (0%)	0.13 (0%)	0.17 (0%)	0.72 (0%)	1.68 (0%)	0.10 (0%)	1.68 (0%)
Lindane	200	0.85 (0%)	0.00 (0%)	1.53 (0%)	0.76 (0%)	1.27 (0%)	0.52 (0%)	1.48 (0%)	0.53 (0%)	1.53 (0%)
Mirex	100	0.42 (0%)	0.20 (0%)	0.47 (0%)	0.13 (0%)	0.23 (0%)	0.38 (0%)	0.60 (0%)	0.09 (0%)	0.60 (0%)
Total chlordanes[a]	300	7.01 (0%)	9.69 (0%)	59.2 (0%)	3.26 (0%)	5.77 (0%)	3.90 (0%)	102 (0%)	3.37 (0%)	102 (0%)
Total DDTs[b]	5,000	22.1 (0%)	37.8 (0%)	97.6 (0%)	25.2 (0%)	66.9 (0%)	51.0 (0%)	1,490 (0%)	12.9 (0%)	1,490 (0%)
Total PCBs[c]	2,000	90.3 (0%)	91.5 (0%)	317 (0%)	150 (0%)	117 (0%)	204 (0%)	1,150 (0%)	72.1 (0%)	1,150 (0%)
Metals (µg/g wet weight)										
As	2	2.25 **(11%)**	0.15 (0%)	0.09 (0%)	5.07 **(30%)**	3.17 **(20%)**	0.68 (0%)	0.45 (0%)	5.52[**] **(55%)**	5.52 **(17%)**
Cd	0.5	0.02 (0%)	0.00 (0%)	0.01 (0%)	0.01 (0%)	0.08 (0%)	0.00 (0%)	0.01 (0%)	0.00 (0%)	0.08 (0%)
Cr	1	0.25 (0%)	0.00 (0%)	0.10 (0%)	0.55 (0%)	0.32 (0%)	1.95 **(13%)**	1.22 **(6%)**	0.33 (0%)	1.95 **(2%)**
Cu	15	2.77 (0%)	1.15 (0%)	1.95 (0%)	2.26 (0%)	3.11 (0%)	1.14 (0%)	1.64 (0%)	1.45 (0%)	3.11 (0%)

(continued)

Table 3-2 continued.

Analyte	Criteria Value*	Atlantic Croaker	Bluefish	Channel Catfish	Scup	Spot	Weakfish	White Perch	Summer & Winter Flounder	All Species‡
		Maximum concentration (% exceeding criteria)								
Pb	0.5	0.04 (0%)	0.00 (0%)	0.00 (0%)	0.03 (0%)	0.03 (0%)	0.04 (0%)	0.06 (0%)	0.07 (0%)	0.07 (0%)
Hg	1	0.02 (0%)	0.05 (0%)	0.04 (0%)	0.07 (0%)	0.03 (0%)	0.07 (0%)	0.26 (0%)	0.03 (0%)	0.26 (0%)
Se	1	0.78 (0%)	0.32 (0%)	0.56 (0%)	0.64 (0%)	0.80 (0%)	0.82 (0%)	1.55 **(17%)**	0.67 (0%)	1.55 **(4%)**
Zn	60	8.86 (0%)	7.88 (0%)	6.44 (0%)	9.85 (0%)	11.7 (0%)	37.7 (0%)	12.7 (0%)	10.5 (0%)	37.7 (0%)

* Criteria values from U.S. FDA (1982, 1984), or, where FDA values were not available, from Nauen (1983).

‡ Represents only those species included in this table.

& Up to five individuals from selected target species were composited to create the sample analyzed. Two samples for metals analyzed were lost, resulting in fewer samples (82 compared to 84 for organics analyses).

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

b "Total DDTs" is the sum of o',p' DDE, p',p' DDE, o',p' DDD, p',p' DDD, o',p' DDT, and p',p' DDT.

c Concentrations reported for "Total PCBs" are the sum of measured congeners (PCBs 8, 18, 28, 44, 52, 66, 101, 105, 118, 128, 138, 153, 170, 180, 187, 195, 206, and 209) and may not be directly comparable to the criteria value for Total PCBs.

** All six winter flounder composites exceeded the criteria value for Arsenic, with the minimum concentration measured being 2.09 µg/g, and the median being 4.20 µg/g. None of the five summer flounder composites exceed the criteria value.

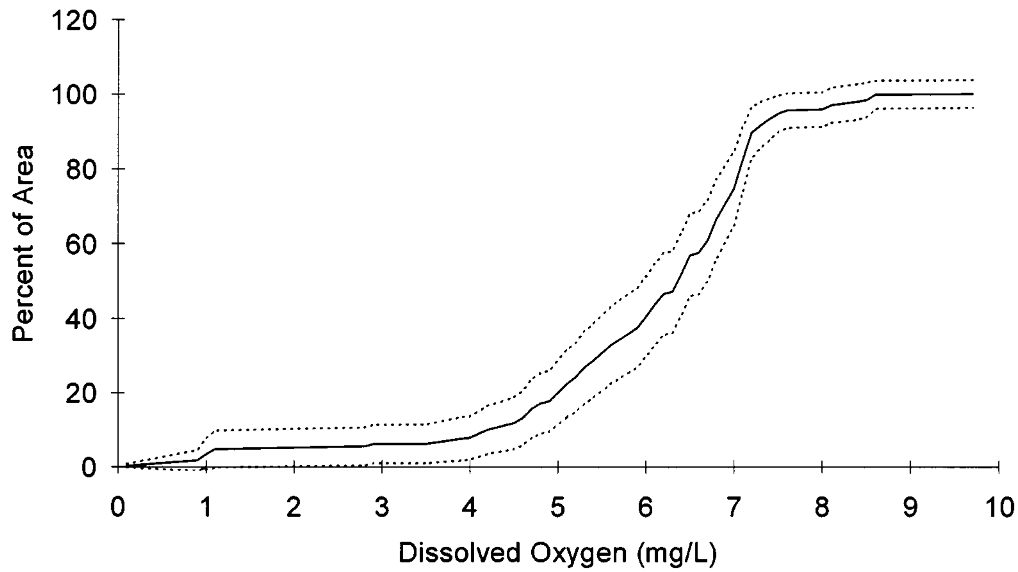


Figure 3-12. Cumulative distribution of instantaneous bottom dissolved oxygen concentration as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

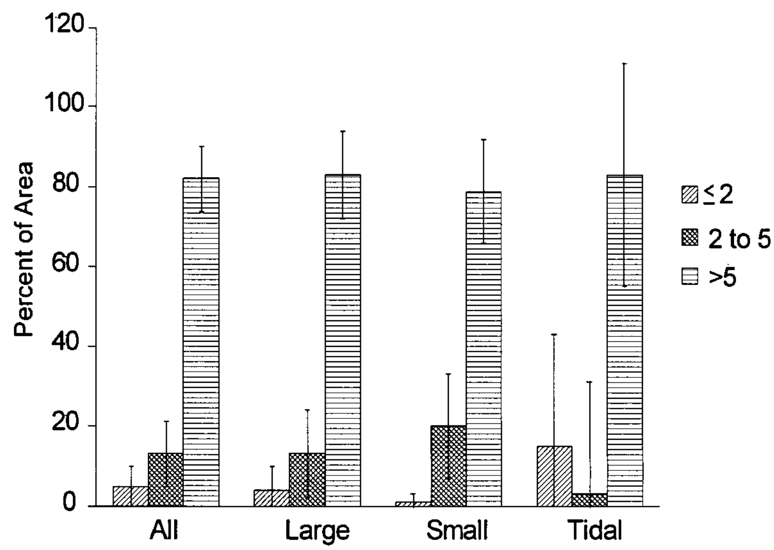


Figure 3-13. The percent of area by class that had a low (≤ 2 mg/L), medium (2 to 5 mg/L), or high (>5 mg/L) oxygen concentration in the bottom waters. (Error bars represent 95% confidence intervals).

a) Large Estuaries

b) Small Estuaries

c) Tidal Rivers

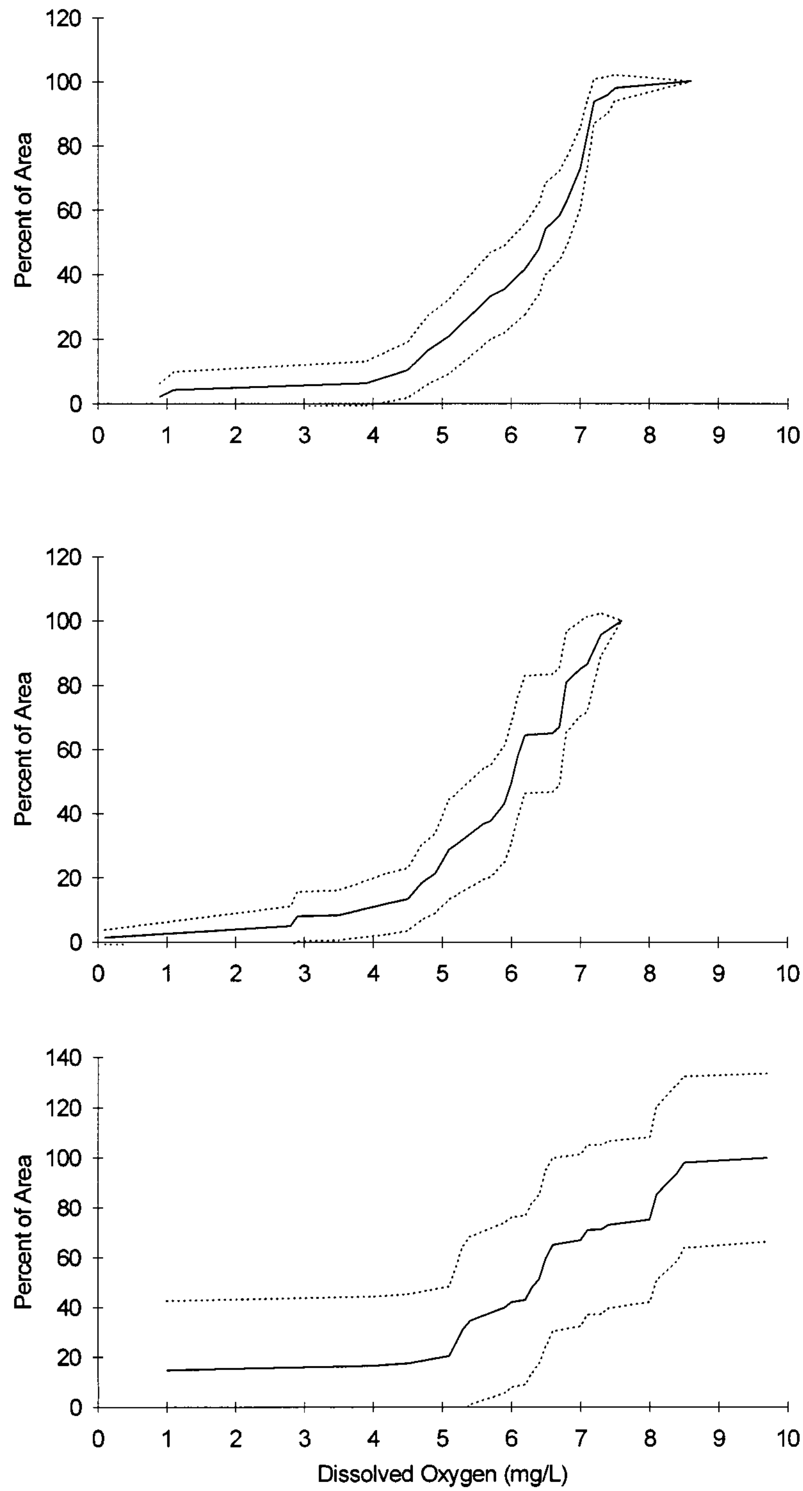


Figure 3-14. Cumulative distribution functions of bottom oxygen concentration by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

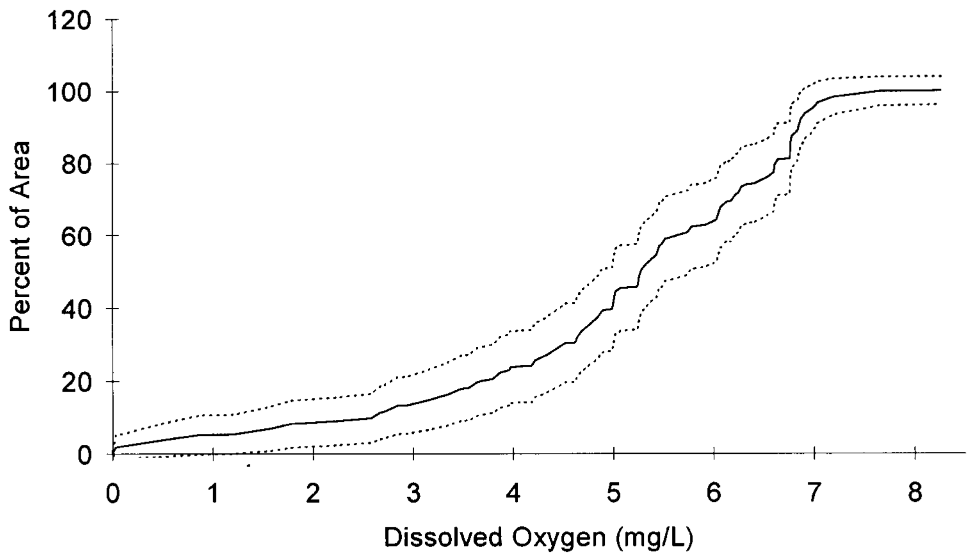


Figure 3-15. Cumulative distribution of the minimum bottom oxygen concentration measured over a 24-hour period as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

The percent area classified as degraded 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 is less diurnal than in other regions (*i.e.*, the Gulf of Mexico), and that a much longer time series is required to "better" classify a station as degraded than 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 this measurement being discontinued after 1991.

3.2.1.3 Dissolved Oxygen Stratification

The difference between surface and bottom DO concentrations measured at base sampling stations is illustrated in Figure 3-16. Differences between bottom and surface DO were less than 1 mg/L in 67 ± 10% of the area of the Province. Approximately 8 ± 6% of the area of the Province showed differences greater than 5 mg/L. This agrees with the data presented on stratification in Section 3.3.5 in which 76 ± 10% of the Province was found to be well-mixed and 7 ± 7% significantly stratified.

Figure 3-17 illustrates DO differences by estuarine class. All of the highly stratified area was found in the large estuaries and large tidal rivers (8 ± 8% and 17 ± 32%, respectively, exceeding 5 mg/L), with the largest Δ DO measured being 7.8 mg/L.

3.2.2 Sediment Toxicity

Sediment toxicity tests were performed on the composite sample of surficial sediments 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 sediment and significantly different. Approximately 21 ± 10% of the sampled area of the Virginian Province exhibited toxic sediments (Figure 3-18). However, only 1 ± 10% of the area had sediments where survival fell below 60% of control survival (*i.e.*, sediments were very toxic). The estuarine class with the largest proportion of toxic sediments was the large estuarine class (24 ± 13%); with the small estuaries and large tidal river classes exhibiting a lesser extent of toxicity (19 ± 14% and 10 ± 7%, respectively: Figure 3-19). However, the confidence intervals around all these

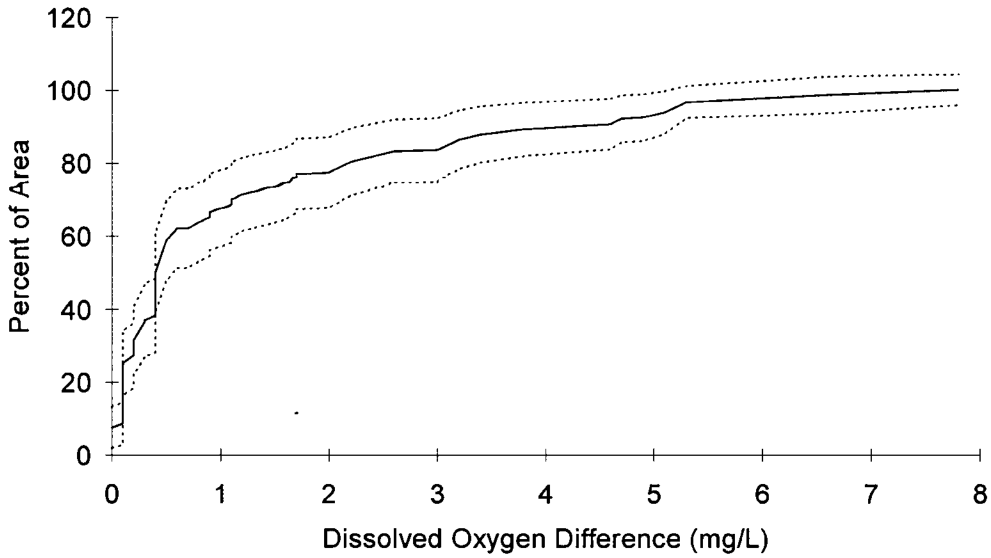


Figure 3-16. Cumulative distribution of the dissolved oxygen concentration difference between surface and bottom waters as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

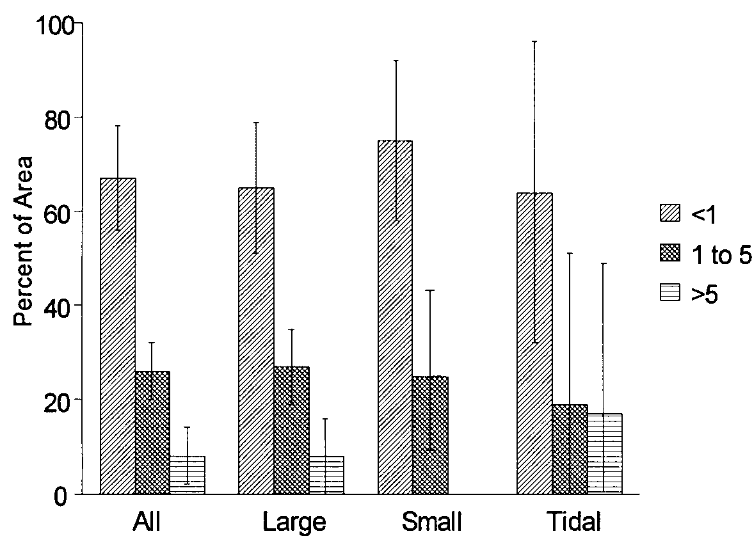


Figure 3-17. The percent of area by class that had a low, medium, or high difference in dissolved oxygen concentration (mg/L) between the surface and bottom waters. (Error bars represent 95% confidence intervals).

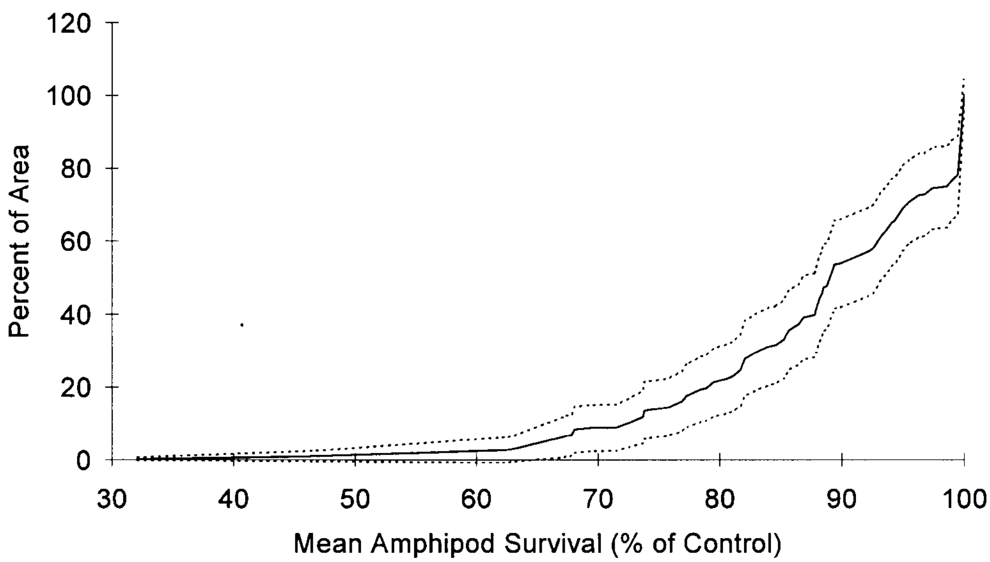


Figure 3-18. Cumulative distribution of mean survival of amphipods in 10-day laboratory toxicity tests (expressed as percent of control survival). (Dashed lines are the 95% confidence intervals).

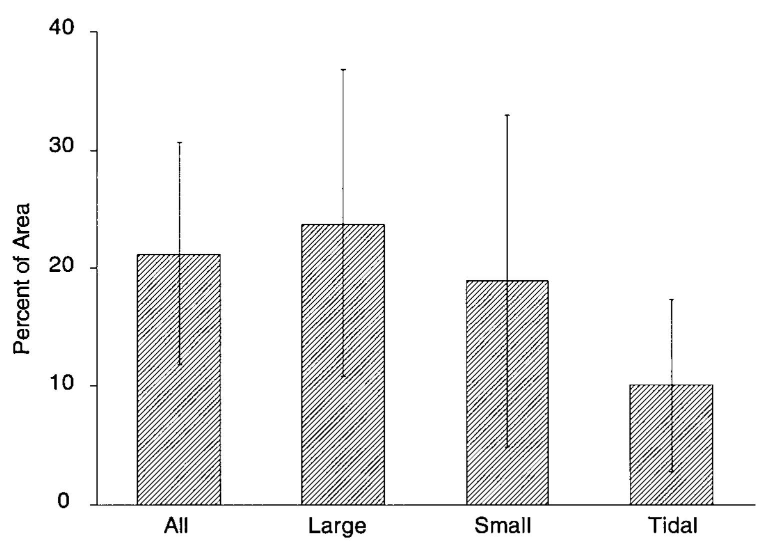


Figure 3-19. Percent of area in the Virginian Province in 1991, by estuarine class, with low amphipod survival (<80% of control) in sediment toxicity tests. (Error bars represent 95% confidence intervals).

values overlap, therefore, there may be no significant differences among classes. The most toxic sediments were found in the small estuarine class, where 5 ± 7% of the area had sediments producing survival of less than 60% of control.

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. 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 analytes measured included selected polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyl (PCB) congeners, chlorinated pesticides, butyltins and several metals. Because of the complex nature of sediment geochemistry, and additive, synergistic, and antagonistic interactions among multiple pollutants, the ecological impact of elevated contaminant levels is not well understood. Therefore, definitive estimates of percent area of the Province with overall contaminant concentrations high enough to cause ecological impacts cannot be provided. However, the data collected will form a baseline for monitoring trends in sediment contamination and are extremely valuable in that respect.

EPA is currently in the process of establishing Sediment Quality Criteria (SQC). Draft SQC are presently available for four of the analytes EMAP-VP is measuring: Acenaphthene, phenanthrene, fluoranthene, and dieldrin (U.S. EPA, 1993a-d). SQC are expressed as μg analyte/g organic carbon; therefore, concentrations must first be normalized for the organic carbon content of the sediment. Only those sediments with organic carbon concentrations ≥0.2% can be examined using this approach. Separate SQC values have been established for freshwater and saltwater sediments. Because criteria values are based on toxicity data, the definition of saltwater *vs* freshwater is based on the organisms present, not the salinity. Where both fresh and saltwater organisms are present, the more protective of the two values is applied.

SQC values for the four analytes measured are listed in Table 3-3, 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	510	1100	240
	S	650	1400	300
Dieldrin				
	F	11	24	5.2
	S	20	44	9.5

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 which include oil spills, natural oil seeps, forest fires, automobile exhaust, domestic heating, power plants and other combustion processes. With the exception of specific oil releases, the majority of PAHs found in marine sediments are believed to originate from combustion processes (Windsor and Hites, 1979). PAH concentrations tend to correlate with the degree of urbanization or industrialization and, therefore, these compounds are often considered to be indicators of anthropogenic activity.

Range and median concentrations for PAHs measured in 1991 are listed in Table 3-4. Combined PAH values reported in this table reflect the summation of the concentrations of all of the PAH compounds that were

Table 3-4. Range and median PAH concentrations in sediments of the Virginian Province, 1991.

Analyte (weight[a])	Concentration (ng/g dry weight) MIN	MAX	Median	Median Detection Limit[b]
Acenaphthene (L)	ND	2,960	ND	9.98
Acenaphthlylene (L)	ND	186	ND	9.98
Anthracene (H)	ND	6,510	ND	9.98
Benz(a)anthracene (H)	ND	10,000	19.0	9.95
Benzo(b+k)fluoranthene (H)	ND	11,300	50.9	9.98
Benzo(g,h,i)perylene (H)	ND	3,780	20.2	9.97
Benz(a)pyrene (H)	ND	6,040	20.3	9.99
Benz(e)pyrene (H)	ND	3,950	19.0	9.99
Biphenyl (L)	ND	240	ND	9.95
Chrysene (H)	ND	9,770	27.3	9.96
Dibenz(a,h)anthracene (H)	ND	342	ND	9.98
Fluoranthene (H)	ND	22,900	40.2	9.95
Fluorene (L)	ND	3,180	ND	9.95
Indeno(1,2,3-c,d)pyrene (H)	ND	4,080	22.5	9.98
Naphthalene (L)	ND	488	16.7	9.98
1-methylnaphthalene (L)	ND	386	ND	9.95
2-methylnaphthalene (L)	ND	459	15.5	9.95
2,6-dimethylnaphthalene (L)	ND	399	ND	9.95
2,3,5-trimethylnaphthalene (L)	ND	518	ND	9.94
Perylene (H)	ND	2,020	38.4	9.98
Phenanthrene (H)	ND	25,500	31.4	9.98
1-methylphenanthrene (H)	ND	2,100	ND	9.95
Pyrene (H)	ND	24,600	46.2	9.98
Combined PAHs	ND	141,000	484	na

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

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

na = not applicable

ND = not detected

measured. This summation is not listed as "total" PAH because only a select list of PAHs were measured and many other PAH compounds could be found in these sediments. Combined PAH concentrations for low level samples are artificially low because analytes that were not detected were assigned a value of zero for calculation of the Combined concentration. Combined PAH concentrations (Table 3-4) showed a large range (ND - 141,000 ng/g) with a median concentration of 484 ng/g in Virginian Province sediments. The station with the highest concentration of PAHs was 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 smoke-stack of a passing ship. Eliminating this station results in a maximum combined PAH concentration of 80,100 ng/g.

This large range of PAH concentrations can be seen in the cumulative distribution of combined PAHs shown in Figure 3-20a&b (note: data from the station discussed above are not included in this figure). This figure shows that the sediments of the vast majority of the area of the Province contain low concentrations of PAHs; for example, about 94 ± 6% of the sampled area of the Province had a combined sediment PAH concentration of less than 4,000 ng/g dry weight. This value has no ecological significance; however, it does appear as an inflection point in the CDF. Figure 3-20b is the CDF plotted on a log scale to better illustrate the distribution of concentrations at the lower end of the scale.

As discussed above, draft Sediment Quality Criteria are available for three PAHs: Acenaphthene, phenanthrene, and fluoranthene. The percent areas exceeding SQC (see Table 3-3) in freshwater and saltwater sediments combined shows that 2 ± 5% of the area of the Virginian Province contains sediments exceeding EPA criteria for each of these PAHs. These exceedences were measured at only three stations within the Province. The station representing the largest area was the one discussed above. Eliminating this station results in 0 ± 0%, 0.3 ± 5% (one station) and 0.4 ± 4% (two stations) of the area of the Province exceeding SQC for acenaphthene, phenanthrene and fluoranthene, respectively. Both stations where exceedences were noted were in small estuaries. Applying the more conservative Lower SQC values in Table 3-3 does not change these percentages. It is important to note that these estimates were based on only those sediments with a total organic carbon content of ≥0.2% (81 ± 9 % of the area of the Province). For the purpose of this exercise, those stations excluded were treated statistically as missing values.

Petroleum and combustion-type PAH sources contain very different PAH compound distributions. Because of this, the distributions of PAHs in a sample can provide information on the relative importance of petroleum versus combustion PAH sources (Lake *et al.*, 1979).

Petroleum products contain relatively large amounts of lower molecular weight compounds relative to combustion sources which are dominated by higher molecular weight compounds.

The CDF of the relative percent of high molecular weight compounds (sum high MW PAHs/sum of all PAHs x 100: see Table 3-4 for a listing of "high molecular weight PAHs) shown in Figure 3-21 indicates that the majority of the Province area contains PAH distributions dominated by higher molecular weight compounds. This indicates that combustion processes are the dominant sources of these compounds in the Province. The percent high molecular weight PAH component (of total PAHs) was less than 50% for only a single station which was located in the large estuary class.

3.2.3.2 Polychlorinated Biphenyls

Environmental measurements of PCBs have been conducted using a variety of techniques including their measurement as industrial mixtures (*e.g.*, Aroclors) (Hutzinger, 1974), by level of chlorination (Gebhart *et al.*, 1985) and as individual congeners (Mullin, 1984; Schantz *et al.*, 1990). Each of these techniques have both positive and negative aspects based on the specific application for which the PCB data are needed. For this study, PCBs were measured as a series of 18 selected congeners (Table 3-5). 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 3-5. 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

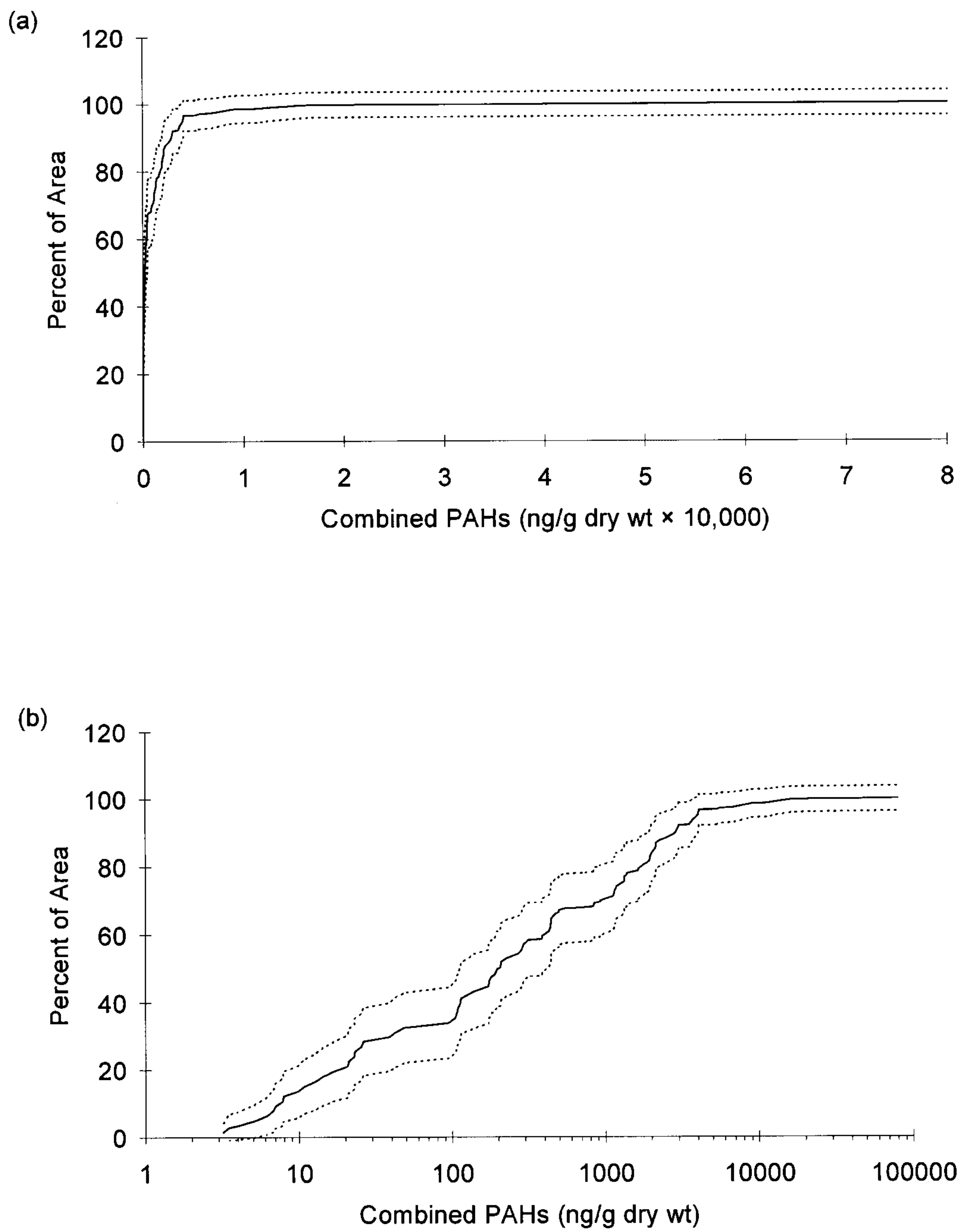


Figure 3-20. Cumulative distribution of combined PAHs in sediments as percent of area in the Virginian Province, 1991: a) linear scale, b) logarithmic scale. (Dashed lines are the 95% confidence intervals).

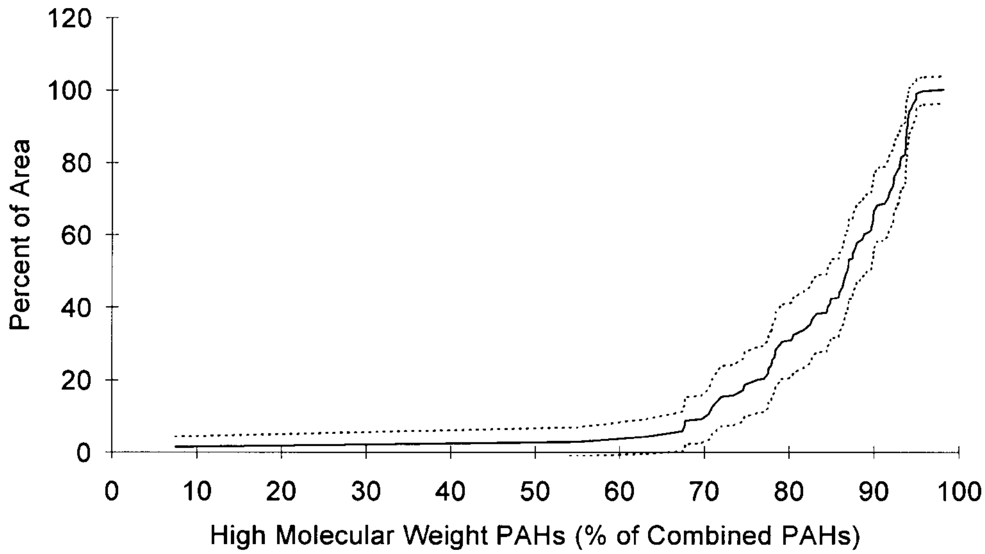


Figure 3-21. Cumulative distribution of the relative percentage of high molecular weight PAHs in sediments as percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

concentrations ranged from the detection limit to 1,020 ng/g dry weight with a median concentration of 3.52 ng/g. The cumulative distribution of combined PCBs in the Virginian Province is shown in Figure 3-22a&b. This plot shows that low concentrations of PCBs were found in the majority of the area of the Province. PCBs were not detected in 40 ± 11% of the area of the Province and approximately 95 ± 5% of the Province contained sediments with PCB concentrations below 50 ng/g dry weight. This value has no ecological significance; however, it does appear as an inflection point in the CDF. Figure 3-22b is the CDF plotted on a log scale to better illustrate the distribution of concentrations at the lower end of the scale.

3.2.3.3 Chlorinated Pesticides

In addition to PCBs, several other chlorinated compounds were also monitored in the sediments of the Virginian Province (Table 3-6). Most of these chemicals are banned in the United States although some are still used in other countries. Several of the compounds measured (*e.g.*, DDEs, DDDs and heptachlor epoxide) are environmental metabolites of the original pesticides (Ernst, 1984) instead of the active ingredients of the original pesticide formulations.

Six DDT-series compounds were measured. These included the original insecticide, p,p'-DDT, and o,p'-DDT which was a contaminant in p,p'-DDT formulations. The four remaining compounds (p,p'-DDE, o,p'-DDE, p,p'-DDD and o,p'-DDD) are metabolites or degradation products of p,p'-DDT and o,p'-DDT, respectively. The use of DDT is now banned in the United States. DDT-series compounds were generally the most abundant of the chlorinated pesticides measured in the Virginian Province sediments (Table 3-6). The CDF of p,p'-DDE is presented in Figure 3-23 as an example of the distribution of DDT-series compounds seen in the Virginian Province. As was previously seen for PAHs and PCBs, the majority of the area of the Province contains low p,p'-DDE levels (94 ± 6% of the area less than 4 ng/g). This value has no ecological significance; however, it does appear as an inflection point in the CDF.

Chlordane is a pesticide that was widely used to control termites and other insects, but its use was severely restricted in 1987. It was sold as a technical mixture containing well over 100 chlorinated compounds (Dearth and Hites, 1991), many of which are persistent in the environment and have been found widely distributed in marine sediments. Two of these compounds (alpha-chlordane and trans-nonachlor) were measured in the sediments of the Virginian Province (Table 3-6). The maximum concentrations observed for these compounds were 7.32 and 3.83 ng/g dry weight for alpha-chlordane and trans-nonachlor, respectively. Figure 3-24 shows the cumulative distribution observed for alpha-chlordane in sediments of the Virginian Province. This plot shows that alpha-chlordane was not detected in 83 ± 8% of the area of the Province. The remaining pesticides measured generally showed concentrations near the analytical detection limits in most samples (Table 3-6).

The only chlorinated pesticide measured by EMAP-VP in sediments for which there is a draft Sediment Quality Criteria for is dieldrin. Draft EPA criteria were not exceeded at any station within the Virginian Province in 1991. It is important to note that this estimate was based on only those sediments with a total organic carbon content of ≥0.2% (81 ± 9% of the area of the Province). For the purpose of this exercise, those stations excluded were treated statistically as missing values.

Table 3-5. Range and median PCB concentrations in sediments of the Virginian Province, 1991.

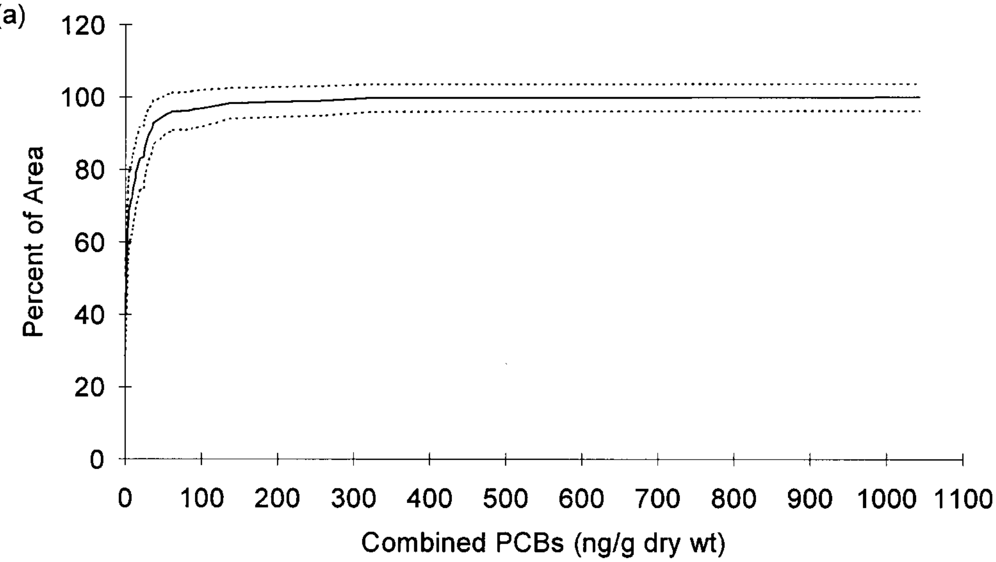
	Concentration (ng/g dry weight)			
Analyte	MIN	MAX	Median	Median Detection Limit[a]
PCB8	ND	35.4	0.317	0.249
PCB18	ND	50.7	ND	0.249
PCB28	ND	346	0.33	0.249
PCB44	ND	72.6	ND	0.249
PCB52	ND	107	ND	0.249
PCB66	ND	152	0.431	0.249
PCB101	ND	53.2	0.393	0.249
PCB105	ND	34.8	0.259	0.249
PCB118	ND	55.7	0.422	0.249
PCB128	ND	8.94	ND	0.249
PCB138	ND	42.2	0.43	0.249
PCB153	ND	31.1	0.485	0.249
PCB170	ND	7.82	ND	0.249
PCB180	ND	17.9	ND	0.249
PCB187	ND	14.4	ND	0.249
PCB195	ND	5.12	ND	0.249
PCB206	ND	10.3	ND	0.249
PCB209	ND	18.2	ND	0.249
Combined PCBs	ND	1,040	3.46	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

(a)



(b)

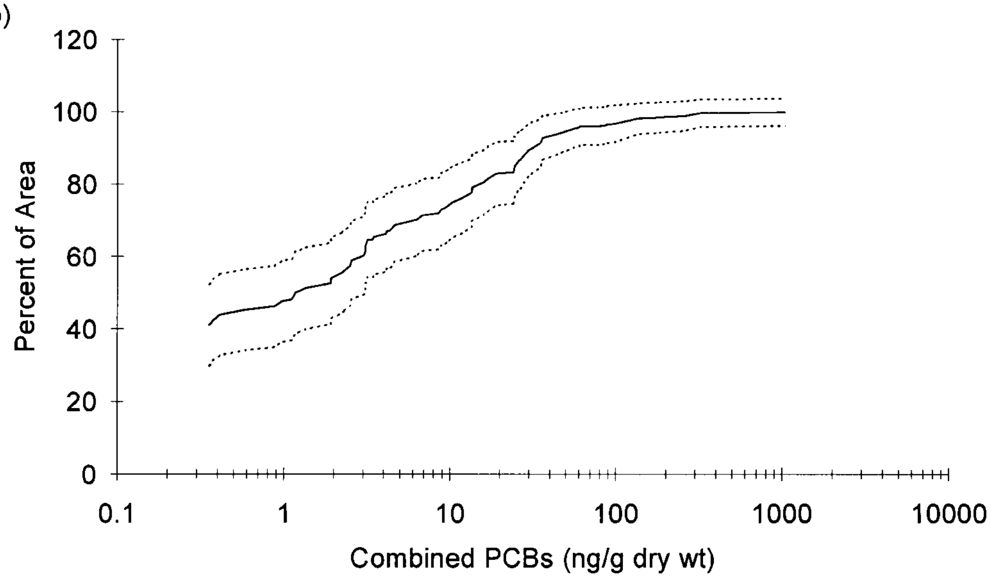


Figure 3-22. Cumulative distribution of combined PCBs in sediments as percent of area in the Virginian Province, 1991: a) linear scale, b) logarithmic scale. (Dashed lines are the 95% confidence intervals).

Table 3-6. Range and median chlorinated pesticide concentrations in sediments of the Virginian Province, 1991.

Analyte	Concentration (ng/g dry weight) MIN	MAX	Median	Median Detection Limit[a]
o,p'-DDD	ND	13.1	ND	0.249
p,p'-DDD	ND	32.9	ND	0.249
o,p'-DDE	ND	12.9	ND	0.249
p,p'-DDE	ND	30.8	0.723	0.249
o,p'-DDT	ND	12.7	ND	0.249
p,p'-DDT	ND	33.3	ND	0.249
Aldrin	ND	1.82	ND	0.249
Alpha-Chlordane	ND	7.32	ND	0.249
Dieldrin	ND	4.56	ND	0.249
Heptachlor	ND	3.19	ND	0.249
Heptachlor epoxide	ND	0.96	ND	0.249
Hexachlorobenzene	ND	3.21	ND	0.249
Lindane (gamma-BHC)	ND	0.46	ND	0.249
Mirex	ND	0.62	ND	0.249
Trans-Nonachlor	ND	3.83	ND	0.249
Total chlordanes[b]	ND	10.4	ND	na

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

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

ND = not detected

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 noted when comparing TBT concentrations among studies because of the different ways that it is reported (*e.g.*, sometimes reported as ng *tin* /g).

The maximum TBT concentration observed was 240 ng/g; DBT and MBT levels were generally lower than those of TBT (Table 3-7). Figure 3-25 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 72 ± 10% of the area of the Province and 89 ± 8% of the area contained sediments with TBT concentrations of less than 25 ng/g.

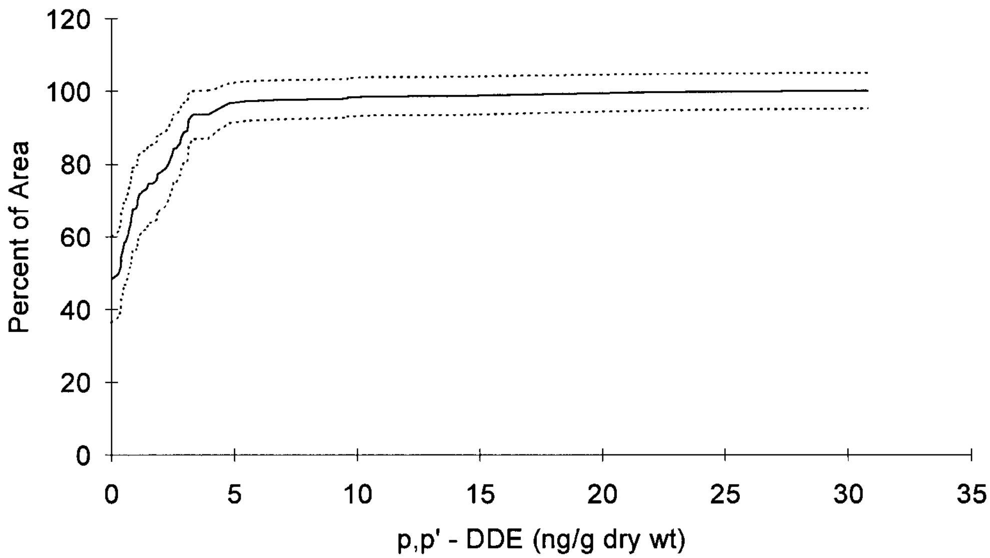


Figure 3-23. Cumulative distribution of p, p' -DDE in sediments as percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

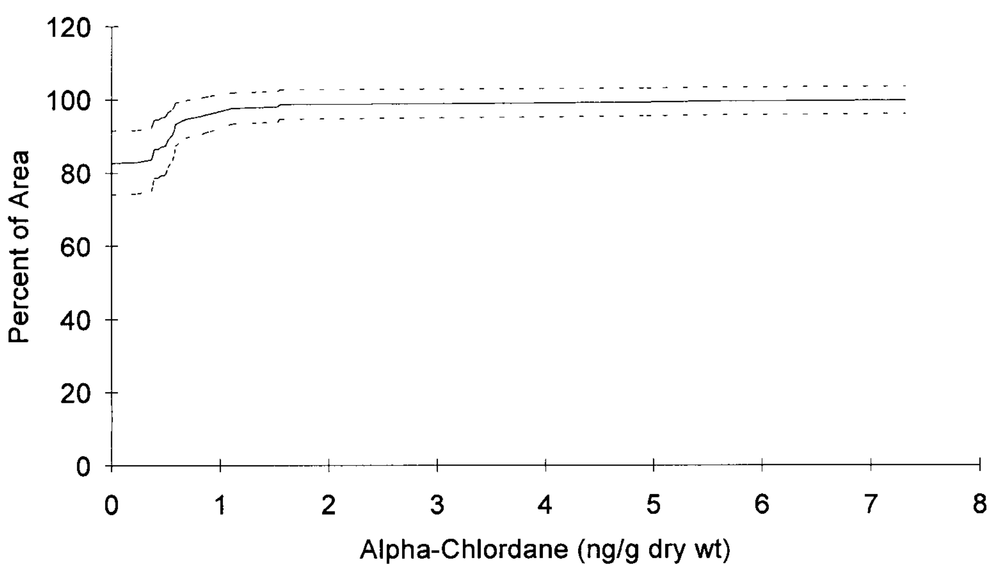


Figure 3-24. Cumulative distribution of alpha-chlordane in sediments as percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

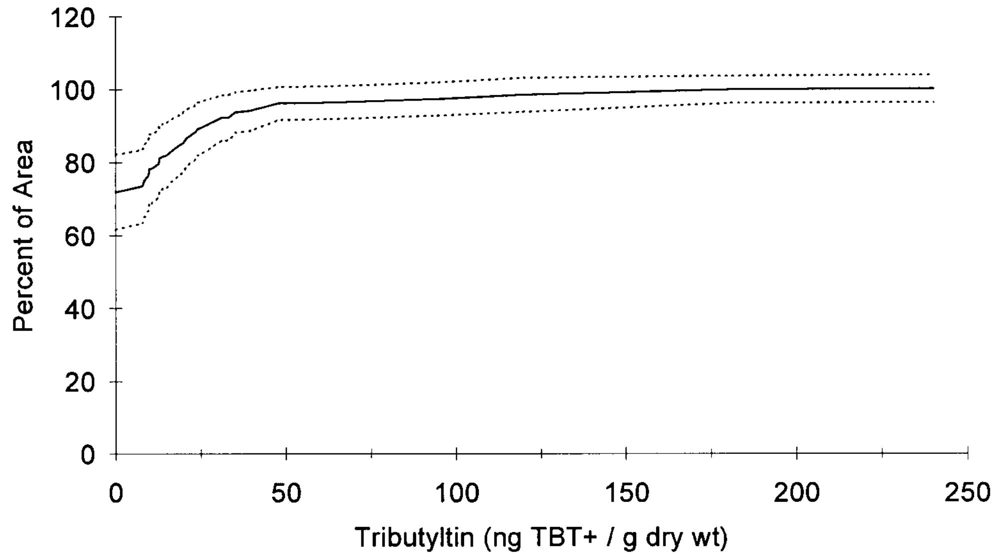


Figure 3-25. Cumulative distribution of tributyltin in sediments as percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

Table 3-7. Range and median butyltin concentrations in sediments of the Virginian Province, 1991.

	Concentration (ng *ion* /g dry weight)			
Analyte	MIN	MAX	Median	Median Detection Limit[a]
Monobutyltin (MBT^{+3})	ND	108	ND	17.6
Dibutyltin (DBT^{+2})	ND	98.6	ND	9.74
Tributyltin (TBT^{+})	ND	240	ND	12.1

[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

3.2.3.5 Total Organic Carbon

Organic carbon as measured here in the sediments includes all forms of carbon except carbonate. Organic carbon accumulates in sediments of the marine environment as a function of the proximity and magnitude of the various sources of organic matter and the physical, and biological factors that influence erosion and deposition. The presence of organic matter is an important modifier of the physical and chemical 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 0.065 to 3.98% 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 3-26. In 81 ± 9% of the area sampled in 1991 the sediments contained ≥0.2% TOC, concentrations allowing the use of existing Sediment Quality Criteria for evaluating contaminant effects. The pattern is largely determined by the large estuaries (Figure 3-27) which account for the largest part of the Province area.

3.2.3.6 Acid Volatile Sulfides

Acid volatile sulfides are defined as the fraction of sulfide in the sediments that can be extracted with cold hydrochloric acid. They exist in sediments mainly as iron monosulfide complexes, and are important in determining the biological availability of a number of cationic metals, primarily zinc, lead, copper, nickel, and cadmium. Acid volatile sulfides measured in sediments of the Virginian Province ranged from 1.39 to 5,000 mg/kg dry weight sediment. The CDF of percent area as a function of AVS concentration is shown in Figure 3-28.

In general, the AVS concentration in the sediment increases with increasing silt-clay and organic content of the sediments and decreasing dissolved oxygen. However there are exceptions to this pattern. Oxidation of the sediments by physical or biological activity may result in lower than expected AVS readings for a given organic and silt-clay content of the sediment. For example, the physical mixing energy present in large tidal rivers and the absence of low DO may have been responsible for the observation that measured AVS concentrations in those sediments did not exceed 279 mg/kg or 8.7 μm/g (Figure 3-29).

Occasionally, a sample with high silt-clay and organic carbon content would have a low AVS concentration which could not readily be explained. These 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 very likely that this mixing process resulted in the oxidation of some of the AVS, reducing the measured concentrations. Collection methodology was changed in 1992 to eliminate this problem.

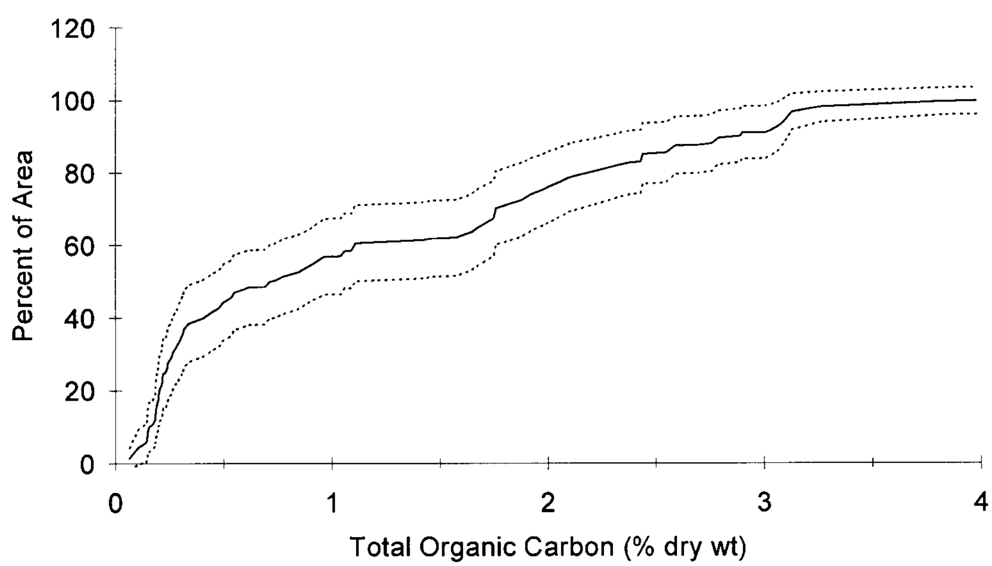
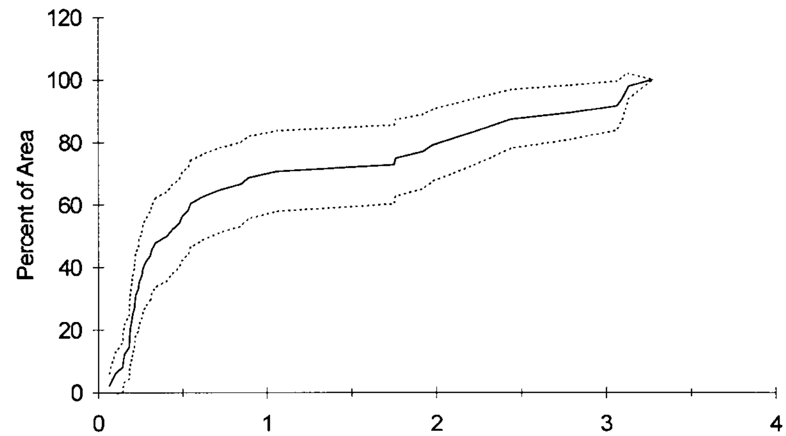
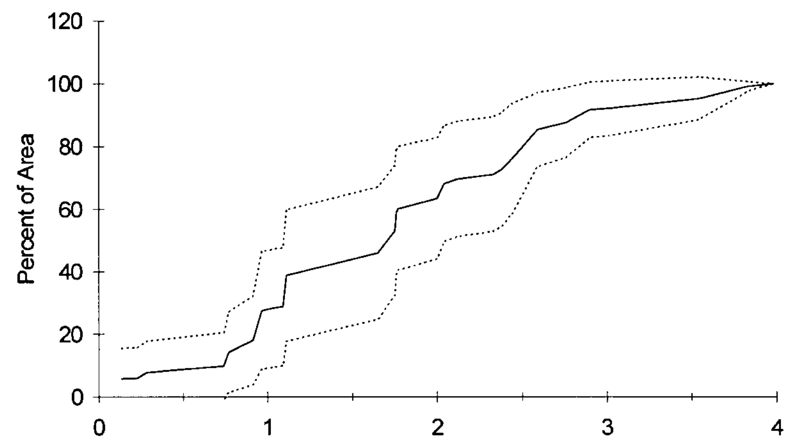


Figure 3-26. The cumulative distribution of the percent total organic carbon in sediments as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

a) Large Estuaries



b) Small Estuaries



c) Tidal Rivers

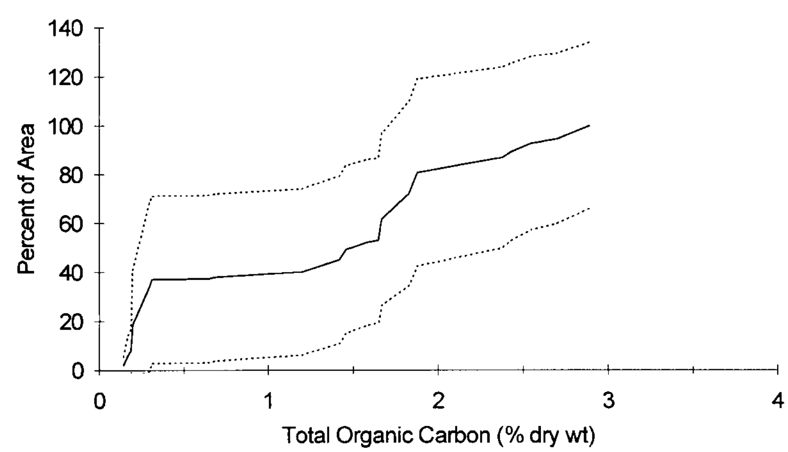


Figure 3-27. Cumulative distribution functions of total organic carbon in sediments by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

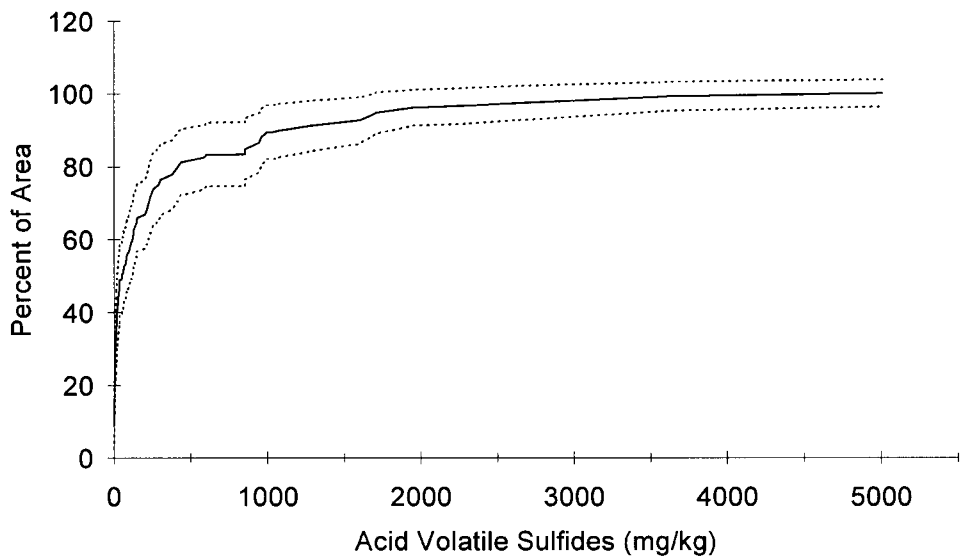


Figure 3-28. The cumulative distribution of the acid volatile sulfide concentration in sediments as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

3.2.3.7 Metals

The median concentration and range of metals that were measured in 1991 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. Three major crustal elements; aluminum, iron and manganese were measured in this program for possible use in normalizing elemental concentrations among sediments. Based on several recent studies, aluminum was selected as the most appropriate element with which to normalize contaminant metal concentrations. The normalization process utilized is discussed in Appendix A. Determination of metal-aluminum relationships in background sediments enables estimation of the extent of enrichment of metals in sediments.

Figure 3-30 presents an example (chromium) of the 1991 sediment metals data for the Virginian Province. The predicted metal-aluminum relationship (solid line) is obtained from the regression, along with the upper bound of the 95% confidence interval for predicted values (dashed line). Values above the upper bound are greater than expected (*i.e.*, enriched) based on the aluminum concentration measured in the sediment. This "excess" metal is derived from additional sources other than crustal background sediment, presumably, although not necessarily, from anthropogenic activity. Regressions for the remaining metals are presented in Appendix D. While some of the metals, *e.g.*, Ni, Cr, Se, Sb and the crustally-derived elements Fe and Mn, are not highly enriched, (the highest measured concentrations are generally less than 2-3 times higher than the upper bound of predicted concentrations) most metals are clearly enriched at many stations. Two metals, Hg and Ag, are found at a number of stations in concentrations more than 10-60 times higher than predicted from the metal aluminum relationship. The highest concentrations of other metals (Pb, Sn, Cu, As, Cd and Zn) are generally 2-10 times higher than predicted. Often a given station exhibits substantial enrichment of more than one metal. The aerial extent of enriched metals concentrations in sediments can be estimated once stations with enriched metals concentrations are identified (Figure 3-31). For several metals, the proportion of the Province in which metals concentrations are enriched is substantial, *e.g.*, Ag, Sn and Hg.

Approximately 41 ± 10% of the area of the Province showed enrichment of sediments with at least one metal. Thirty five (± 14), 53 ± 22, and 51 ±23 percent of the large estuary, small estuary, and large tidal river class areas sampled contained sediments with metals concentra-

a) Large Estuaries

b) Small Estuaries

c) Tidal Rivers

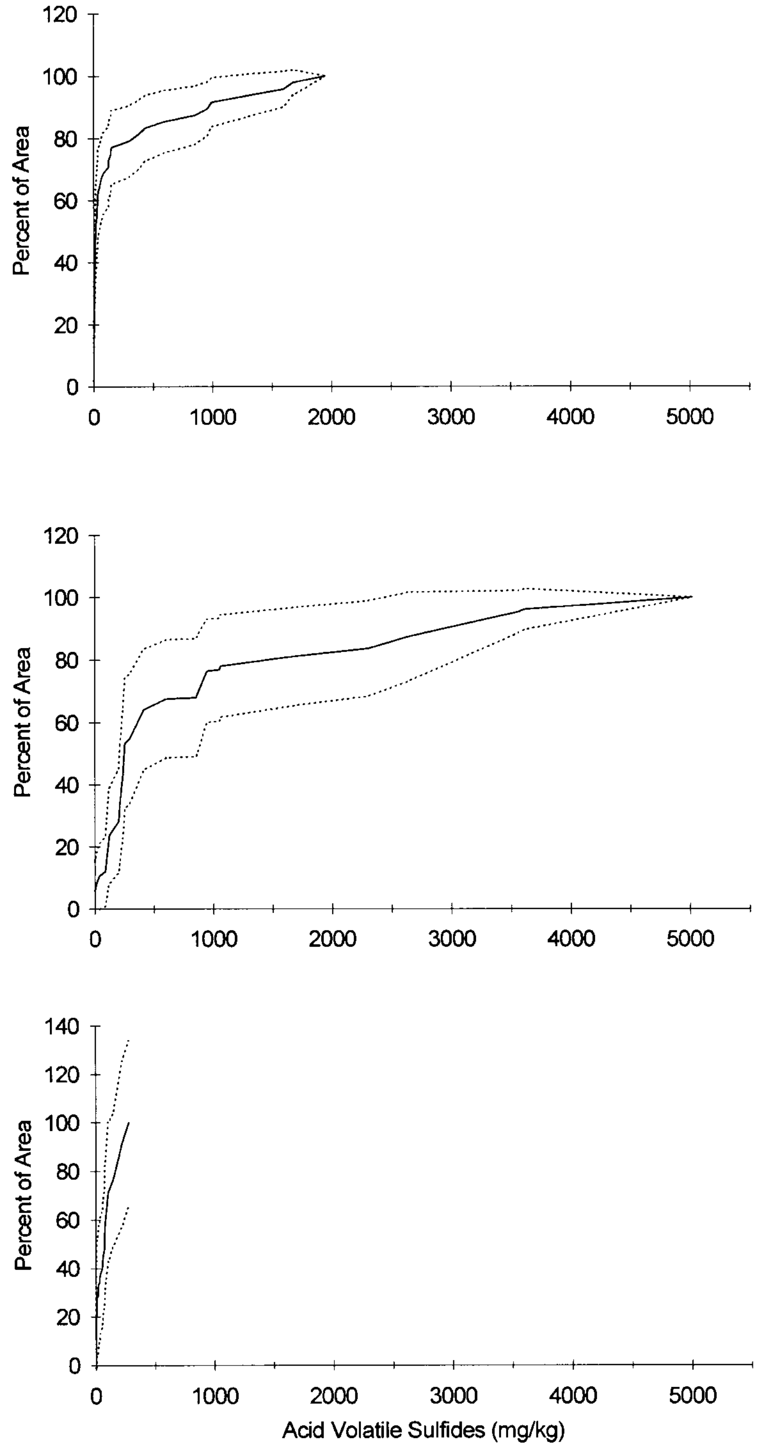


Figure 3-29. Cumulative distribution functions of the AVS concentration in sediments by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

Table 3-8. Range and median metal concentrations in sediments of the Virginian Province, 1991.

		Concentration (µg/g dry weight)		
Analyte	MIN	MAX	Median	Median Detection Limit[a]
Major				
Aluminum	1,760	89,300	42,800	na
Iron	653	54,500	21,700	na
Manganese	11.6	6,430	368	na
Trace				
Antimony	ND	49.1	0.299	0.050
Arsenic	0.773	34.9	5.36	na
Cadmium	ND	6.58	0.187	0.031
Chromium	1.88	174	39.0	na
Copper	0.492	263	15.3	na
Lead	ND	323	27.6	1.79
Mercury	ND	1.96	0.052	0.004
Nickel	ND	70.1	16.5	1.68
Selenium	ND	1.76	0.364	0.111
Silver	ND	9.69	0.048	0.007
Tin	ND	27.0	2.24	0.116
Zinc	3.66	484	74.5	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

tions exceeding predicted background levels. Although a significant proportion of the Province contains sediments with potentially enriched levels of metals, this does not imply ecological impacts.

The results obtained from the regression analyses determined in this study should be similar to those obtained by other investigators. Results of these comparisons are described in Appendix D.

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.

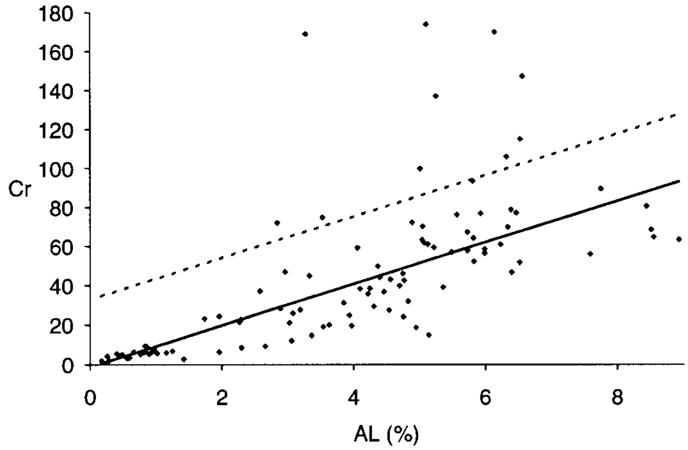


Figure 3-30. Example linear regression (with upper 95%confidence intervals) of chromium against aluminum.

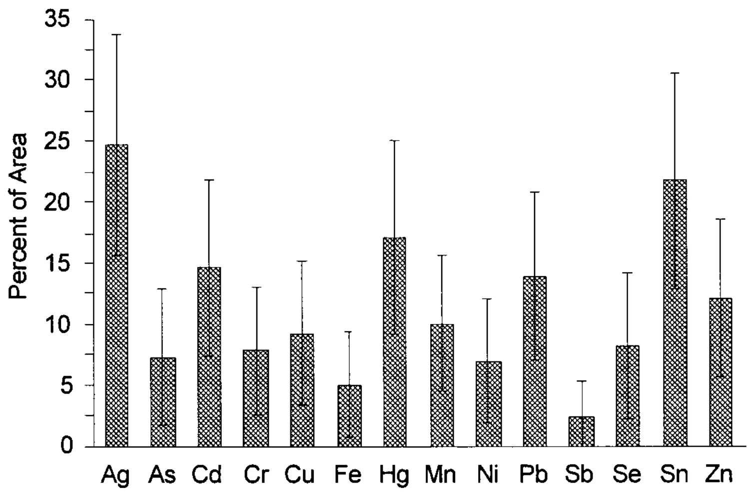


Figure 3-31. Percent area of the Virginian Province with enriched concentrations of individual metals in sediments in 1991. (Error bars represent 95% confidence intervals).

The debris collected in bottom trawls was examined as an indicator of environmental degradation in the Virginian Province. Debris was found on the bottom of approximately 18 ± 8% of the Virginian Province area sampled in 1991 (Figure 3-32). The small estuary class had the largest percent area (35 ± 17%) where trash was found. Trash was found in 12 ± 9% of the area of the large estuaries and 16 ± 38% of the area of large tidal rivers.

3.3 Habitat Indicators

Habitat indicators describe the natural physical and chemical conditions of the sites sampled in the 1991 Virginian Province study.

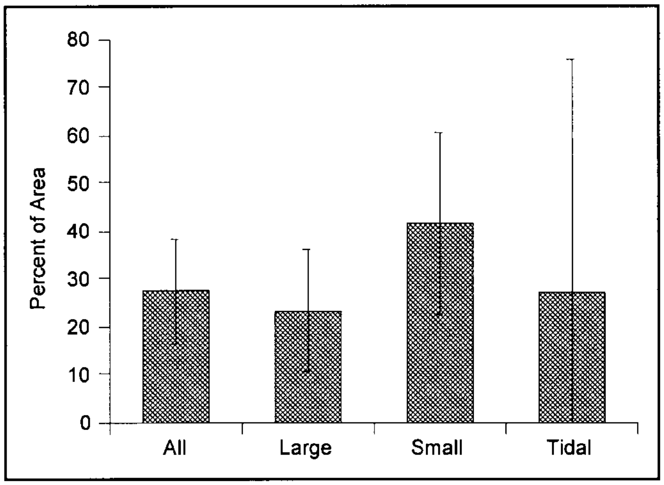


Figure 3-32. The percent of area of the Virginian Province by estuarine class where anthropogenic debris was collected in fish trawls, 1991.

3.3.1 Water Depth

The depth distribution in the Virginian Province is shown in Figure 3-33. The area shallower than 2 m is underestimated because this is the minimum depth sampled. Based on the sampling design where a single station represents a given area, 12% of the area of large estuaries was unsampleable due to inadequate water depth. Small estuaries were considered unsampleable if the water depth did not exceed 2 m anywhere in the system. Such systems account for approximately 1.5% of the area of small systems in the Virginian Province. Overall, 9% of the area of the Province was deemed unsampleable in 1991 due to water depth.

3.3.2 Temperature

Bottom water temperature in the Virginian Province ranged from 16.2°C to 30.0°C during the summer sampling period. The cumulative distribution function of bottom temperature is shown in Figure 3-34. The overall pattern is dominated by the CDF of the large estuary class which shows inflections at 26.5°C and 22°C (Figure 3-35a), representing the bottom temperature characteristic of Chesapeake Bay and Long Island Sound, respectively. The lowest bottom temperatures measured in the Province occurred in Block Island Sound.

Bottom temperature in the small estuaries ranged from 20.7°C to 29.5°C (Figure 3-35b). More enclosed small estuaries had warmer temperatures than might be expected for their latitude. Large tidal rivers had a steep CDF (Figure 3-35c) and, as a result, they exhibited the smallest temperature range (24.6°C to 30.0°C). The three warmest stations in the Province were found in the upper Potomac River, which is surrounded by the Washington DC metropolitan area. Approximately 18 ± 40% of the area of the large tidal river class and 2 ± 4% of the Province area had a bottom temperature above 29°C.

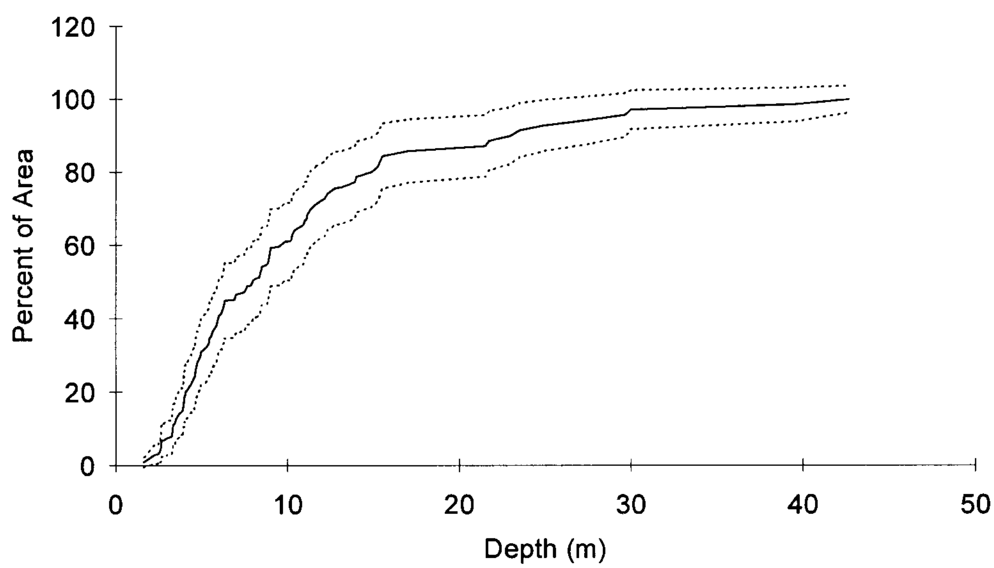


Figure 3-33. Cumulative distribution of water depth as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

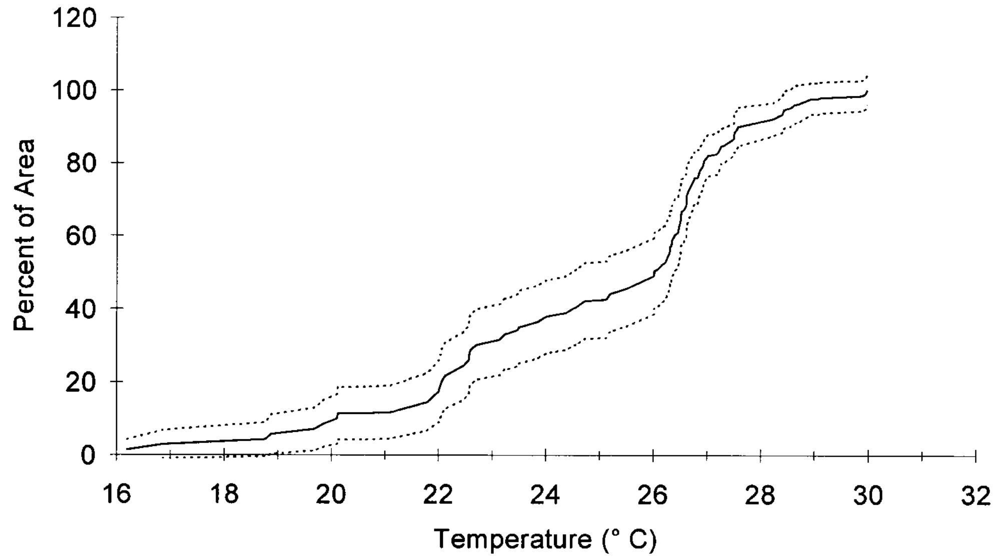


Figure 3-34. Cumulative distribution of bottom temperature as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

3.3.3 Salinity

Salinity is determined by freshwater discharge and seawater intrusion. Salinity in the broad sounds of the northern Province is, in general, higher than salinity in the coastal plain estuaries south of the Hudson River. The CDF for bottom salinity (Figure 3-36) reflects the different salinity characteristics of the large estuarine systems. Chesapeake Bay accounts for the inflection at 17‰ while Long Island Sound is responsible for the one at 28‰.

The CDF for small estuaries (Figure 3-37) 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 to 32 ‰), with the ranges for large estuaries and large tidal rivers being 9 to 32 and 0 to 15 ‰, respectively (Figure 3-37).

The 1991 data showed over 30 ± 12% of the large tidal river area to be fresh water (salinity < 0.5‰). Large tidal rivers contain the largest tidal fresh/oligohaline area (45 ± 19% < 5 ‰) compared to 11 ± 10% for small estuaries and 0% for the large estuaries (Figure 3-38).

3.3.4 pH

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

The measured pH of Virginian Province estuaries ranged from 6.8 to 8.6, with 67 ± 11% of the Province area between pH 7.7 and 8.2. The lowest pH values occurred in large tidal rivers, upper Chesapeake Bay, and in small estuaries associated with tidal rivers or other fresh water inflows. High pH values were generally associated with sea water inflow; however, some of the highest pH values were found in the fresh water portions of the Hudson and Potomac Rivers.

3.3.5 Stratification

Vertical density differences, or 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,

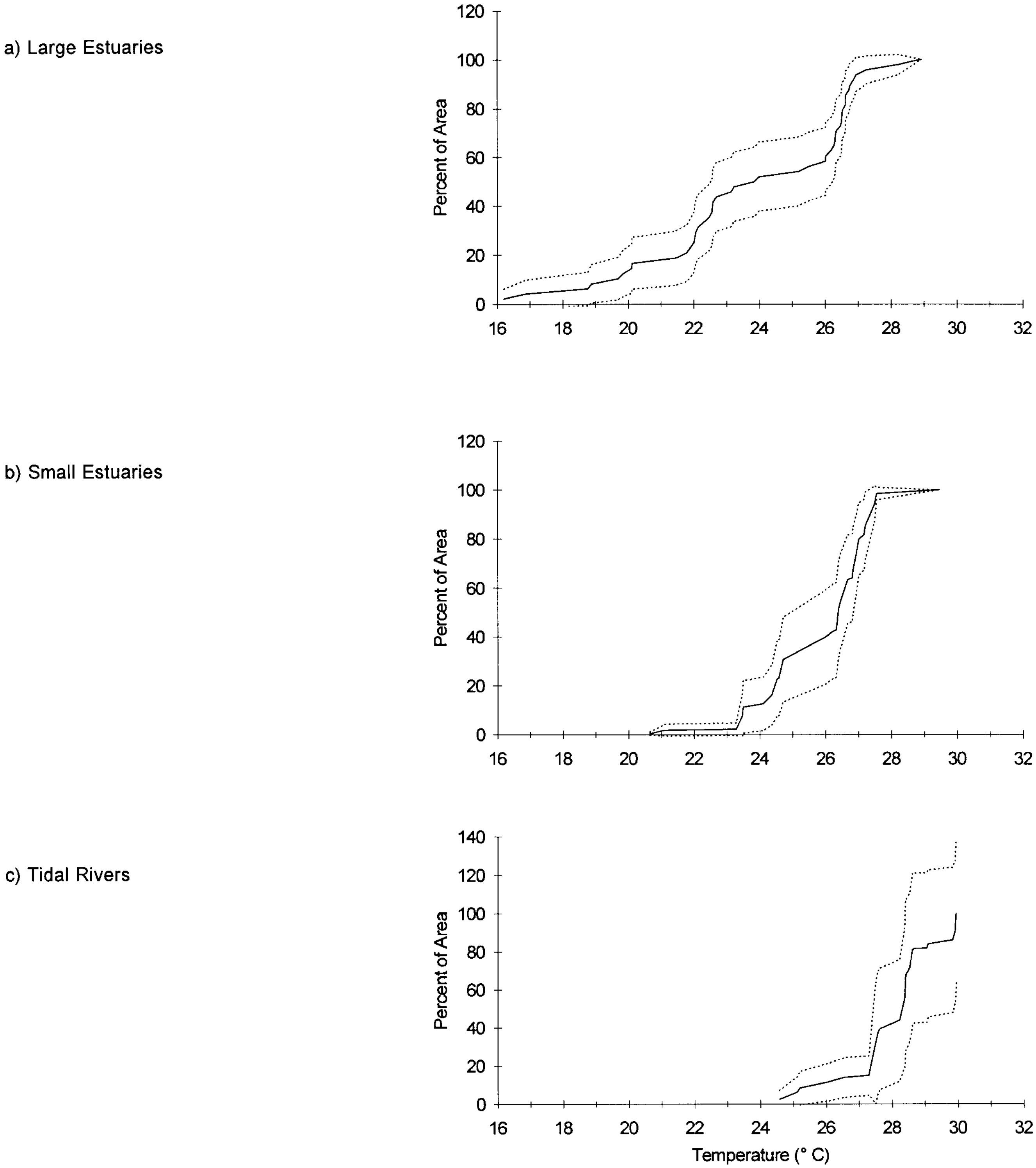


Figure 3-35. Cumulative distribution functions of bottom temperature by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

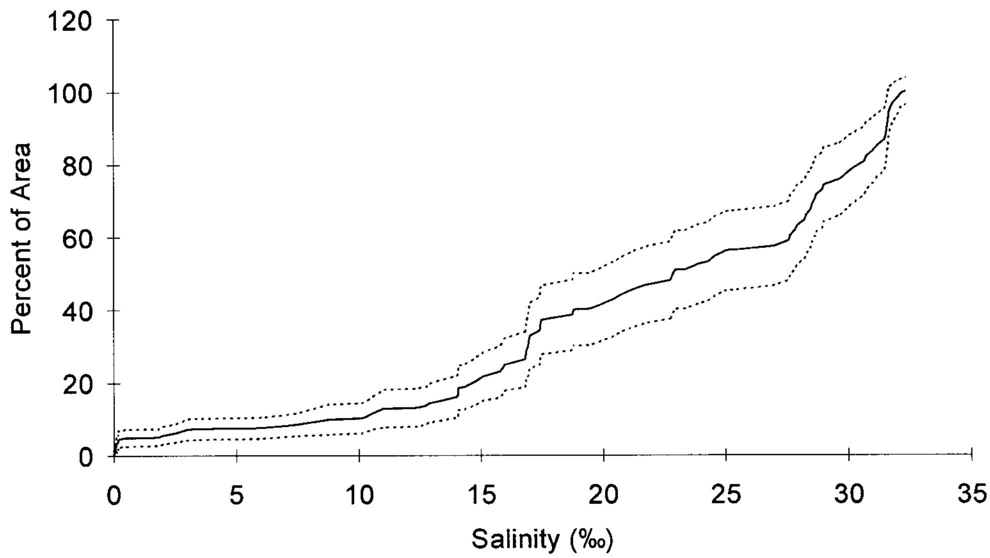


Figure 3-36. The cumulative distribution of bottom salinity as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

which might ultimately result in increased biomass settling to the bottom contributing an additional biological oxygen demand in the stratified environment.

Fresh water runoff can be an important factor in this process because it both provides low density water 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.

Stratification in the Virginian Province is shown as a CDF of $\Delta\sigma_t$, which is the σ_t (sigma-t density) difference between surface and bottom waters (Figure 3-39). Sigma-t is a density measurement commonly used in oceanographic studies. It is a measurement of the density a parcel of water with a given temperature and salinity would have at the surface (*i.e.*, atmospheric pressure), and is presented as:

(density - 1) x 1000

The CDF for all estuaries shows that 76 ± 10% of the Province area had a $\Delta\sigma_t$ of <1 kg/m^3, with 52 ± 11% being ≤0.2; thus the majority of the water in the Virginian Province was well-mixed. Only 7 ± 7% of the Province area was stratified ($\Delta\sigma_t \geq 2$). The bar chart for stratification by class (Figure 3-40) show that small estuaries were least stratified (0% with $\Delta\sigma_t \geq 2$) and the best mixed (96 ± 4% with $\Delta\sigma_t < 1.0$). Large estuaries had the greatest range of $\Delta\sigma_t$ (0 to 6).

3.3.6 Suspended Solids

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

The data presented in this section represent surface values only. Suspended solids concentrations in the waters of the Virginian Province ranged from 3.2 to 78.1 mg/L in 1991 (Figure 3-41). The relative condition of Virginian Province waters in large estuary, small estuary, and large tidal river classes, are similar (Figure 3-42).

a) Large Estuaries

b) Small Estuaries

c) Tidal Rivers

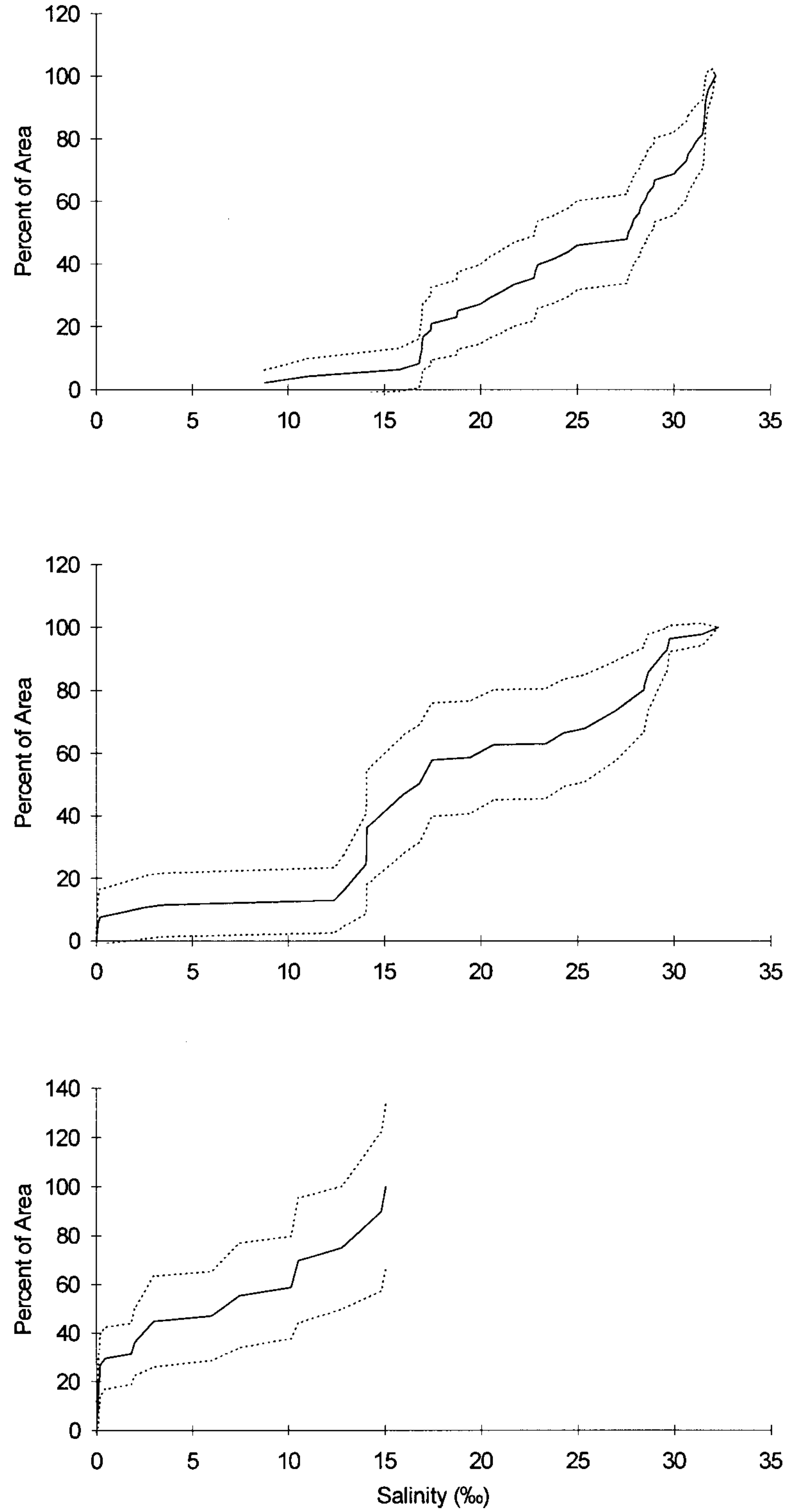


Figure 3-37. Cumulative distribution functions of bottom salinity by estuarine class. (a) Large estuaries. (b) Small estuaries. (c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

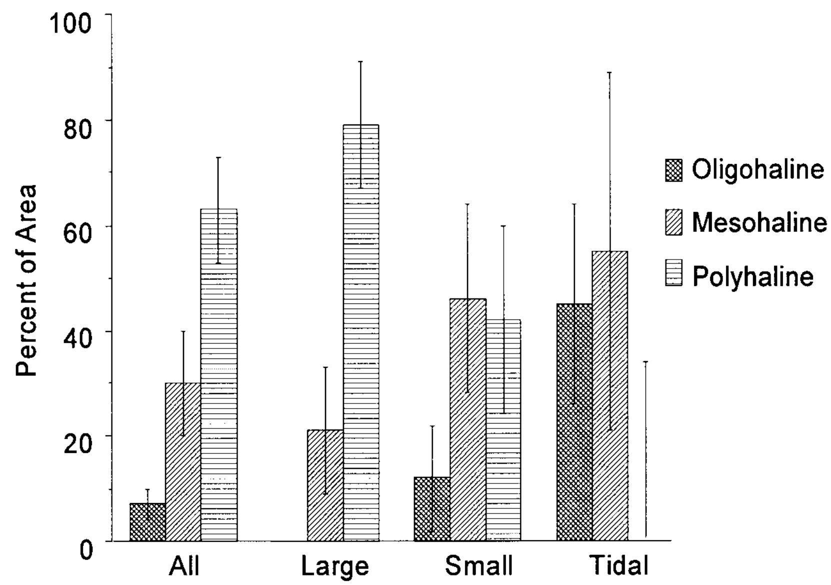


Figure 3-38. The percent of area by estuarine class classified as oligohaline (<5 ppt), mesohaline (5 to 18 ppt), and polyhaline (>18 ppt). (Error bars represent 95% confidence intervals).

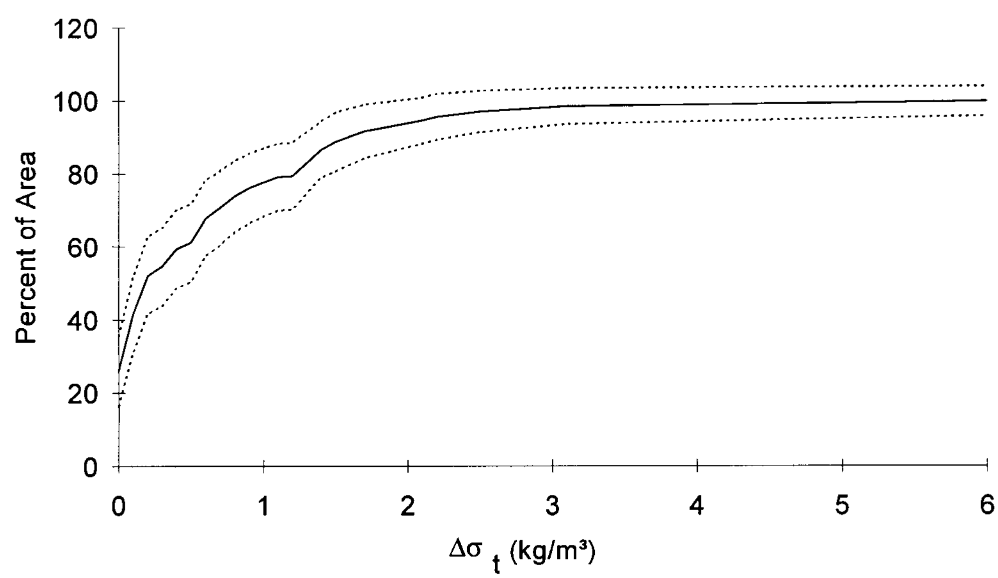


Figure 3-39. Cumulative distribution function of the stratified area in the Virginian Province in 1991 based on the sigma-t density difference between surface and bottom waters. (Dashed lines are the 95% confidence intervals).

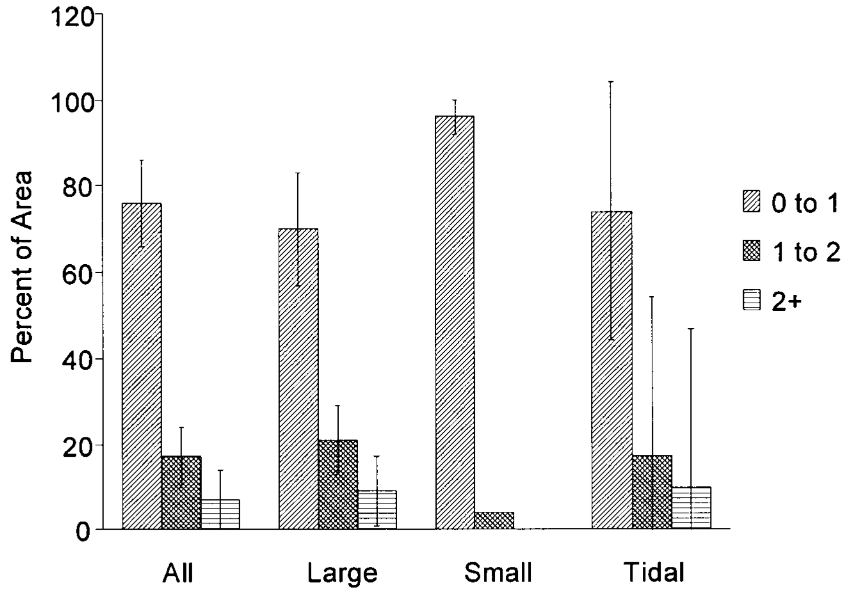


Figure 3-40. The percent of the area by estuarine class that had a low (<1), medium (1 to 2), or high (>2) degree of stratification (Δ σ_t in kg/m^3). (Error bars represent 95% confidence intervals).

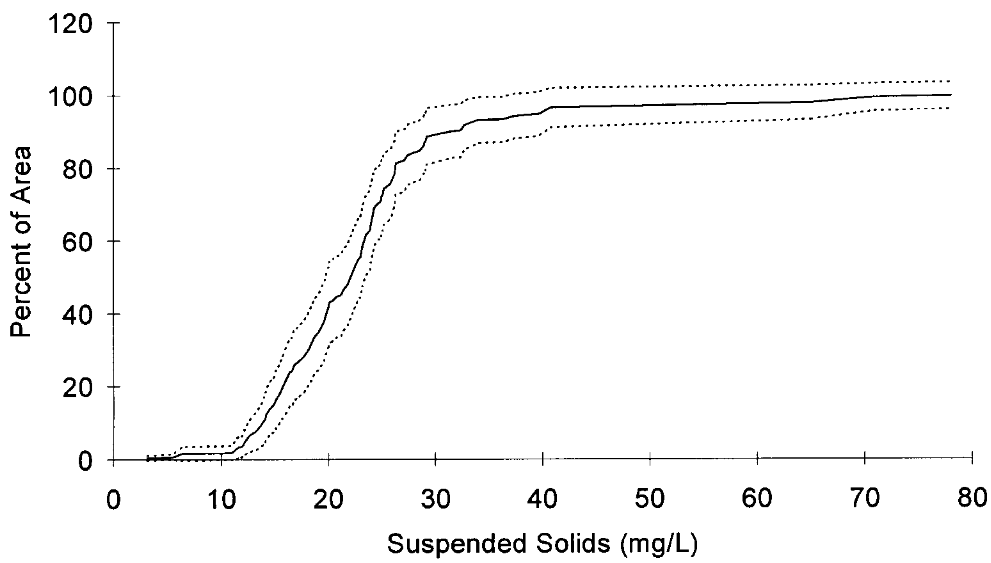
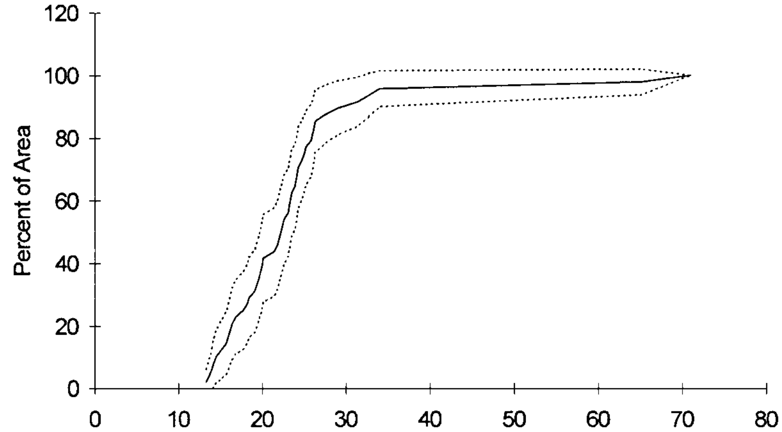
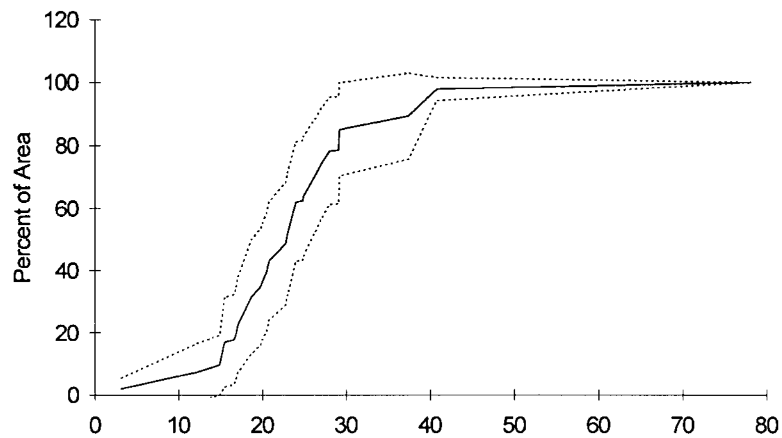


Figure 3-41. The cumulative distribution of total suspended solids concentration as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

a) Large Estuaries



b) Small Estuaries



c) Tidal Rivers

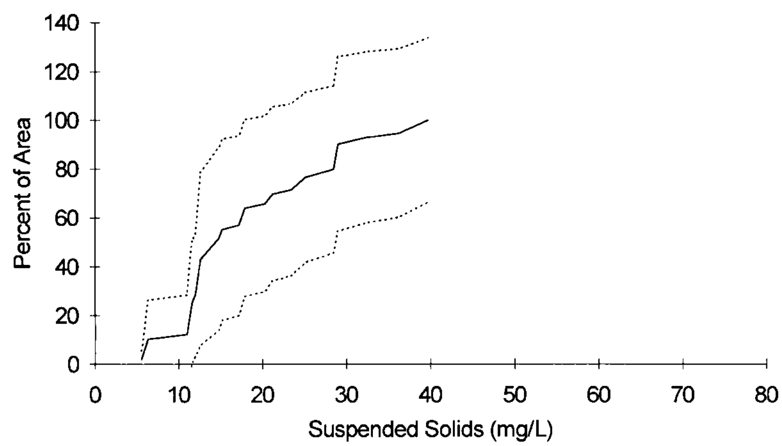


Figure 3-42. Cumulative distribution functions of total suspended solids concentration by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

3.3.7 *Light Extinction*

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

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

Water clarity was good in 80 ± 7% of the sampled area of the Virginian Province (Figure 3-43). Water of low clarity was found in 8 ± 6% of the Province and an additional 12 ± 7% of the Province had water of moderate clarity. Thus, in 20 ± 7% 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 4 ± 6% of the large estuarine area, 16 ± 15% of the small estuarine area, and in 20 ± 37% of the large tidal river area (Figure 3-44). 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 (92 ± 8%) and large tidal rivers the least (27 ± 31%).

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.

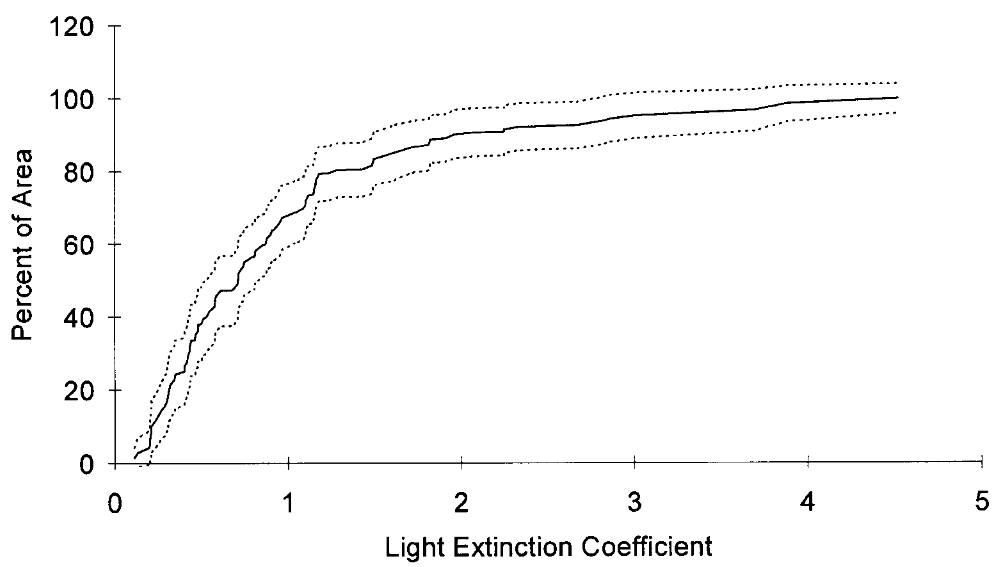


Figure 3-43. The cumulative distribution of light extinction coefficient as a percent of area in the Virginian Province in 1991. (Dashed lines are the 95% confidence intervals).

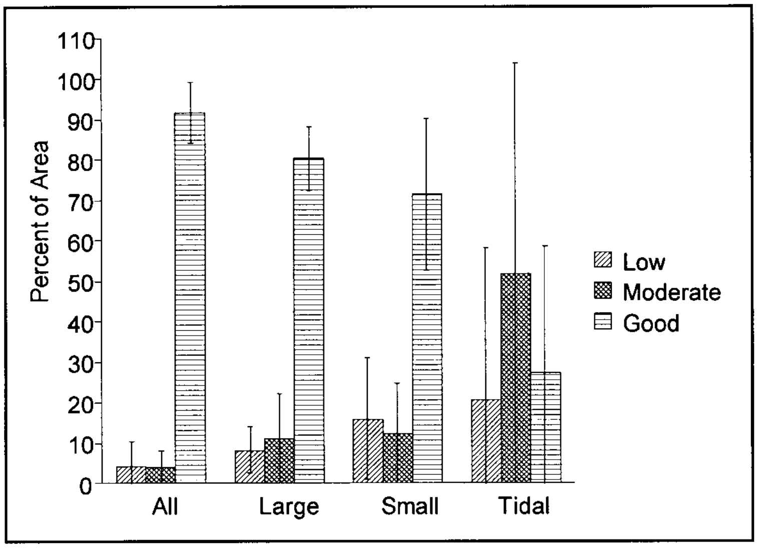


Figure 3-44. The percent of area by estuarine class where water clarity was poor, moderate, or good. (Error bars represent 95% confidence intervals).

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

The CDF of silt-clay content for the Virginian Province is shown in Figure 3-45. Forty-six (± 11) percent of the area had sandy sediments (<20% silt-clay), and 31 ± 9% of the area had muddy sediments (>80% silt-clay). The sediment size distribution in large estuaries was dominated by sands, whereas small estuaries and large tidal rivers were dominated by muds (Figure 3-46).

3.4 Integration of Estuarine Conditions

The condition of estuaries of the Virginian Province can be estimated through the examination of multiple indicators. As an example, we have integrated data on stations that can be considered "degraded" based on water clarity, the presence of anthropogenic trash caught in fish trawls, and the benthic index. The summation of these indicators was used as an indicator of the maximum

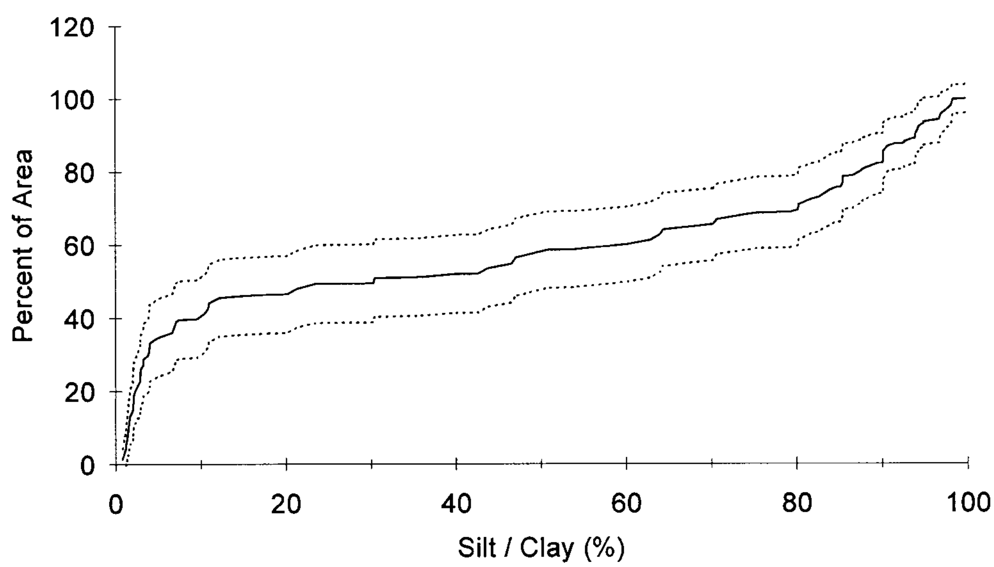


Figure 3-45. The cumulative distribution of the percentage of silt-clay in the sediments as a percent of area in the Virginian Province, 1991. (Dashed lines are the 95% confidence intervals).

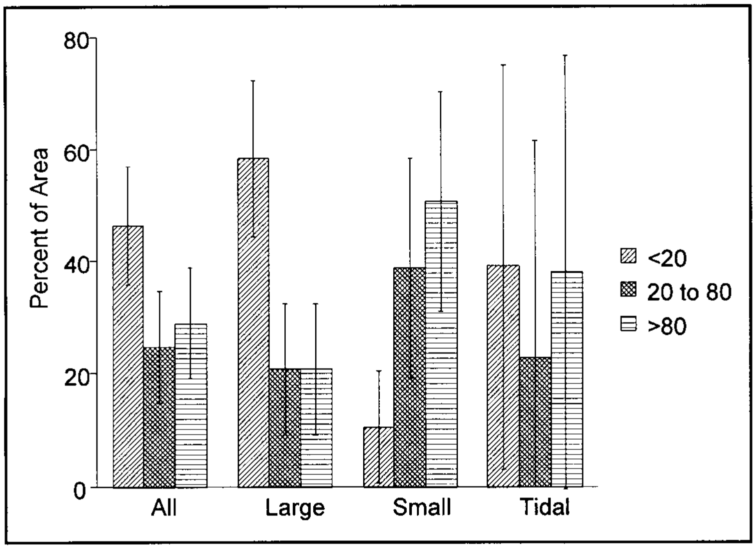


Figure 3-46. The percent of area by estuarine class with a low (<20), medium (20 to 80), or high (>80) percent silt-clay in the sediments. (Error bars represent 95% confidence intervals).

extent of potential degradation. Figure 3-47 shows that, in this example, 36% of the Province is potentially degraded in terms of its benthic biology and ability to support desired human commercial or recreational uses. Aesthetic value (water clarity and presence of trash) was degraded in 25% of this area, whereas 14% of the area may be degraded as a result of subnominal benthic communities.

There was only a 3% overlap between areas which were biologically degraded (low benthic index values) and those that were aesthetically degraded. Poor water clarity may dictate impairment of some human uses, but it is probably not a good indicator of ecological degradation; therefore, the area of the Virginian Province that is, in fact, degraded is probably much less than indicated in this example.

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

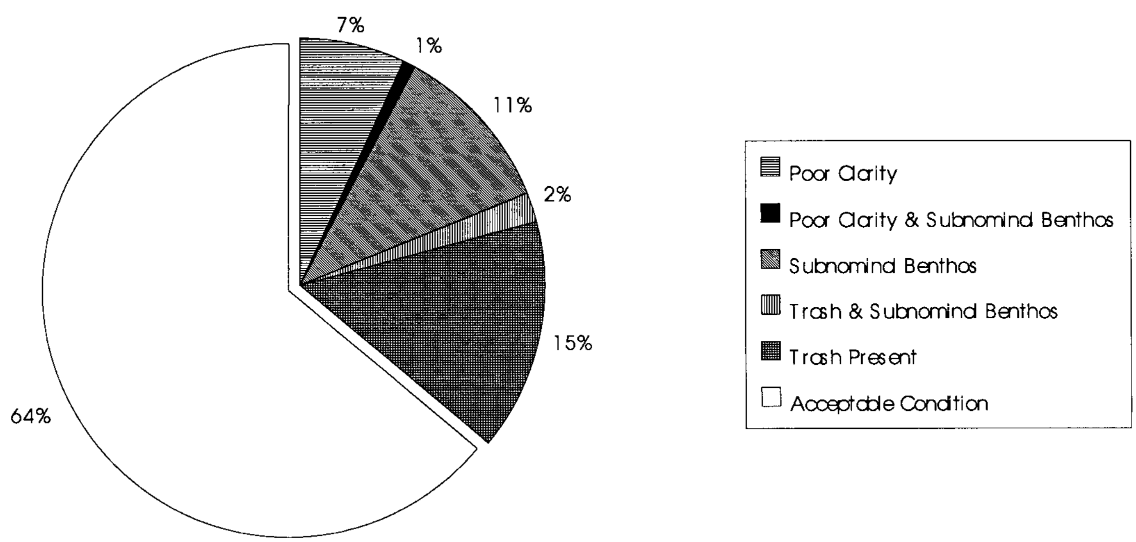


Figure 3-47. Integration of estuarine conditions based on presence of bottom trash, water clarity, and the benthic index.

SECTION 4

QUALITY ASSURANCE

The 1991 Virginian Province monitoring effort was implemented using a quality assurance program to ensure comparability of data with those collected in other EMAP-E provinces, and to assure data quality consistent with the goals of the Program. As described in the Quality Assurance Project Plan (Valente and Schoenherr, 1991), Measurement Quality Objectives (MQOs) were established for data quality. Quality control steps taken to assure that MQOs were met included intensive training of field and laboratory personnel, field performance reviews of sampling crews, laboratory certification and audits.

4.1 CREW TRAINING

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

Crew chiefs underwent detailed training during the first two weeks of June, 1991. Training was limited to two weeks because all but one of six crew chiefs were a returnee from the previous year. This training was conducted at the U.S. EPA Environmental Research Laboratory-Narragansett, RI (ERL-N) and focused mainly on the sampling methods, with emphasis placed on the electronic measurements and the computer system. Crew chief training was conducted by SAIC and CSC (Computer Sciences Corporation) personnel with oversight by EPA ERL-N staff.

Crew training was held from 17 June to 19 July 1991. Both safety and sampling methods were important components of training. Crew training was broken into two phases: formal training which lasted for approximately 2-½ weeks, and one week (per crew) of dry runs.

Dry runs consisted of four days in the field during which crews operated as they would during the sampling season. They were assigned four stations to monitor for all parameters, including DataSonde deployment and retrieval. Crews members stayed in motels, prepared samples for shipment, entered data into the field computer, and electronically transmitted all data to the Field Operations Center (FOC) just as they would during actual field operations. In addition, the Field Coordinator or the QA Coordinator visited each crew during dry runs, completing a performance review sheet to determine the crew's overall grasp of the program. All crews were deemed properly prepared to begin sampling activities on 22 July, 1991.

Certification examinations for crew chiefs and field crew members were administered at the end of each course and proved to be very useful. As a result of testing, two crew chiefs were identified as needing additional training. This coaching was provided and they were fully competent by the start of crew training. The examination administered at the end of crew training suggested some areas, such as contingencies for moving stations, were not adequately covered, so additional time was spent discussing these topics prior to dry runs.

4.2 FIELD DATA AND SAMPLE COLLECTION - QUALITY CONTROL CHECKS

Several measures were taken during the 1991 field season to assure the quality of the data collected. These consisted of QC checks, the collection of QC samples, and performance reviews by senior Program personnel (QA Coordinator or Field Coordinator).

4.2.1 Water Quality Measurements

Generally the first activity performed at each station was to obtain a vertical profile of the water column for key parameters. The instrument chosen for this operation was the SeaBird SBE 25 SeaLogger CTD. This instrument is generally regarded as a very sensitive, accurate and reliable device. All CTDs were calibrated according to manufacturers instructions at the EMAP-VP calibration facility just before the field season began. The procedures for calibration and checks are described in the 1991 Quality Assurance Project Plan (Valente and Schoenherr, 1991).

Field QC checks on the performance of the CTD fell into two categories: daily and weekly. The daily check consisted of taking duplicate bottom measurements with a YSI Model 58 dissolved oxygen meter (instrument air calibrated at each station), a refractometer (salinity), and thermometer (temperature) at every station. Acceptable differences are listed in Valente and Schoenherr (1991). It is worth noting that the salinity values produced by the CTD are expected to be much more accurate than those from the refractometer, and are more accurate than is required by EMAP. The refractometer only provided a "gross" check to determine if there was an electrical problem with the CTD's conductivity sensor; it provided no information about gradual drift. If the instrument "failed" QC, the cast was repeated. If it failed on the second attempt, the cast was saved but flagged. Of the 134 casts for which separate dissolved oxygen measurements were successfully obtained with the YSI meter, 98.5% "passed" QC, showing differences of $\leq$ 1 mg/L. Eighty six percent of the bottom CTD DO values differed from the YSI by $\leq$ 0.5 mg/L. All temperatures and salinities passed QC.

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

Following this check of the YSI meter, the CTD was immersed in water and the DO, temperature, and salinity compared with values obtained from the YSI, thermometer, and refractometer respectively. The unit was brought back on the deck and the pH probe immersed in a pH 10 standard for comparison (pH 10 was used instead of pH 7 because the instrument defaults to a reading of 7 when malfunctioning). If the unit failed for any variable it was returned to the Field Operations Center for recalibration. A total of 27 checks were performed during the field season, with all meeting the criteria for acceptance, and only 3 of the 27 resulting in dissolved oxygen differences of more than 0.5 mg/L.

In addition to the CTD cast, Hydrolab DataSonde 3 dataloggers were deployed at all Base Sampling Sites to collect continuous dissolved oxygen data. Each unit was calibrated and checked prior to deployment as described in the 1991 Virginian Province Field Operations and Safety Manual (Strobel and Schimmel, 1991b). Upon retrieval an additional check was performed; immersing the DataSonde in a bucket of water and comparing the dissolved oxygen, salinity, and temperature values to a YSI Model 58 DO meter, refractometer, and thermometer respectively. Salinity and temperature passed QC in all cases. Of the 105 successful retrievals, 98 (93%) met the acceptability criteria for DO (1 mg/L). Seventy nine percent showed differences of 0.5 mg/L or less. Differences between the DO values were generally attributed to fouling of the DataSonde 3's DO probe.

4.2.2 Benthic Indicators

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

Crews were observed closely during field performance reviews to ensure that standard protocols were being followed for all benthic sampling. Laboratory QA measures are described below in Section 4.3.

In addition to the infaunal samples, sediment was collected for chemical analysis, toxicity testing, and grain size determination. Additional QC samples were collected for chemistry at one station per crew. A second duplicate sample was removed from the homogenate, and a "blank" bottle was left open whenever the sample was exposed to the atmosphere. The purpose of the blank was to determine if atmospheric contamination was a significant problem. Additional analytical measures are described in Section 4.4. Grain size and toxicity QA results are discussed in Section 4.3.

4.2.3 Fish Indicators

The two fish indicators for which field data, as opposed to samples, were collected were fish community structure and gross external pathology. The QA Project Plan (Valente and Schoenherr, 1991) called for QA samples to be collected for both of these indicators.

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

Three types of errors were detected: misspelled or incomplete species names (in the database), misidentifications, and fish that could not be identified in the field. Errors falling into the first category were easily detected, corrected in the database, and documented. An example of this type of error can be found looking at the "Atlantic tomcod". Records were received from the field for "Atlantic tomcod", "tomcod", and "tom cod" (two words). Each was listed by the computer as separate species.

The second type of error was mis-identifications. Of the 187 fish sent in for taxonomic verification, 14 were misidentified, representing 9 species. In all cases the crew identified a closely-related species, such as longspine porgy instead of scup, brown bullhead catfish instead of the yellow bullhead, and lizardfish instead of inshore lizardfish. An additional 14 individuals (5 species) were sent in as unknowns or partial unknowns (*e.g.*, herring uncl.).

The total of 28 incomplete identifications or misidentifications represent 51 fish records in the database (including other fish of the same species caught in the same trawl). A total of 7,134 fish were collected in standard trawls during the 1991 field season representing 69 species. The percentage of errors detected was therefore less than one percent.

Crews examined all individuals of the 10 target species collected for evidence of gross external pathologies. To verify each crew's ability to properly identify pathologies, fish identified as having an external pathology by the field crews were shipped to ERL-N for verification by the laboratory's pathologist. This provided an estimate of the percentage of "false positives". In addition, in order to develop an estimate of the rate of "false negatives" (*i.e.*, number of pathologies missed, therefore never sent in for verification), crews collected and shipped up to 25 individuals of each target species (which they determined to be free from external pathologies) caught at Indicator Testing and Evaluation stations.

Results of laboratory examinations reveal that the crews were generally conservative, classifying "borderline" conditions as pathologies so the fish would be examined by an expert rather than being discarded. Of the 12 fish sent in for verification of a pathology (four additional fish were not shipped), only five were verified by the pathologist. Of the 183 "reference" fish shipped, the pathologist determined that four did have a pathology, but in all cases the pathology was some form of discoloration which is difficult for a novice to determine. Fin erosion was not included in these statistics as damage was incurred due to the method of shipping fish (packaged in mesh onion bags) prohibiting accurate examinations by the laboratory staff.

4.2.4 Field Performance Reviews

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

The only problem noted was the determination of the depth of the apparent Redox Potential Discontinuity (RPD). This measurement was determined to be too subjective, variable, and difficult to accurately measure based on a visual inspection of a clear plexiglass core taken from a grab sample. Although reasonable measurements could be made in muddy sands, the majority of the sediments encountered by field crews were fine grained muds where adhesion to the plexiglass core creates too much smearing to allow for an accurate measurement. Therefore, RPD data are not reported in this document and will not be used in the assessment of condition of the Province.

4.3 LABORATORY TESTING AND ANALYSIS

Quality control requirements for laboratory testing and sample analysis are covered in detail in the 1991 EMAP-VP QA Project Plan (Valente and Schoenherr, 1991) and the EMAP-E Laboratory Methods Manual (U.S. EPA, 1991) and will not be reiterated here. All laboratories were required to perform QA activities, and the results of those activities will be discussed in this report. Because of the complexity of chemical analyses, QA results for those analyses are listed separately in Section 4.4.

4.3.1 Sediment Toxicity Testing

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

As per the QA Project Plan, the laboratory was required to maintain a control chart for toxicity testing using a reference toxicant. The ETC used SDS (sodium dodecyl sulfate) as their reference material, running a standard 48-hour water-only toxicity test with SDS whenever EMAP samples were run. The control chart shows that the LC50 for SDS ranged from 4.0 to 8.37 mg/L, with all values falling within two standard deviations of the mean as required in the QA Plan. In addition to maintaining a control chart and making it available for review at any time, a QA audit of the facility was performed in September, 1991. The results of the audit showed the staff at the ETC to be cognizant of all QA concerns, and that no remedial action was required.

Several tests failed to meet EMAP QA requirements for control organism survival. Of the 19 tests run, 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 and were not included in the data set utilized to generate this statistical summary.

4.3.2 Grain Size Analysis

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

4.3.3 Benthic Infauna Analysis

Two QA steps were required by the EMAP-VP 1991 QA Project Plan: 10% recounts and independent verification of species identification. The recounts (multiple types - see Table 4-1) and preliminary species verification were performed by the laboratory performing the analyses. All of these met the requirements established in the QA Plan. Definitive verification of species identification was performed by an independent laboratory and the results are described below.

Table 4-1. Results of recounts performed by the laboratory processing benthic infauna samples. Approximately 10% of all samples were processed in duplicate.

Measurement	Mean Error	Range of Error
Benthic sorting	4.5%	0 - 20.5%
Species identification and enumeration	2.4%	0 - 14%
Biomass	0.13%	0 - 1.6%
Weighing blanks for biomass	0.0001g	0 - 0.0023g

A total of 137 specimens collected from oligohaline stations were sent to the Aquatic Resources Center in Franklin, TN for independent taxonomic verification. Eleven (8%) were mis-identified, representing 8 species. The identification of an additional 15 specimens could not be confirmed because of the condition of the specimen (*i.e.*, key taxonomic features missing or destroyed, or male needed for identification and only females sent).

The identification of many of these species is difficult. Misidentified species were closely related taxonomically to the "true" species. In general, the report on species verification was "largely favorable" indicating the analytical laboratory performed well. Suggestions will be made regarding identification of tubificid oligochaetes and molluscs prior to the next season.

4.4 LABORATORY CERTIFICATION AND CHEMICAL ANALYSIS

EMAP-E requires that analytical laboratories participate in an extensive certification process prior to the analysis of any EMAP-E chemistry samples. This certification is in addition to normal quality control measures that are required during analysis to ensure quality data (*i.e.*, blanks, spikes, controls, duplicates, etc.). Standard Reference Materials (SRMs) with known or certified values for metals and organic compounds were used by the Virginian Province laboratories conducting analyses to confirm the accuracy and precision of their analyses. Many of the SRMs used extensively in the EMAP-E program are naturally-occurring materials (*e.g.*, marine sediments or oyster tissue) in which the analytes of interest are present at levels that are environmentally realistic, and for which analyte concentrations are known with reasonable certainty. The certification results for the laboratory conducting the sediment analyses can be found in Table 4-2. Fish certification results are presented in Table 4-3.

The 1991 Virginian Province QA Project Plan (Valente and Schoenherr, 1991) lists warning and control limit criteria for the analysis of Certified (or Standard) Reference Materials. The more conservative warning limit for all organics is stated to be "Lab's value should be within ± 25% of true value on average for all analytes; not to exceed ± 30% of true value for more than 30% of individual analytes for each batch". Both laboratories' performance during certification resulted in permission being granted for the analysis of samples to begin.

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

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

Table 4-2. Results of certification analysis for sediment contaminants performed by EMSL-Cinn. The Reference Material for the organics certification was NIST SRM 1941. The SRM for inorganics was the National Research Council of Canada BCSS-1 CRM. For organic analyses, only those analytes with certified values at least 10x the detection limit are included.

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

(continued)

Table 4-2 continued.

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

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

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

4.5 DATA MANAGEMENT

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

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

Table 4-3. Results of certification analysis for fish contaminants performed by Texas A&M University. The Reference Material for the organics certification was NIST SRM 1974. The SRM for inorganics was the NIST SRM 1566a.

Analyte	Certified Concentration	Measured Concentration
Inorganics (μg/g dry weight)		
Al	202.5	181.0
As	14.0	13.1
Cd	4.15	4.02
Cr	1.43	1.49
Cu	66.3	63.6
Fe	539	533
Ni	2.25	2.25
Pb	0.371	0.36
Se	2.21	2.20
Sn	3[1]	2.22
Zn	830	807
Organics (PCBs/pesticides - ng/g dry weight)		
PCB 18	24 ± 9[1]	20.9
PCB 28	62 ± 3[1]	85.2
PCB 44	65 ± 23[1]	72.4
PCB 52	98 ± 39[1]	113.7
PCB 66	110 ± 5[1]	98.7
PCB 101	105 ± 11[1]	127.0
PCB 105	45 ± 3[1]	46.9
PCB 118	110 ± 5[1]	115.9
PCB 128	15 ± 2[1]	17.3
PCB 138	110 ± 11[1]	122.2
PCB 153	145 ± 8[1]	153.9
PCB 180	13 ± 1[1]	13.3
PCB 187	30 ± 1[1]	27.2

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

Results of the checks described above showed a value error rate of <3%. The rate of record errors was approximately 10%, with most of these (76%) being from the fish data set. The major problem with the field computer system used in 1991 was the difficulty of entering and editing fish data. This resulted in the relatively large number of record errors (missing or duplicate records). This component of the field system was significantly modified for 1992 to reduce the error rate.

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

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

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

4.6 REPORTING

To ensure the data summaries presented in this document accurately reflect the data, the analyses were validated by duplication. Two separate analysts developed the cumulative distribution functions reported in Section 3. The two analysts worked from the same data base but developed the analysis programs separately for two indicators. In both instances the resulting estimates matched one another. Bar charts were checked in a similar fashion. Such checks were deemed necessary because of the complexity of the calculation of percent area and 95% confidence intervals.

SECTION 5

SUMMARY OF FINDINGS

Thousands of pieces of information on the condition of estuarine resources in the Virginian Province in 1991 were collected and analyzed. The major findings of the 1991 study year are highlighted in this section.

5.1 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 tidal rivers, 2,602 km^2.

- The large estuary class includes Chesapeake Bay (main stem plus lower Potomac River), Delaware Bay, Long Island Sound, Block Island Sound, Buzzard's Bay, Narragansett Bay, and Nantucket Sound.

- The tidal river class includes, the James, Rappahanock, Potomac, Delaware, and Hudson Rivers.

- The small estuary class includes 144 estuarine systems of various types between 2.6 and 260 km^2 in area of which 29 were sampled in 1991.

5.2 Findings of the 1991 Sample Year

All but 1 of the 155 scheduled stations were successfully sampled. The majority of the data collected at these stations met the quality control standards set by the Program.

The incidence of gross external fish pathologies was 0.6% (16 occurrences among 2,513 fish examined) based on field observations. However, fewer than half of the pathologies identified by field crews were confirmed by a qualified pathologist.

Table 5-1 summarizes the data presented in Section 3 for selected Biotic Condition, Abiotic Condition, and Habitat indicators.

Table 5-1. Percent area of the Virginian Province (with 95% confidence intervals) above or below values of interest for biotic and abiotic condition indicators.

	Percent area			
Estuarine Condition	Province	Large Estuary	Large Tidal River	Small Estuary
Benthic Index				
<0	14 ± 6	6 ± 7	27 ± 14	32 ± 17
Total Benthic Abundance				
≤200 / m^2	6 ± 5	2 ±4	15 ± 28	13 ± 13
Instantaneous Bottom DO				
<2 mg/l	5 ± 5	4 ± 6	15 ± 28	1 ± 2
<5 mg/l	18 ± 8	17 ± 10	18 ± 28	21 ± 13
Sediment Toxicity (% control survival)				
<80%	21 ± 10	24 ± 13	10 ± 7	19 ± 14
Marine Debris				
presence	18 ± 8	12 ± 9	16 ± 38	35 ± 17
Enriched metals				
any metal above background	41 ± 10	35 ± 14	51 ± 23	53 ± 22
Salinity				
Polyhaline (>18 ‰)	63 ± 10	79 ± 11	0 ± 0	42 ± 16
Mesohaline (5 to 18 ‰)	30 ± 10	21 ± 11	55 ± 34	47 ± 16
Oligohaline (< 5 ‰)	7 ± 3	0 ± 0	45 ± 18	11 ± 11

SECTION 6

REFERENCES

Adelman, D., K.R. Hinga, and M.E.Q. Pilson. 1990. Biogeochemistry of butyltins in an enclosed marine ecosystem. *Environ. Sci. Technol.* 24: 1027-1032.

Akapati, B.N. 1974. Mineral composition and sediments in eastern Long Island Sound. *Maritime Seds.* 10: 19-30.

ASTM (American Society of Testing and Materials). 1991. Standard guide for conducting 10-day static sediment toxicity tests with marine and estuarine amphipods. *Annual Book of ASTM Standards Volume 11.04*:1052-1075.

Ballschmiter , K. and M. Zell. 1980. Analysis of polychlorinated biphenyls (PCBs) by glass capillary gas chromatography. *Fresenius Z. Anal. Chem.* 302: 20-31.

Bell, S. and B.C. Coull. 1978. Field evidence that shrimp predation regulates meiofauna. *Oecologia* 35:141-148.

Bilyard, G.R. 1987. The value of benthic infauna in marine pollution monitoring studies. *Mar. Poll. Bull.* 18:581-585.

Boesch, D.F. and R. Rosenberg. 1981. Response to stress in marine benthic communities. In: G.W. Barret and R. Rosenberg, eds., pp. 179-200. *Stress Effects on Natural Ecosystems.* New York: John Wiley and Sons.

Carriker, M.R. 1967. Ecology of estuarine benthic invertebrates: A perspective. In: G.H. Lauff, ed., pp. 442-487. *Estuaries*, Publ. No. 83. Washington, DC: American Association for the Advancement of Science.

Chao, L.N. and J.A. Musick. 1977. Life history, feeding habitats, and functional morphology of juvenile sciaenid fishes in the York River estuary. *Fishery Bull.* 75:657-702.

Cloern, J.E. 1982. Does the benthos control phytoplankton biomass in South San Francisco Bay? *Mar. Ecol. Prog. Ser.* 9:191-202.

Cochran, W. G. 1977. *Sampling Techniques.* 3rd edition. John Wiley, New York.

Dearth, M.A. and R.A. Hites. 1991. Complete analysis of technical chlordane using negative ionization mass spectrometry. *Environ. Sci. Technol.* 25: 245-254.

DiToro, D.M., J.D. Mahony, D.J. Hansen, K.J. Scott, M.B. Hicks, S.M. Mayr, and M.S. Redmond. 1990. Toxicity of cadmium in sediments: The role of acid volatile sulfide. *Environ. Toxicol. and Chem.* 9:1487-1502.

DiToro, D.M., C.S. Zarba, D.J. Hansen, W.J. Berry, R.C. Swartz, C.E. Cowan, S.P. Pavlou, H.E. Allen, N.A. Thomas, and P.R. Paquin. 1991. Techinical basis for establishing sediment quality criteria for nonionic organic chemicals using equilibrium partitioning. *Environ. Toxicol. and Chem.* 10:1541-1583.

Ernst, W. 1984. Pesticides and technical organic chemicals. In: Otto Kinne ed., pp. 1627-1709. *Marine Ecology.* New York: John Wiley & Sons.

Forstner, U. and G.T.W. Wittmann. 1981. *Metal pollution in the aquatic environment.* 2nd revised edition. New York: Springer-Verlag.

Gebhart, J.E., T.L. Hayes, A.L. Alford-Stevens, and W.L. Budde. 1985. Mass spectrometric determination of polychlorinated biphenyls as isomer groups. *Anal. Chem.* 57: 2458-2463.

Gordon, R.B. 1980. The sedimentary system of Long Island Sound. *Advances in Geophysics* 22: 1-39.

Hanson, P.J., D.W. Evans, D.R. Colby, and V.S. Zdanowicz. 1993. Assessment of elemental contamination in estuarine and coastal environments based on geochemical and statistical modeling of sediments. *Mar. Environ. Res.* (in press).

Heard, C.S., W.W. Walker, and W.E. Hawkins. 1989. Aquatic toxicological effects of organotins: An overview. *Proceedings,* pp. 554-563. Oceans '89 Conference and Exposition on Science and Engineering. Washington, DC: Institute of Electrical and Electronics Engineers.

Hinga, K.R. 1988. Seasonal predictions for pollutant scavenging in two coastal environments using a model calibration based upon thorium scavenging. *Mar. Environ. Res.* 26:97-112.

Hobbs, C.H., III, J.P. Halka, R.T. Kerhin, and M.J. Carron. 1992. Chesapeake Bay sediment budget. *J. Coast. Res.* 8(2): 292 - 300.

Holland, A.F., ed. 1990. *Near Coastal Program Plan for 1990: Estuaries.* EPA 600/4-900/033. Narragansett, RI: U.S. Environmental Protection Agency, Environmental Research Laboratory, Office of Research and Development.

Holland, A.F., A.T. Shaughnessy, L.C. Scott, V.A. Dickens, J.A. Ranasinghe, and J.K. Summers. 1988. *Progress report: Long-term benthic monitoring and assessment program for the Maryland portion of Chesapeake Bay (July 1986-October 1987).* PPRP-LTB/EST-88-1. Prepared for Maryland Power Plant Research Program and Maryland Department of the Environment, Office of Environmental Programs. Columbia, MD: Versar, Inc., ESM Operations.

Holland, A.F., A.T. Shaughnessy, L. C. Scott, V.A. Dickens, J. Gerritsen, and J.A. Ranasinghe. 1989. *Long-term benthic monitoring and assesssment program for the Maryland portion of Chesapeake Bay: Intepretive report.* Columbia, MD: Versar, Inc. for Maryland Department of Natural Resources, Power Plant Research Program. CBRM-LTB/EST-2.

Huggett, R.J., M.A. Unger, P.F. Seligman, and A.O. Valkirs. 1992. The marine biocide tributyltin. *Environ. Sci. Technol.* 26: 232-237.

Hunsaker, C. and D. Carpenter, eds. 1990. *Ecological indicators for the Environmental Monitoring and Assessment Program*. Research Triangle Park, NC: U.S. Environmental Protection Agency, Office of Research and Development. EPA 600/3-90/060.

Hutzinger, O., S. Safe, and V. Zitko. 1974. *The Chemistry of PCBs*. Cleveland, OH: CRC Press. 269pp.

Karr, J.R. and D.R. Dudley. 1981. Ecological perspective on water quality goals. *Environ. Manage.* 5:55-68.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser. 1986. *Assessing biological integrity in running waters: a method and its rationale.* Special Publication 5. Champaign, IL: Illinois Natural History Survey.

Kemp, W.M. and W.R. Boynton. 1980. Influence of biological and physical processes on dissolved oxygen dynamics in an estuarine system: Implications for measurements of community metabolism. *Estuarine and Coastal Mar. Sci.* 11:407-431.

Kemp, W.M. and W.R. Boynton. 1981. External and internal factors regulating metabolic rates of an estuarine benthic community. *Oecologia* 51:19-27.

Knapp, C.M., D.R. Marmoreck, J.P. Baker, K.W. Thornton, J.M. Klopateck, and D.F. Charles. 1990. *The indicator development strategy for the Environmental Monitoring Assessment Program.* Washington, DC: U.S. EPA Office of Research and Development, EPA 600/3-91/023.

Laflamme, R.E. and R.A. Hites. 1978. The global distribution of polycyclic aromatic hydrocarbons in recent sediments. *Geochimica et Cosmochimica Acta* 42: 289-303.

Lake, J.L., C. Norwood, C. Dimock, and R. Bowen. 1979. Origins of polycyclic aromatic hydrocarbons in estuarine sediments. *Geochimica et Cosmochimica Acta* 43: 1847-1854.

Long, E.R. and L.G. Morgan. 1990. The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program. NOAA Technical Memorandum NOS OMA 52. Rockville, MD: US Departement of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service.

McFarland, V.A. and J.U. Clarke. 1989. Environmental occurrence, abundance, and potential toxicity of polychlorinated biphenyl congeners: Considerations for a congener-specific analysis. *Environ. Health Perspectives* 81: 225-239.

Messer, J.J. 1990. EMAP Indicator Concepts. In: C.T. Hunsaker and D.E. Carpenter, eds., *Ecological Indicators for the Environmental Monitoring and Asssessment Program.* EPA 600/3-90/060. Research Triangle Park, NC: U.S. Environmental Protection Agency, Office of Research and Development.

Mullin, M.D., C.M. Pochini, S. McCrindle, M. Romkes, S.H. Safe, and L.M. Safe. 1984. High-resolution PCB analysis: Synthesis and chromatographic properties of all 209 PCB congeners. *Environ. Sci. Technol.* 18: 468-476.

Nauen, C.E. 1983. *Compilation of legal limits for hazardous substances in fish and fishery products.* FAO Fisheries Cricular No. 764. Rome, Italy: Food and Agriculture Organization of the United Nations. 102 pp.

Nixon, S.W., C.D. Hunt, and B.L. Nowicki. 1986. The retention of nutrients (C,N,P), heavy metals (Mn, Cd, Pb, Cu), and petroleum hydrocarbons in Narragansett Bay. In: P. Lasserre and J.M. Martin, eds., pp. 99-122. *Biogeochemical Processes at the Land-sea Boundary.* New York: Elsevier.

Officer, C.B., T.J. Smayda, and R. Mann. 1982. Benthic filter feeding: A natural eutrophication control. *Mar. Ecol. Prog. Ser.* 9:203-210.

Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. Mar. Biol. Ann. Rev.* 16:229-311.

Plumb, R.H. 1981. *Procedure for handling and chemical analysis of sediment and water samples.* Technical Report EPA/CE-81-1. Prepared for the U.S. Environmental Protection Agency/Corps of Engineers Technical Committee on Criteria Dredge and Fill Material. Vicksburg, MS: Environmental Laboratory, U.S. Army Waterways Experiment Station.

Rexrode, M. 1987. Ecotoxicity of tributyltin. *Proceedings*, pp. 554-563. Oceans '87 Conference and Exposition on Science and Engineering. Washington, DC: Institute of Electrical and Electronics Engineers.

Rhoads, D.C. 1974. Organism-sediment relations on the muddy sea floor. *Oceanogr. Mar. Biol. A. Rev.* 12:263-300.

Rhoads, D.C., P.L. McCall, and J.Y. Yingst. 1978. Disturbance and production on the estuarine sea floor. *Amer. Sci.* 66:577-586.

Rosen, J.S., J. Beaulieu, M. Hughes, H. Buffum, J. Copeland, R. Valente, J. Paul, F. Holland, S. Schimmel, C. Strobel, K. Summers, K.J. Scott, and J. Parker. 1990. *Data base management system for coastal demonstration project.* EPA-600-x-90-207. Narragansett, RI: EPA Office of Research and Development. (Internal report).

Schantz, M.M., B.A. Benner, Jr., S.N. Chesler, B.J. Koster, K.E. Hehn, S.F. Stone, W.R. Kelly, R. Zeisler, and S.A. Wise. 1990. Preparation and analysis of a marine sediment reference material for the determination of trace organic constituents. *Fresenius J. Anal. Chem.* 338: 501-514.

Schimmel, S.C. 1990. *Implementation Plan for Environmental Monitoring and Assessment Program Near Coastal Demonstration Project.* Narragansett, RI: U.S. Environmental Protection Agency, Environmental Research Laboratory, Office of Research and Development.

Schropp, S.J., F.G. Lewis, H.L. Windom, J.D. Ryan, F.D. Calder, and L.C. Bumey. 1990. Interpretation of metal concentrations in estuarine sediments of Florida using aluminum as a reference element. *Estuaries* 13:227-235.

Schubel, J.R. and H.H. Carter. 1984. The estuary as a filter for the fine-grained suspended sediment. In: V.S. Kennedy, ed., pp. 81-104. *The Estuary as a Filter.* Orlando, FL: Academic Press.

Seligman, P.F., J.G. Grovhoug, A.O. Valkirs, P.M. Stang, R.Fransham, M.O. Stallard, B. Davidson, and R.F. Lee. 1989. Distribution and fate of tributyltin in the United States marine environment. *Applied Organometalic Chem.* 3: 31-47.

Stevens, D.L., Jr., A.R. Olsen, and D. White. 1991. *Environmental Monitoring and Assessment Program -- integrated sampling design.* Draft report. Corvallis, OR: Environmental Research Laboratory, U.S. Environmental Protection Agency.

Strobel, C.J. 1991. *EMAP-Estuaries 1991 Virginian Province Effort: Field Readiness Report.* Narragansett, RI: U.S. Environmental Protection Agency, Environmental Research Laboratory, Office of Research and Development, July 1991.

Strobel, C.J. and S.C Schimmel. 1991a. *Environmental Monitoring and Assessment Program EMAP-Estuaries, Virginian Province Logistics Plan for 1991.* Narragansett, RI: U.S. Environmental Protection Agency, Environmental Research Laboratory, Office of Research and Development, April 1991.

Strobel, C.J. and S.C. Schimmel. 1991b. *EMAP-Estuaries 1991 Virginian Province Field Operations and Safety Manual.* Narragansett, RI: U.S. Environmental Protection Agency, Office of Research and Development, June 1991.

Swartz R.C., W.A. DeBen, J.K. Jones, J.O. Lamberson, and F.A. Cole. 1985. Phoxocephalid amphipod bioassay for marine sediment toxicity. In: R.D. Cardwell, R. Purdy, and R.C. Bahner, eds., pp. 284-307. *Aquatic Toxicology and Hazard Assessment: Seventh Symposium.* Philadelphia, PA: American Society for Testing and Materials.

Terrell, T.T. 1979. *Physical regionalization of coastal ecosystems of the United States and its territories.* FWS/OBS-79/80. Office of Biological Services, U.S. Fish and Wildlife Service.

Turekian, K.K. 1977. The fate of metals in the oceans. *Geochimica et Cosmochimica Acta* 41:1139-1144.

U.S. EPA. 1989. *Briefing Report to the EPA Science Advisory Board on the equilibrium partioning approach to generating sediment quality criteria.* EPA 440/5-89-002. Washington, DC: U.S. EPA, Criteria and Standards Division.

U.S. EPA/ACE. 1991. *Evaluation of dredged material proposed for ocean disposal (Testing manual).* Prepared by the U.S. Environmental Protection Agency, Office of Marine and Estuarine Protection and Department of the Army, United States Army Corps of Engineers, February 1991.

U.S. EPA. 1991. *EMAP Laboratory Methods Manual: Estuaries.* Cincinnati, OH: U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Office of Research and Development.

U.S. EPA. 1993a. *Proposed Sediment Quality Criteria for the Protection of Benthic Organisms: Acenaphthene.* Washington DC: U.S. Environmental Protection Agency, Office of Science and Technology. In Preparation.

U.S. EPA. 1993b. *Proposed Sediment Quality Criteria for the Protection of Benthic Organisms: Phenanthrene.* Washington DC: U.S. Environmental Protection Agency, Office of Science and Technology. In Preparation.

U.S. EPA. 1993c. *Proposed Sediment Quality Criteria for the Protection of Benthic Organisms: Fluoranthene.* Washington DC: U.S. Environmental Protection Agency, Office of Science and Technology. In Preparation.

U.S. EPA. 1993d. *Proposed Sediment Quality Criteria for the Protection of Benthic Organisms: Dieldrin.* Washington DC: U.S. Environmental Protection Agency, Office of Science and Technology. In Preparation.

U.S. FDA. 1982. *Levels for poisonous or deleterious substances in human food and animal feed.* Washington, DC: U.S. Food and Drug Administration. 13pp.

U.S. FDA. 1984. *Polychlorinated biphenyls (PCBs) in fish and shellfish; reduction of tolerances; final decision.* Rockville, MD: U.S. Food and Drug Administration. Federal Register 49: 21514 - 21520.

Valente, R. and J. Schoenherr. 1991. *EMAP-Estuaries Virginian Province Quality Assurance Project Plan.* Narragansett, RI: U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory. July 1991.

Warwick, R.M. 1980. Population dynamics and secondary production in benthos. In: K.R. Tenore and B.C. Coull, eds., *Marine Benthic Dynamics*, Belle W. Baruch Library in Science Number 11. Columbia, SC: University of South Carolina Press.

Weisberg, S.B., J.B. Frithsen, A.F. Holland, J.F. Paul, K.J. Scott, J.K. Summers, H.T. Wilson, R.Valente, D.G. Heimbuch, J. Gerritsen, S.C. Schimmel, and R.W. Latimer. 1993. *EMAP-Estuaries, Virginian Province 1990 Demonstration Project Report.* EPA/620/R-93/006. Narragansett, RI: U.S. Environmental Protection Agency, Environmental Research Laboratory, Office of Research and Development.

Wells, J.T. and S-Y. Kim. 1991. The relationship between beam transmission and concentration of suspended particulate material in the Neuse River Estuary, North Carolina. *Estuaries* 14(4):395-403.

Welsh, B.L. and F.C. Eller. 1991. Mechanisms controlling summertime oxygen depletion in Western Long Island Sound. *Estuaries* 14:265-278.

Windom, H.L., S.J. Schropp, F.D. Calder, J.D. Ryan, R.G. Smith, L.C. Bumey, F.G. Lewis, and C.H. Ralinson. 1989. Natural trace metal concentrations in estuarine and coastal marine sediments of the southeastern United States. *Environ. Sci. Technol.* 23:314-320.

Windsor, J.G., Jr. and R.A. Hites. 1979. Polycyclic aromatic hydrocarbons in Gulf of Maine sediments and Nova Scotia soils. *Geochimica et Cosmochimica Acta* 43: 27-33.