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Assessment of the Ecological Condition of the Delaware and Maryland Coastal Bays

J.C. Chaillou
S.B. Weisberg
Versar, Inc.
Columbia, MD 21045

F.W. Kutz
T.E. DeMoss
U.S. Environmental Protection Agency
Annapolis, MD 21401

L. Mangiaracina
U.S. Environmental Protection Agency
Region III
Philadelphia, PA 19107

R. Magnien
Maryland Department of Natural Resources
Annapolis, MD 21401

R. Eskin
Maryland Department of the Environment
Baltimore, MD 21224

J. Maxted
Delaware Department of Natural Resources and Environmental Control
Dover, DE 19903

K. Price
College of Marine Sciences
University of Delaware
Lewes, DE 19958

J.K. Summers
U.S. Environmental Protection Agency
Gulf Breeze, FL 32561-5299

FOREWORD

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Data requests should be submitted to Dr. R. Kutz at the U.S. Environmental Protection Agency, Region III, Annapolis, MD.

Phone: (410) 573-6842

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EXECUTIVE SUMMARY

The coastal bays of Delaware and Maryland are an important ecological and economic resource whose physical characteristics and location make them particularly vulnerable to the effects of pollutants. This project was undertaken as a collaborative effort between state and federal agencies to assess the ecological condition of this system and fill a data void identified in previous characterization studies. Two hundred sites were sampled in the summer of 1993 using a probability-based sampling design that was stratified to allow assessments of the coastal bays as a whole, each of four major subsystems within coastal bays (Rehoboth Bay, Indian River Bay, Assawoman Bay, and Chincoteague Bay) and four target areas of special interest to resource managers (upper Indian River, St. Martin River, Trappe Creek, and dead-end canals). Measures of biological response, sediment contaminants, and eutrophication were collected at each site using the same sampling methodologies and quality assurance/quality control procedures used by EPA's Environmental Monitoring and Assessment Program (EMAP). As an additional part of the study, trends in fish communities structure were assessed by collecting monthly beach seine and trawl measurements during the summer at about 70 sites where historic measurements of fish communities have been made.

Major portions of the coastal bays were found to have degraded environmental conditions. Twenty-eight percent of the area in the coastal bays had degraded benthic communities, as measured by EMAP's benthic index. More than 75% of the area in the coastal bays failed the Chesapeake Bay Program's Submerged Aquatic Vegetation (SAV) restoration goals, which are a combination of measures that integrate nutrient, chlorophyll, and water clarity parameters. Most areas failed numerous SAV goal attributes. Sixty-eight percent of the area in the coastal bays had at least one sediment contaminant with concentrations exceeding published guidelines for protection of benthic organisms. Further study is needed to assess whether the biological effects observed were the direct result of contamination.

Within the coastal bays, Chincoteague Bay was in the best condition of the four major subsystems, while Indian River was the worst. Only 11% of the area in Chincoteague Bay had degraded benthos compared to 77% in Indian River. Less than 10% of the area in Indian River met the Chesapeake Bay SAV Restoration Goals. In comparison, almost 45% of the area in Chincoteague Bay met the Chesapeake Bay Program's SAV restoration goals, a figure which increased to almost 85% when only the most controllable components of the goals (nutrient and chlorophyll) were considered.

All of the target areas of special management interest were in poorer condition than the remainder of the coastal bays, with dead-end canals having the poorest condition. Chemical contaminants exceeded published guideline values in 91% of the area of the dead-end canals, and 57% of their area had dissolved oxygen concentrations less than the state standard of 5 ppm. Dead-end canals also were biologically depauperate, averaging only 4 benthic species per sample compared to 26 species per sample in the remaining portions of the coastal bays.

The consistency of the sampling design and methodologies between our study and EMAP allows unbiased comparison of conditions in the coastal bays with that in other major estuarine systems in EPA Region III that are sampled by EMAP. Based on comparison to EMAP data collected between 1990 and 1993, the coastal bays were found to have a similar or higher frequency of degraded benthic communities than in Chesapeake or Delaware Bays. Twenty-eight percent of the area in the coastal bays had degraded benthic communities as measured by EMAP's benthic index, which was significantly greater than the 16% EMAP estimated for Delaware Bay using the same methods and same index, and statistically indistinguishable from the 26% estimated for Chesapeake Bay. The coastal bays also had a prevalence of chemical contamination in the sediments that was higher than in either Chesapeake Bay or Delaware Bay. Sixty-eight percent of the area in the coastal bays exceeded published guideline values for at least one contaminant compared to 46% for Chesapeake Bay and 34% for Delaware Bay. While the percent of area having these concerns is higher in the coastal bays, the absolute amount of area having these concerns is greater in the Delaware and Chesapeake Bays because of their larger size.

The fish community structure in Maryland's coastal bays was found to have remained relatively unchanged during the past twenty years while that of similar systems in Delaware have changed substantially. Fish communities of the Maryland coastal bays are dominated by Atlantic silversides, bay anchovy, Atlantic menhaden, and spot, which is similar to the community structure measured in the Delaware coastal bays 35 years ago. The fish fauna in Delaware's coastal bays has shifted toward species of the Family Cyprinodontidae (e.g., killifish and sheepshead minnow) which are more tolerant to low oxygen stress, and salinity and temperature extremes.

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Leonard Mangiaracina	
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John Maxted Bennett Anderson	Delaware Department of Natural Resources and Environmental Control
Richard Eskin Robert Magnien	Maryland Department of the Environment
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Kent Price	University of Delaware, Delaware Inland Bays Estuary Program

1.0 INTRODUCTION

1.1 THE COASTAL BAYS JOINT ASSESSMENT: BACKGROUND AND RATIONALE

The coastal bays formed by the barrier islands of Maryland and Delaware are important ecological and economic resources. The coastal bays are spawning and nursery areas for more than 100 species of fish, almost half of which are of commercial or recreational value. The bays are surrounded by an extensive network of tidal wetlands that contributes to and sustains this nursery and many other functions. The coastal bays also provide important habitat for migratory birds; the bays are part of the Atlantic flyway, one of four major migratory routes in the United States. For these reasons, both the coastal bays of Delaware and Maryland are included in the National Estuary Program.

The coastal bays are also an important economic resource. More than 10 million people visit the Delmarva Peninsula annually. The primary recreational attractions of the region are boating, swimming, and fishing, with more than a half-million user-days of recreational fishing each year (Seagraves 1985). The coastal bays also support commercial fisheries for hard clams, blue crabs, sea trout, and several other species of fish. The total economic return from recreational and commercial activities associated with the coastal bays is estimated to exceed 3 billion dollars, and the bays support almost 50,000 jobs.

The physical characteristics and location of the coastal bays make them particularly vulnerable to the effects of pollutants. The bays are mostly land-locked and have few outlets to the ocean. This, combined with a relatively limited volume of freshwater inflow, results in a low flushing rate (Pritchard 1960), and makes them susceptible to concentration of pollutants (Quinn et al. 1989). Water quality data suggest that several tidal creeks supplying the coastal bay's limited freshwater inflow are eutrophied (ANSP 1988), largely as a result of nutrient enrichment from surrounding agricultural lands (Ritter 1986), thereby enhancing this concern. Steady population increases in the watershed add to the future concerns for this resource; an increase of almost 20% by the year 2000 is expected for the Maryland portion alone (Andriot 1980).

A first step in developing management strategies for these systems is to characterize their present condition and describe how it has changed over time. Two recent efforts have attempted to characterize the condition of the coastal bays for that purpose (Boynton et al. 1993, Weston 1993), but both of these assessments noted that the amount of data available for the system was limited. The available data were generally collected more than a decade ago and usually represented a limited number of collection sites confined to areas perceived to have pollution problems. The system-wide information necessary to characterize the spatial extent of any problems has never been collected.

An important part of such an assessment is characterizing biological responses to environmental problems, since protecting these resources is the focus of management actions and biological data are particularly lacking in the coastal bays. The most comprehensive data for characterizing benthic invertebrate condition of the coastal bays comes from a 20-year-old survey of a single system (Maurer 1977) and that survey was used almost exclusively to describe species distributions, not to evaluate the ecological condition of the bays. Recent fish surveys are available for Maryland's coastal bays (Casey et al. 1993), but the last comprehensive survey of Delaware's coastal bays was conducted almost a quarter-century ago (Derickson and Price 1973).

1.2 OVERVIEW OF CBJA

The Coastal Bays Joint Assessment (CBJA) is a collaborative State and Federal effort to characterize the condition of the coastal bays of Delaware and Maryland and to fill the void identified in the previous characterization efforts. The CBJA has three major objectives:

(1) to assess the current ecological condition of the coastal bays of Delaware and Maryland;
(2) to compare the current condition of the bays with their historical condition; and
(3) to evaluate indicators and sampling design elements that can be used to direct future monitoring activities in the system.

The participants in the CBJA are the Delaware Department of Natural Resources and Environmental Control (DNREC), the Maryland Department of the Environment (MDE), the Maryland Department of Natural Resources (MDNR), EPA Region III, the Delaware Inland Bays Estuary Program (DIBEP), and EPA's Office of Research and Development. The CBJA was initiated as a multi-state effort with the recognition that the stresses on these systems, and thus the management actions necessary for their protection, are similar across state boundaries. The CBJA focuses on assessing condition of the coastal bays as a whole, for each of four major subsystems within the coastal bays (Rehoboth Bay, Indian River Bay, Assawoman Bay, and Chincoteague Bay) and four areas of special concern to resource managers (upper Indian River, St. Martin River, Trappe Creek, and dead-end canals).

In 1993, the CBJA initiated a comprehensive field survey of the coastal bays in which data were collected at 200 sites. The data collection approaches used in the survey borrowed heavily from methodologies developed by EPA's Environmental Monitoring and Assessment Program (Weisberg et al. 1993) and were predicated on three general principles. First, data were collected using a probability-based sampling design. A probability-based sampling design ensures unbiased estimation of condition, which is not possible when sampling sites are preselected by the investigator, and ensures that all areas within the system are potentially subject to sampling. The probability based sampling design also allows calculation of confidence intervals around estimates of condition. Confidence intervals provide managers with full knowledge of the strength or weakness of the data upon which their decisions will be based. Another advantage of the probability-based sampling design is that it allows investigators to estimate the actual area (i.e., number of acres) throughout the system in which ecological conditions differ from reference areas. This emphasis on estimating areal extent is a departure from traditional approaches to environmental monitoring, which generally estimate the average condition.

Second, the survey collocated measurements of pollution exposure with measurements of biological response, enabling examination of associations between degraded ecological condition and particular environmental stresses. Although associations do not conclusively identify the causes of degradation, associations are valuable for establishing priorities for more specific research and could contribute to developing the most efficient regional strategies for protecting or improving the environment by identifying the predominant types of stress on the system.

Third, a common set of indicators, sampling methodologies, and QA protocols were used across state boundaries. The probability-based sampling design provides a framework for integrating data into a comprehensive regional assessment; however, the validity of such an assessment depends on ensuring that all the data that contribute to it are comparable.

1.3 PURPOSE AND ORGANIZATION OF THIS REPORT

This report addresses the first objective of the CBJA. It summarizes the data collected during a 1993 sampling survey and provides a preliminary assessment of the current ecological condition of the coastal bays. Intended future analyses of the CBJA include an examination of trends in the condition of the bays using historical data, an effort to associate the ecological condition of the major bays and areas of special concern with particular patterns of land use, and an evaluation of the utility of EMAP approaches within the coastal bays.

This report includes six chapters: Methods - Chapter 2, chapters describing each of four general groups of indicators (i.e., Physical Characteristics - Chapter 3, Water Quality - Chapter 4, Sediment Contaminants - Chapter 5, Benthos - Chapter 6), and Conclusions - Chapter 7. Chapters 3 through 6 include tables of the average values of the respective indicators in the four major subsystems and the areas of special concern, figures showing the percent of area within the major subsystems and special target areas that exceeds or falls below a generally accepted threshold value (i.e., percent "degraded" area) for selected indicators, and maps showing the distribution of degraded sites for selected indicators. These chapters also compare the preliminary conclusions of the CBJA with the results of other recent characterizations of the coastal bays and with assessments of other estuaries within EPA Region III. These comparisons help to put the CBJA results into regional perspective. The report also includes three appendices: Appendix A describes the methods and results of a fish sampling effort that was conducted as an ancillary part of the present study. The fish data were placed in an appendix because they were collected using a different sampling design than what was used for the rest of the project, and because the purpose of the fish analysis was different from the rest of the report. Fish analyses focus on description of trends rather than an estimation of current status. Appendix B provides average concentrations for all sediment contaminants measured in the survey; Appendix C provides a species list of benthic macroinvertebrates collected in the coastal bays during 1993; Appendix D provides the minimum, maximum, median and quartile values of all attributes measured in the present study; Appendix E provides a data summary for a benthic survey of Turville Creek which was conducted as an ancillary part of this study.

2.0 METHODS

2.1 SAMPLING DESIGN

Sampling sites were selected using a stratified random sampling design in which the coastal bays were stratified into several subsystems for which independent estimates of condition were desired:

- upper Indian River
- Trappe Creek/Newport Bay
- St. Martin River
- dead-end canals throughout the coastal bays
- all remaining areas within Maryland's coastal bays
- all remaining areas within Delaware's coastal bays

The upper Indian River, Trappe Creek, and St. Martin River were defined as sampling strata because resource managers expressed particular concern about these areas. Water quality data suggest that each of these tidal creeks is subject to excessive nutrient enrichment, algal blooms, and low concentrations of dissolved oxygen. These creeks are also believed to transmit large nutrient loads (from agricultural runoff) downstream, contributing to eutrophication throughout the coastal bays (Boynton et al. 1993).

Dead-end canals were defined as a stratum because of their high potential for impact based on their physical characteristics and their proximity to a variety of contaminant sources (Brenum 1976). These dredged canal systems can form the aquatic equivalent of streets in development parcels; they already encompass 105 linear miles and almost 4% of the surface area of Delaware's inland bays. In general, these systems are constructed as dead-end systems with little or no freshwater inflows for flushing. They are often dredged to a depth greater than the surrounding waters, leaving a ledge that further inhibits exchange with nearby waters and leads to stagnant water in the canals. The placement of these systems in relatively high density residential areas increases the potential for contaminant input. Much of the modified land-use in dredged canal systems extends to the bulkheaded water's edge, providing a ready source of unfiltered runoff of lawn-care and structural pest control products. In many cases, the bulkhead and dock systems in these canal systems are built from treated lumber containing chromium, copper, and arsenic, providing another source of contaminants.

Two-hundred sites were sampled, 25 in each of the first 4 sampling strata and 50 in each of the last 2 (Figure 2-1). Sites for all strata except canals were selected by using a two stage process. First, the EMAP hexagonal grid (Overton et al. 1990) was enhanced for the coastal bays study area and the appropriate number of grid cells was selected randomly for each stratum. In the second stage, a random site from within these cells was selected. Sites in the dead-end canals were selected by developing a list frame (of all existing canals), randomly selecting 25 canals from that list, and then randomly selecting a site within each canal.

All sampling was conducted between July 12 and September 30, 1993. Sampling was limited to a single index period because available resources were insufficient to sample in all seasons. Late summer is the time during which environmental stress on estuarine systems in the mid-Atlantic region is expected to be greatest owing to high temperatures and low dilution flows (Holland 1990). The sampling period coincided with the period during which EMAP samples estuaries of the mid-Atlantic region; therefore, data collected in the coastal bays annually for EMAP can be incorporated into estimates of ecological condition generated from CBJA data and CBJA data can contribute to continuing development and evaluation of EMAP indicators.

2.2 SAMPLE COLLECTION

Samples were collected during daylight hours from a 21-ft Privateer equipped with an electric winch with a 12-ft boom. Sampling sites were located using a Global Positioning System (GPS) receiver. Dead reckoning was used to locate sites when signal interference or equipment malfunction prevented reliable performance of the GPS receiver. Obvious landmarks, channel markers, and other fixed structures were noted to identify the site location whenever dead reckoning was used.

2.2.1 Water Column

Temperature, dissolved oxygen, pH, conductivity, and salinity were measured at each site using a Hydrolab Surveyor II. The number of depths for which water quality measurements were collected depended upon the bottom depth (Table 2-1). Water clarity was measured using a 20-cm Secchi disk. The presence of floating debris within 50 m of the boat was noted. Debris was categorized as paper, plastic, cans, bottles, medical waste, or other.

Water samples were collected for analysis of nitrogen, phosphorus and carbon species, total suspended solids (TSS), turbidity, and chlorophyll *a*. A 250-ml sample bottle was deployed 0.5 m below the surface, rinsed three times with ambient water, filled, capped, and stored at 4° C for total suspended solids analysis. The procedure was repeated with a 125-ml bottle for measuring turbidity and a 1-gallon bottle for nutrients. Three filtrations were performed for each nutrient parameter using measured aliquots from the same one-gallon sample. The volume of filtered sample varied according to the relative turbidity at a site; high turbidity caused low filtering volumes. A 47-mm diameter GF/F filter was used for total particulate phosphorus analysis; a 25-mm GF/F filter was used for chlorophyll *a* analysis; and an ashed, 25-mm GF/F filter was used for particulate carbon and nitrogen analysis. Each filter was removed from the vacuum filtration apparatus using forceps, wrapped in aluminum foil, placed in a small zip-lock bag, and frozen on

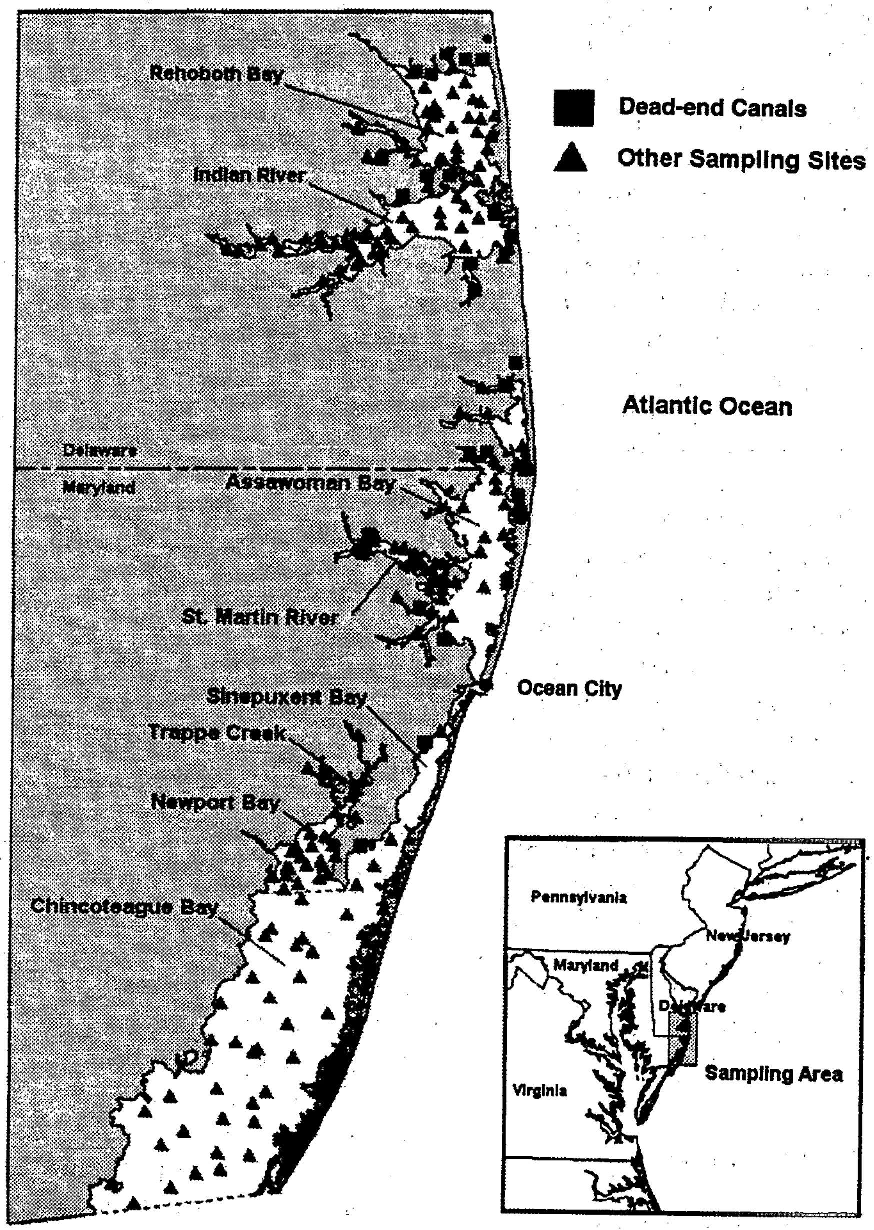

Figure 2-1. Location of sampling sites in the Delaware/Maryland coastal bays.

Table 2-1. Criteria for in situ water quality measurements

Bottom Depth (m)	Water Quality Measurements
≤1	Surface [a]
1 to 2	Surface, bottom [b]
2 to 3.3	Surface, midpoint, bottom
> 3.3	3-ft intervals from surface to bottom

[a] Measured 0.5 m below the surface.
[b] Measured 0.5 m above the bottom.

dry ice. The filtrates from all three samples for each parameter were combined, and the following aliquots were distributed into scintillation vials and frozen: two samples of 20 ml each for analysis of total dissolved nitrogen and phosphorous, and two samples of 15 ml each for analysis of dissolved inorganic nitrogen and phosphorus (NO_2, NO_3, NH_4, and PO_4).

2.2.2 Sediment and Benthic Macroinvertebrates

Sediment samples for analyses of benthic macroinvertebrates, silt-clay content, benthic chlorophyll, and chemical contaminants were collected using a 0.044-m^2, stainless steel, Young-modified Van Veen grab. This sampler has a hinged top for removing surficial sediment and is the same sampler used by EMAP. Samples for analysis of benthic macroinvertebrates were sieved in the field using a 0.5-mm screen and preserved in a 10% solution of buffered formaldehyde stained with rose bengal. A sediment core was retained from the benthic macroinvertebrate grab to determine silt-clay content. One plug of approximately 50 cc was withdrawn, placed in a plastic bag, and frozen.

Additional grabs were collected for sediment chemistry and benthic chlorophyll samples. For benthic chlorophyll, 5 1-cm plugs of surficial sediment were collected with a 50-cc plastic syringe, placed in a Nalgene bottle, wrapped in aluminum foil, and frozen immediately on dry ice. For chemistry, the top 2 cm of sediment from multiple grabs was removed and placed in a teflon bowl to obtain a final volume of approximately 1,500 ml of sediment. Care was taken to avoid sediment that had touched the surface of the grab and to use only samples with undisturbed surfaces. The teflon bowl was placed on ice in a closed cooler between grabs to reduce the temperature of the sample and prevent accidental contamination. The composite sample was homogenized and distributed to separate containers to provide appropriate samples for analysis of organics, acid volatile sulfides, and metals; all samples were frozen.

2.3 SAMPLE PROCESSING METHODS

2.3.1 Water Chemistry

Chemical analyses of water samples followed standard procedures used by the Chesapeake Bay Program, which are summarized in Table

2.3.2 Benthic Macroinvertebrates

Species composition, abundance, and biomass of benthos, and silt-clay content were determined using methods outlined in the EMAP Near Coastal Laboratory Methods Manual (Klemm et al. 1993) and updated in Frithsen et al. (1994). The macrobenthos were identified to the lowest practical taxonomic category and counted. Identified organisms were placed into predetermined biomass groups and formaldehyde dry weight was determined. Bivalves and gastropods were acidified prior to weighing to remove inorganic shell material. To standardize the biomass measurements, all samples were preserved in a 10% solution of buffered formaldehyde for at least two months before measuring biomass.

Table 2-2. Analytical methods for water column chemistry.

Analyte	Method	References
Chlorophyll *a* Phaeophytin	Spectrophotometric; Trichromatic	APHA (1981)
Nitrate and Nitrite	Calorimetric; cadmium reduction	EPA Method 353.2
Ammonium	Calorimetric; automated phenate	EPA Method 350.1
Total Dissolved Nitrogen	Calorimetric; persulfate oxidation	D'Elia et al. (1977)
Orthophosphate	Calorimetric; automated ascorbic acid	EPA Method 365.1
Total Dissolved Phosphorous	Calorimetric; persulfate digestion and automated ascorbic acid	EPA Method 365.1
Total Particulate Nitrogen	Oxidative combustion	Leeman Labs (1988)
Total Particulate Phosphorous	Calorimetric; persulfate digestion	Aspilla et al. (1976)
Total Particulate Carbon	Oxidative Combustion	Leeman Labs (1988)
Dissolved Organic Carbon	Persulfate Digestion	Menzel and Vaccaro 1964)
Total Suspended Solids	Gravimetric	APHA (1981)
Turbidity	Nephelometer	

2.3.3 Silt-Clay Content

Sediment samples were processed to determine silt-clay content according to EMAP procedures described in Klemm et al. 1993. Sediment samples were sieved through a 63-µm mesh sieve. The filtrate and the fraction remaining on the sieve were dried at 60°C and weighed to calculate the proportion of silts and clays in the sample.

2.3.4 Benthic Chlorophyll

Sediment samples were processed to determine benthic chlorophyll concentrations. Sample aliquots were suspended in 90% acetone, extracted overnight at -20°C, resuspended, and the supernatant was collected. Each sample was extracted three times and the supernatants were combined. The benthic chlorophyll concentration of the supernatant was determined by two different methods: (1) high-performance liquid chromatography described by Heukelem et al. (1992) and (2) the fluorometric method described in Parsons et al. (1984).

2.3.5 Sediment Chemistry

Sediments were analyzed for the NOAA National Status and Trends suite of contaminants (Table 2-3) using standard analytical methods (Table 2-4). Due to cost constraints, only a random subset of 11 samples from the dead-end canals and 10 samples from the remaining coastal bays were processed in the laboratory. Data from non-canal areas were supplemented with 14 samples recently collected by EMAP using a compatible sampling design and identical field and laboratory methods.

2.4 DATA ANALYSIS

For reporting purposes, the study area was post-stratified into the following subpopulations: Rehoboth Bay, Indian River (including upper Indian River), Assawoman Bay (including St. Martin River), and Chincoteague Bay (Figure 2-2). Boundaries of the four special target areas (i.e., upper Indian River, St. Martin River, Trappe Creek/Newport Bay, and dead-end canals) were not changed. Dead-end canals were evaluated as a separate subpopulation and were not included in calculations for the remaining study area.

The condition of each of these areas was assessed in two ways: the mean condition and the percent of area exceeding threshold values for selected parameters. Since the sampling sites within each stratum (except the dead-end canals) were selected with equal inclusion probabilities, the mean parameter values (eq. 1) for a stratum, *h*, and its variance (eq. 2) were calculated as:

$$\bar{y}_h = \sum_{j=1}^{n_h} \frac{y_{hi}}{n_h} \qquad \text{(EQ.1)}$$

where

y_{hi} is the variable of interest (e.g., concentration of phosphorus), and n_h is the number of samples collected from stratum *h*.

The stratified mean value for *L* strata with combined area *A* is given by

$$s_h^2 = \sum_{j=1}^{n_h} \frac{(y \quad - \bar{y}_h)^2}{n_h - 1} \qquad \text{(EQ.2)}$$

Table 2-3. Analytes for CBJA sediment samples.

Polyaromatic Hydrocarbons (PAHs)			
Acenaphthene	2,6-dimethylnaphthalene	Perylene	Anthracene
Fluoranthene	Phenanthrene	Benz(a)anthracene	Fluorene
Pyrene	Benzo(a)pyrene	Ideno(1,2,3-c,d)pyrene	Benzo(b)fluoranthene
Benzo(e)pyrene	2-methylnaphthalene	Acenaphthylene	Biphenyl
1-methylnaphthalene	Benzo(k)fluoranthene	Chrysene	1-methylphenanthrene
Benzo(g,h,i)perylene	Dibenz(a,b)anthracene	Naphthalene	2,3,5-Trimethylnaphthalene

DDT and its metabolites	
o,p'-DDD	p,p'-DDE
p,p'-DDD	o,p'-DDT
o,p'-DDE	p,p'-DDT

Chlorinated pesticides other than DDT		
Aldrin	Heptachlor epoxide	Alpha-Chlordane
Hexachlorobenzene	Trans-Nonachlor	Lindane gamma-BHC)
Dieldrin	Mirex	Heptachlor

Major Elements
Aluminum
Iron
Manganese

Trace Elements			
Antimony	Arsenic	Cadmium	Chromium
Copper	Selenium	Lead	Silver
Mercury	Tin	Nickel	Zinc

18 PCB Congeners:

No.	Compound Name
8	2,4'-dichlorobiphenyl
18	2,2',5-trichlorobiphenyl
28	2,4,4'-trichlorobiphenyl
44	2,2',3,5'-tetrachlorobiphenyl
52	2,2',5,5'-tetrachlorobiphenyl
66	2,3',4,4'-tetrachlorobiphenyl
101	2,2',4,5,5'-pentachlorobiphenyl
105	2,3,3',4,4'-pentachlorobiphenyl
118	2,3',4,4',5-pentachlorobiphenyl
128	2,2',3,3',4,4'-hexachlorobiphenyl
138	2,3',3,4,4',5-hexachlorobiphenyl
153	2,2',3,4,4',5'-hexachlorobiphenyl
170	2,2',4,4',5,5'-hexachlorobiphenyl
180	2,2',3,3',4,4',5-heptachlorobiphenyl
187	2,2',3,4,4',5,5'-heptachlorobiphenyl
195	2,2',3,3',4,4',5,6-octachlorobiphenyl
206	2,2',3,3',4,4',5,5',6-nonachlorobiphenyl
209	decachlorobiphenyl

Other measurements		
Tributyltin	Acid volatile sulfides	Total organic carbon

Table 2-4. Analytical methods used for determination of chemical contaminant concentrations in sediments

Compound(s)	Method
Inorganics:	
Ag, Al, Cr, Cu, Fe, Mn, Ni, Pb, Zn	Total digestion using HF/HNO_3 (open vessel hot plate) followed by inductively coupled plasma-atomic emission spectrometry (ICP-AES) analysis.
As, Cd, Sb, Se, Sn	Microwave digestion using HNO_3/HCl followed by graphite furnace atomic absorption (GFAA) analysis.
Hg	Cold vapor atomic absorption spectrometry
Organics:	
Extraction/Cleanup	Soxhlet extraction, extract drying using sodium sulfate, extract concentration using Kuderna-Danish apparatus, removal of elemental sulfur with activated copper, removal of organic interferents with GPC and/or alumina.
PAH measurement	Gas chromatography/electron spectrometry (GC/MS)
PCB/pesticide	Gas chromatography/electron capture detection (GC/ECD) with second column confirmation

where the weighting factors, $W_h = A_h/A$, ensure that each stratum *h* is weighted by its fraction of the combined area for all *L* strata. An estimator for the variance of the stratified mean (3) is

$$\bar{y}_{st} = \sum_{h=1}^{L} W_h \bar{y}_h \qquad \text{(EQ.3)}$$

Strata were combined following Holt and Smith (1979). Confidence intervals were calculated as 1.64 times the standard error, where the standard error is the square root of the variance (estimated by eq. 4). Statistical differences between populations of interest were defined on the basis of non-overlapping confidence intervals.

$$V(\bar{y}_{st}) = \sum_{h=1}^{L} W_h^2 Var(y_h) \qquad \text{(EQ.4)}$$

The samples from the dead-end canals were treated as a cluster sample, in which the canals formed clusters (areas) of unequal size. Mean parameter values were calculated as area-weighted means:

where

$$\bar{q} = \Sigma c_i y_i \, / \, C \qquad \text{(EQ.5)}$$

$\bar{q}$ is the area-weighted mean
c_i is the area of canal i,
C is the combined area of all the canals sampled,
y_i is the variable of interest (e.g., concentration of phosphorus), and
n is the number of canals sampled.

The standard error was calculated using the jackknife estimator (Cochran 1977, Efron and Gong 1983):

$$\sigma_j = \{[(n-1)/n]\Sigma(\mu_{(i)} - \mu_{(\cdot)})^2\}^{1/2} \qquad \text{(EQ.6)}$$

where

$$\mu_{(j)} = \sum_{i \neq j} c_i \bar{y} / (C - c_j) \qquad \text{(EQ.7)}$$

is the weighted mean value deleting the jth canal and

$$\mu_{(\cdot)} = \sum \mu_{(j)} / n \qquad \text{(EQ.8)}$$

is the jackknife estimate of the mean y for the n canals.

Estimates of percent of area exceeding selected thresholds (e.g., dissolved oxygen concentration less than 5 ppm) was calculated as $p = B/n$, where B is number of samples exceeding the threshold and n is the total number of samples in the stratum. For strata with equal inclusion probability, the exact confidence intervals for p were estimated from the binomial distribution using the formula of Hollander and Wolfe (1973).

The exact confidence intervals could not be obtained directly from the binomial distribution for stratified random sampling or for clustered sampling (canals). Since these sample sizes are large, the confidence interval was calculated using the normal approximation to the binomial. For a combination of strata, the 90% confidence interval of stratified estimates of proportions, p_{st}, was estimated as

$$p_{st} \pm 1.64[Var(p_{st})]^{1/2}, \qquad \text{(EQ.9)}$$

where

$$p_{st} = \sum_{h=1}^{L} W_h p_h \qquad \text{(EQ.10)}$$

$$Var(p_{st}) = \sum_{h=1}^{L} W_h^2 Var(p_h) \qquad \text{(EQ.11)}$$

The formulas for estimating means and variances for canals also were used to estimate the percentage of area in the canals with y values that fell into some defined class. An indicator variable, I_i, was assigned the value if the value of y_i fell in a specified class, and 0 otherwise. The sample mean and variance of I_i is an estimate of the proportion of area in the canals that has y values within the specified class.

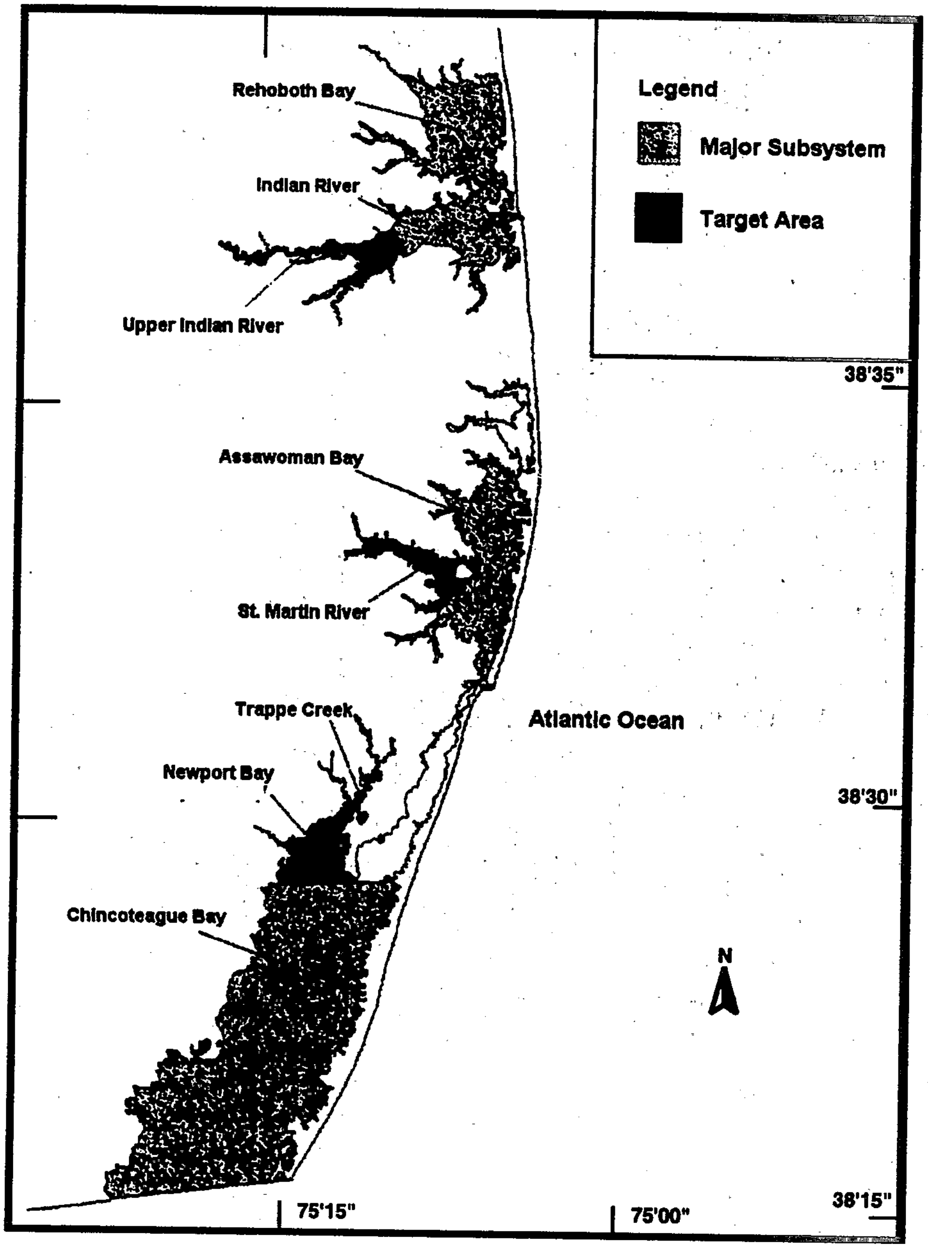

Figure 2-2. Boundaries of post-stratified subpopulations which were used in the study.

3.0 PHYSICAL CHARACTERISTICS

3.1 BACKGROUND

Measurements of physical characteristics provide basic information about the natural environment. Knowledge of the physical context in which biological and chemical data are collected is important for interpreting results accurately because physical characteristics of the environment determine the distribution and species composition of estuarine communities, particularly assemblages of benthic macroinvertebrates. Salinity, sediment type, and depth are all important influences on benthic assemblages (Snelgrove and Butman 1994, Holland et al. 1989). Sediment grain size also affects the accumulation of contaminants in sediments. Fine-grained sediments generally are more susceptible to accumulating contaminates than sands because of the greater surface area of fine particles (Rhoads 1974; Plumb 1981).

Depth, silt-clay content of the sediment, bottom salinity, temperature, and pH were measured to describe the physical conditions at sites in the coastal bays. Sediment type was defined according to silt-clay content (fraction less than 63μ); classifications were the same as those used for EMAP. Biologically meaningful salinity classes were defined according to a modified Venice System (Symposium on the Classification of Brackish Waters 1958).

3.2 MAJOR SUBSYSTEMS

3.2.1 Depth

The coastal bays of Delaware and Maryland are shallow systems with an average depth of 1.5 m (Table 3-1). Depth exceeded 3 m at only 3 of 200 sampling sites. Average depth among the four major subsystems was not significantly different. The amount of area shallower than 0.6 m may have been underestimated because this was the minimum depth accessible for sampling; however, less than 5% of the area in each major system was unsampleable because of insufficient depth.

3.2.2 Silt-Clay Content

The coastal bays had a diverse bottom habitat including broad areas of mud, sand, and mixed substrates (Figure 3-1). Sand was a more predominant substrate than mud and accounted for more than 40% of the study area. Muddy sediments were less prevalent, accounting for less than 20% of the area (Figure 3-2). The distribution of mud, sand, and mixed substrates was similar among Rehoboth, Assawoman, and Chincoteague bays. The average silt-clay content of Indian River Bay was significantly

Table 3-1. Area-weighted means of physical parameters (90% confidence intervals).

		Major Subsystems				Target Areas			
Parameter	Entire Study Area	Rehoboth Bay	Indian River	Assawoman Bay	Chincoteague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
Depth (m)	1.5 ± 0.1	1.3 ± 0.2	1.5 ± 0.2	1.4 ± 0.2	1.5 ± 0.1	1.5 ± 0.2	1.3 ± 0.1	1.6 ± 0.1	1.8 ± 0.4
Silt-Clay Content (%)	40 ± 5	37 ± 11	60 ± 11	44 ± 13	35 ± 9	71 ± 9	58 ± 9	65 ± 9	59 ± 13
Salinity	30.6 ± 0.4	29.7 ± 0.8	28.7 ± 0.6	29.7 ± 0.5	32.2 ± 0.7	24.3 ± 1.5	28.6 ± 0.9	25.9 ± 2.2	29.2 ± 1.3
Temperature (°C)	25.4 ± 0.4	25.7 ± 0.8	24.9 ± 1.1	27.4 ± 1.1	24.9 ± 0.6	28.0 ± 1.0	27.4 ± 0.6	25.7 ± 0.7	26.4 ± 1.6
pH	7.8 ± <0.1	7.7 ± 0.1	7.7 ± 0.1	8.0 ± 0.1	7.8 ± 0.1	7.7 ± 0.1	7.8 ± 0.1	7.8 ± 0.1	7.6 ± 0.3

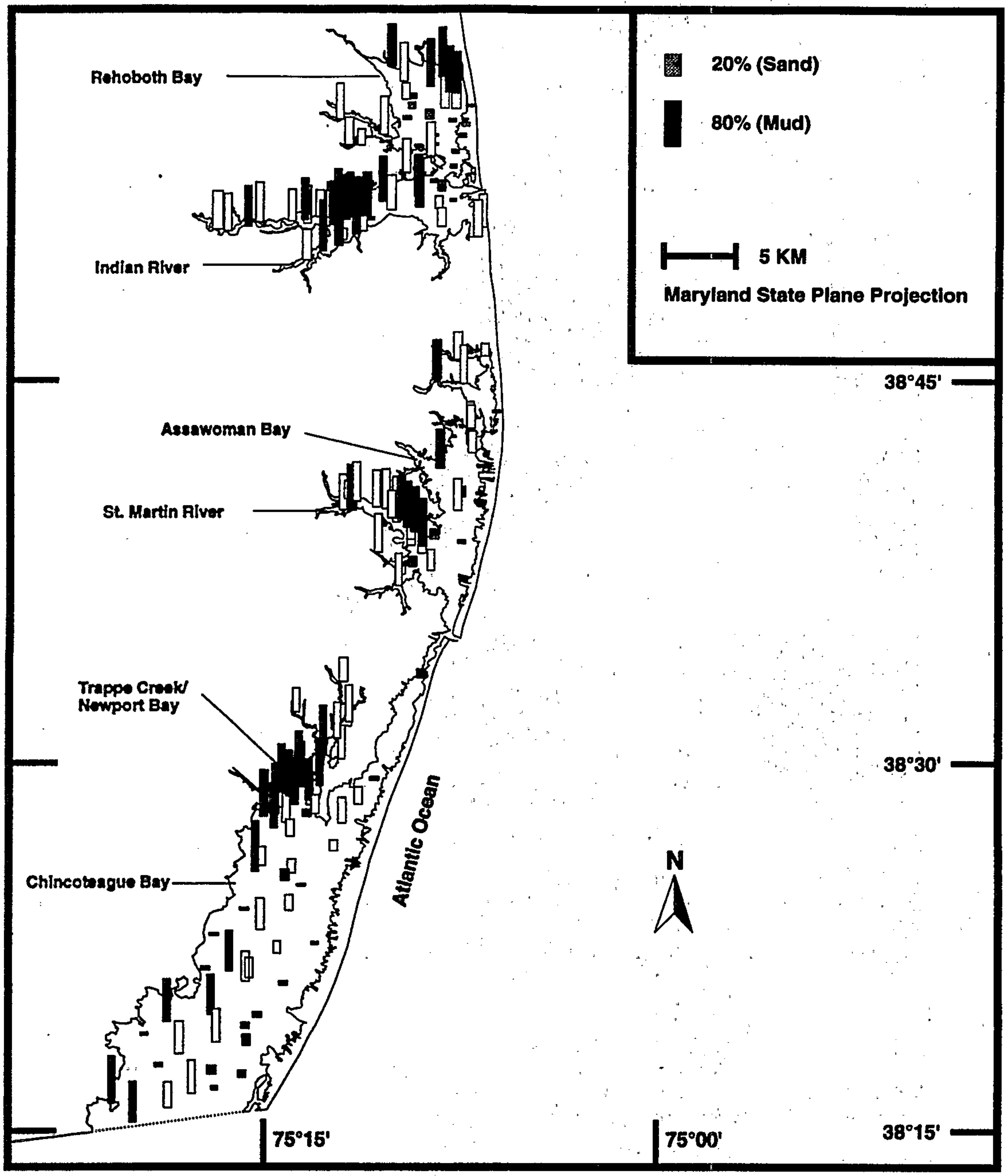

Figure 3-1. Spatial distribution of silt-clay content in non-lagoon sites in the Delaware/ Maryland coastal bays study area. Bar height is directly proportional to the percent of silt-clay. Cross-hatched bars represent sandy sediments, clear bars represent mixed sediments, and solid bars represent muddy sediments.

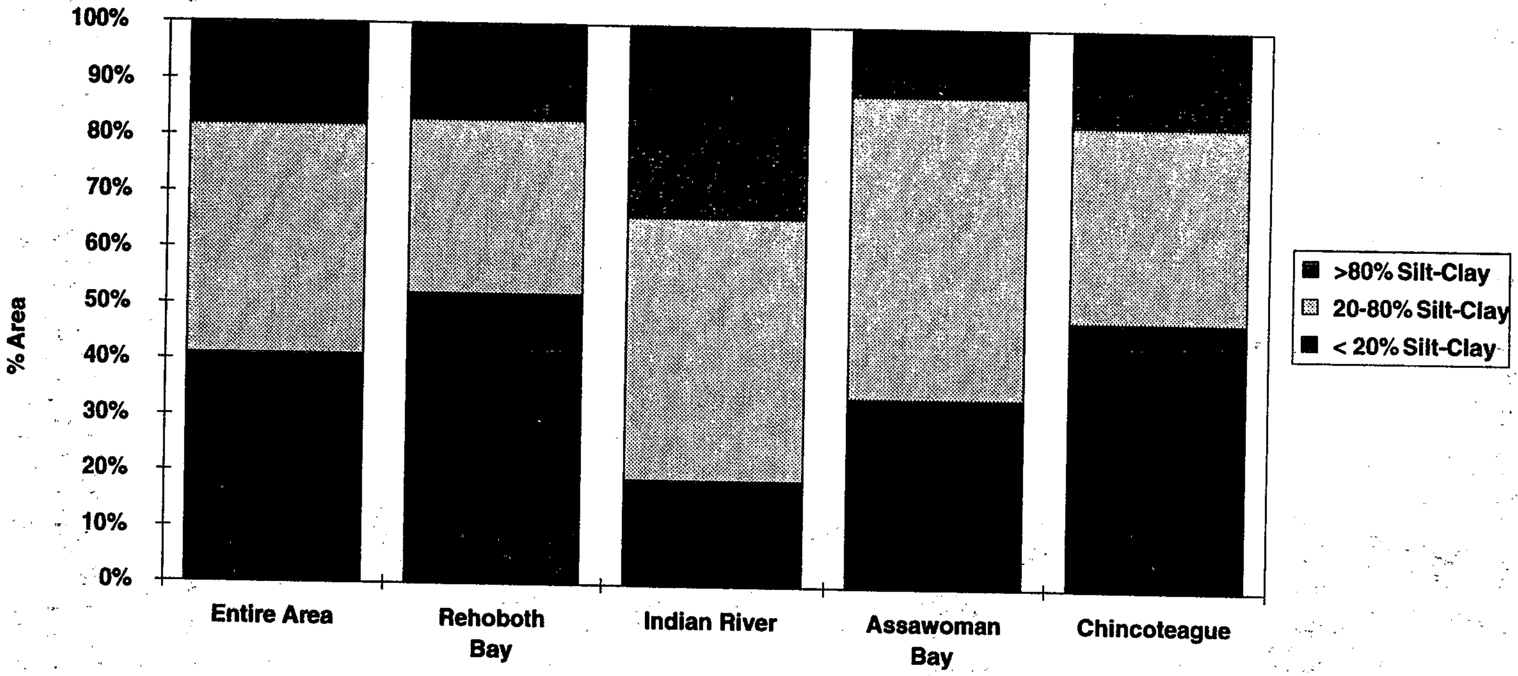

Figure 3-2. Composition of bottom sediments in the major subsystems of the Delaware/Maryland coastal bays.

higher than in the other three systems, and the percentage of muddy substrate was twice that of any other system (Table 3-1).

3.2.3 Salinity

The coastal bays were predominantly polyhaline (> 25 ppt salinity). Average salinity in Chincoteague Bay was about 2 ppt greater than in the other three coastal bays (Table 3-1). No measured area in Chincoteague Bay had salinity less than 25 ppt, whereas salinities less than 25 ppt accounted for at least 5% of the area in each of the other major subsystems (Figure 3-3). Only Indian River had measured salinities less than 18 ppt; this salinity class encompassed approximately 5% of the area. Some unsampled portions of the coastal bays undoubtedly have lower salinities but the percentage of area they represent is small.

3.2.4 Temperature and pH

Average temperature for the coastal bays was 25.5 C and average pH was 7.8 (Table 3-1). Neither parameter varied appreciably among the four major subsystems.

3.3 TARGET AREAS

3.3.1 Depth

Average depths in the special target areas were not significantly different than the average depth of the entire study area. Average depths of the four special target areas ranged from 1.3 m to 1.8 m (Table 3-1).

3.3.2 Silt-Clay Content

All of the special target areas were significantly muddier than the coastal bays as a whole (Table 3-1). The upper Indian River was the muddiest; almost half of the area had a silt-clay content of greater than 80% (Figure 3-4). Sandy substrate covered less than 20% of each of the four special target areas. Less than 10% of the upper Indian River had sandy sediments.

3.3.3 Salinity

The special target areas were predominantly polyhaline, but average salinities in all special target areas except the dead-end canals were less than that of the entire study area (Table 3-1). Approximately 40% of upper Indian River had salinities less than 25 ppt (Figure 3-5). The closed-ended dead-end canals, which have no freshwater input, were almost completely polyhaline. All other systems had sources of fresh water.

3.3.4 Temperature and pH

All special target areas had higher average temperatures than the entire study area (Table 3-1). The maximum temperature of 37.4 C was measured in the discharge canal of a power generating station in upper Indian River. The average pH levels of the special target areas were not significantly different than the average pH of the entire study area. The highest pH (9.4) was measured at the uppermost sampling site in Trappe Creek.

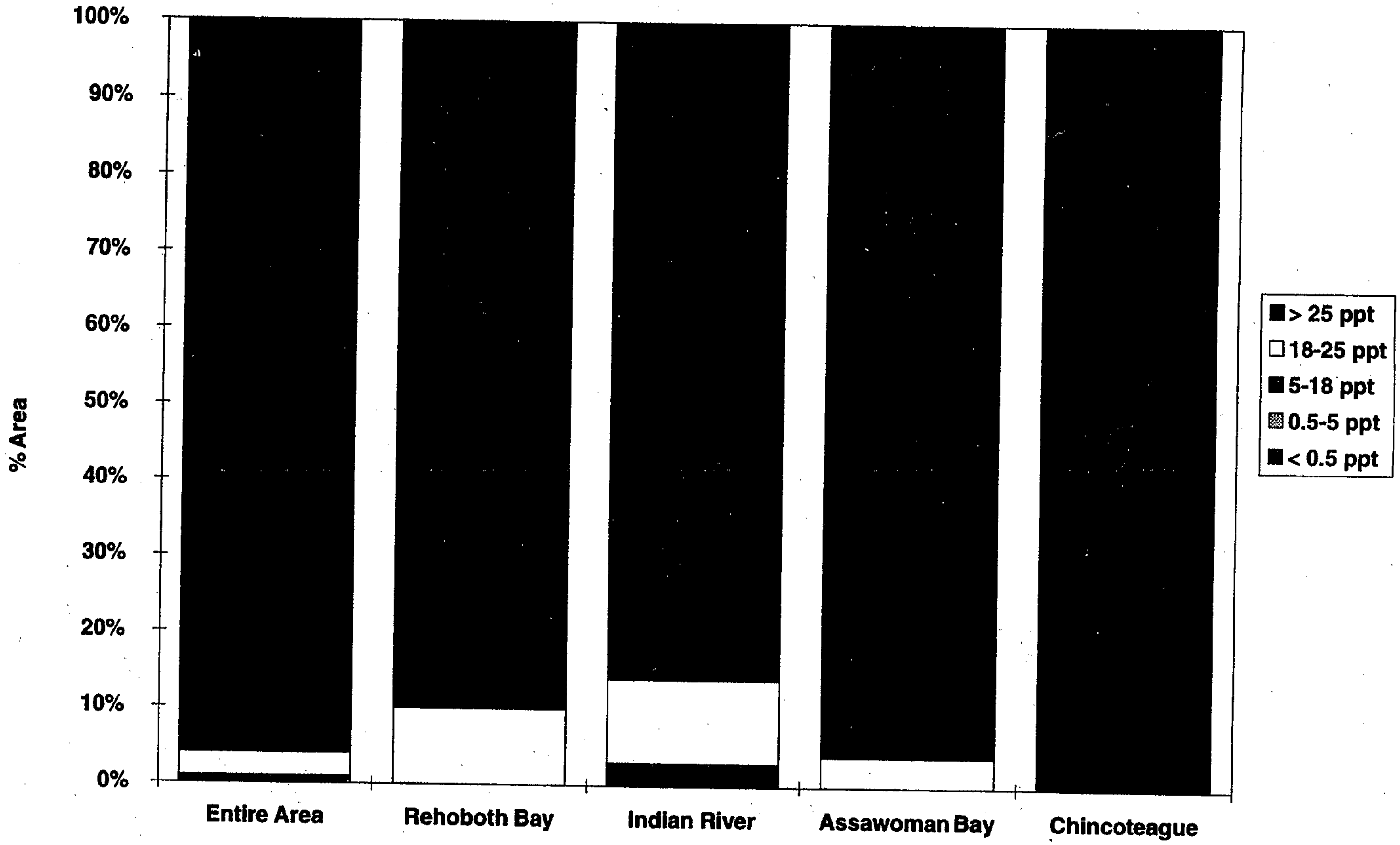

Figure 3-3. Percent of area in three salinity classes in the major subsystems of the Delaware/Maryland coastal bays.

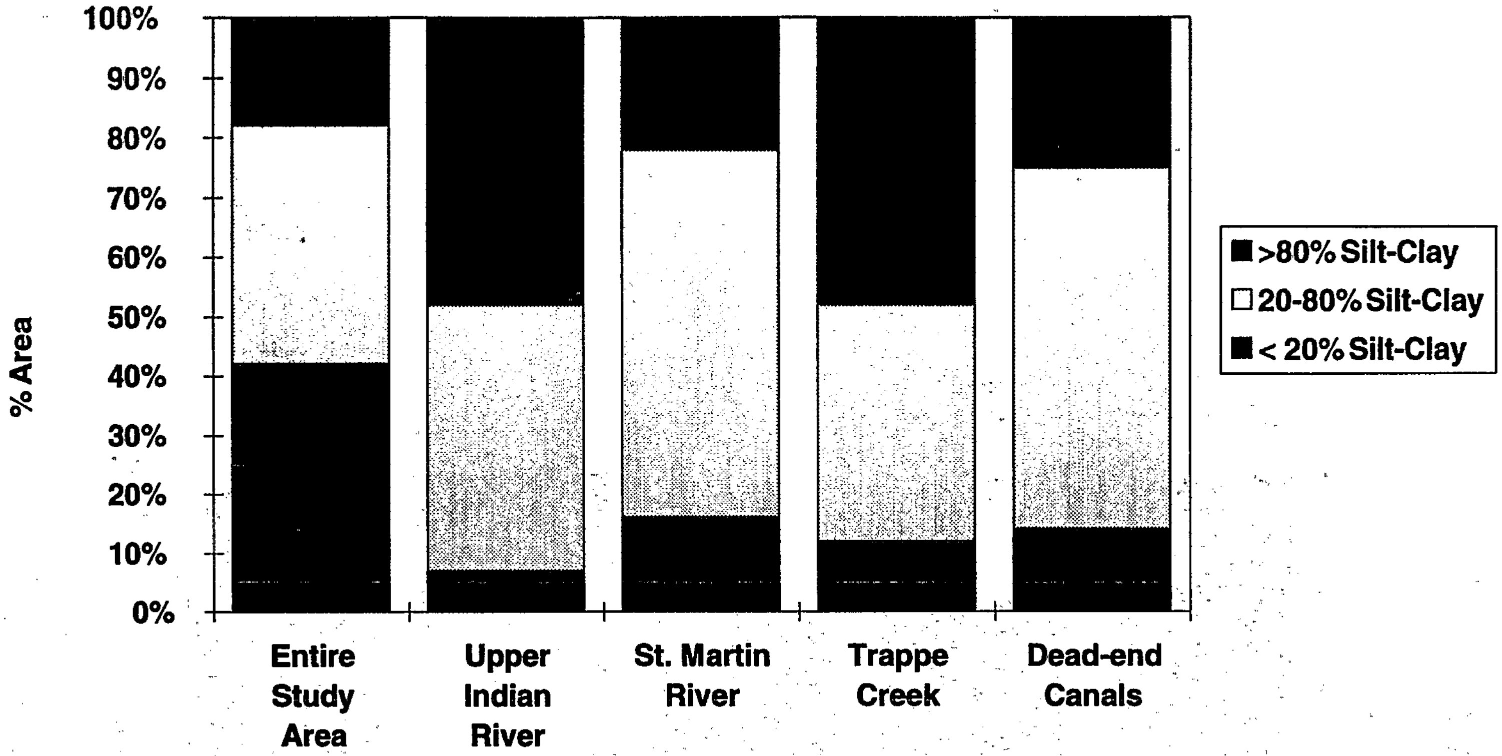

Figure 3-4. Composition of bottom sediments in special target areas in the Delaware/Maryland coastal bays.

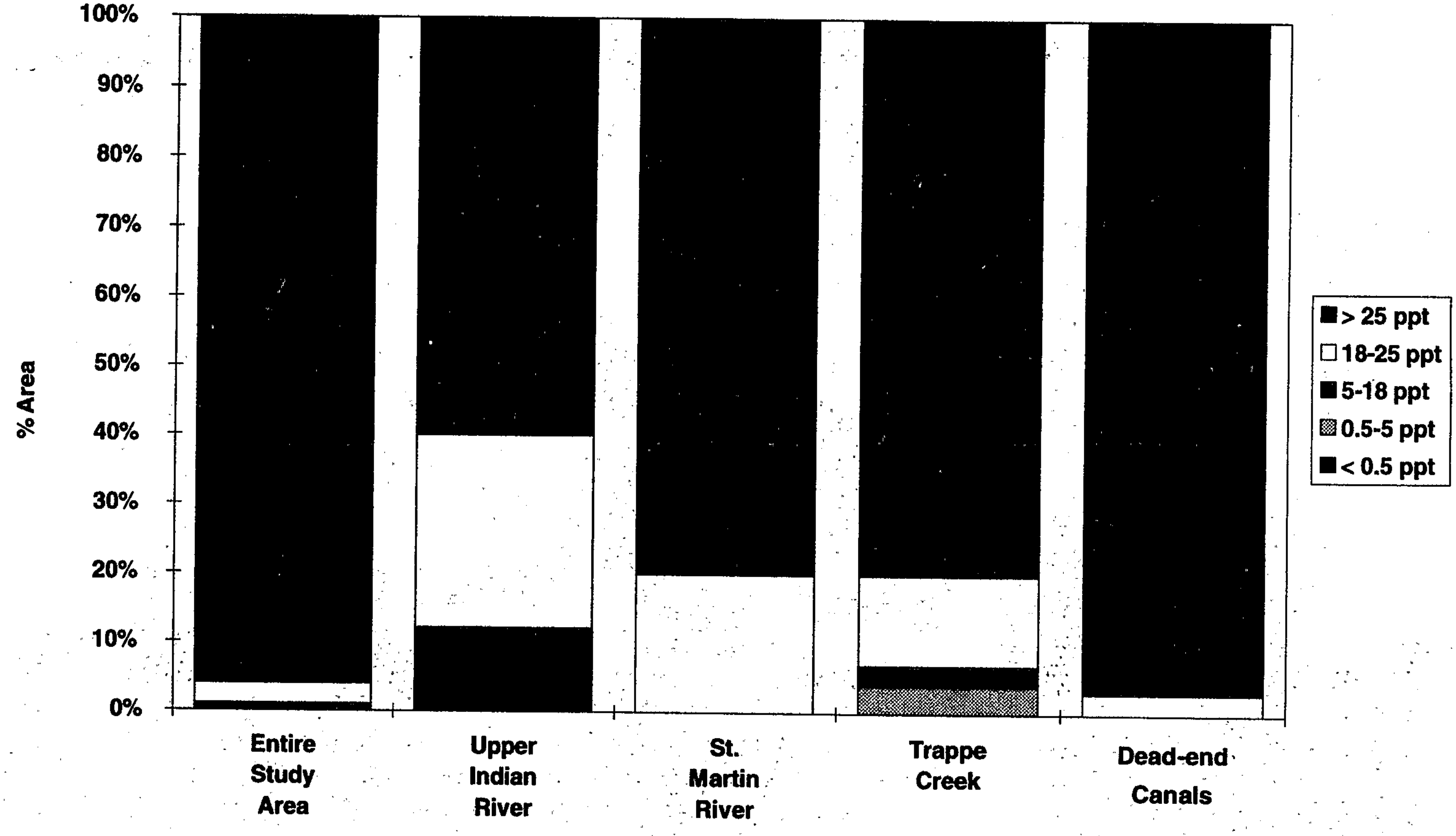

Figure 3-5. Percent of area in four salinity classes in special target areas in the Delaware/Maryland coastal bays.

3.4 COMPARISON WITH PREVIOUS STUDIES

Physical characteristics measured during the 1993 coastal bays study generally agree with those reported in previous characterizations of the Maryland (Boynton et al. 1993) and Delaware (Weston 1993) coastal bays. Rehoboth Bay and Indian River are described as shallow systems with an average depth less than 2 m; the eastern third of Rehoboth averages less than 1 m deep. Average depths of about 1.2 m are reported for Maryland bays, including Chincoteague and Assawoman.

Fang et al. (1977) described the Maryland coastal bays as a polyhaline environment; similarly, Rehoboth Bay and lower Indian River were classified as polyhaline in the Weston (1993) characterization. The salinity range measured in upper Indian River during our study did not vary appreciably from similar data reported in the Weston (1993) characterization.

Maps of the areal distribution of bottom sediments, as reported by Bartberger and Biggs (1970) in Maryland and by Chrzastowski (1986) in Delaware are generally similar to those from this study, but a few minor differences can be noted. The previous characterization described Rehoboth Bay as predominantly sand (41%), with equal proportions of mixed and muddy sediments. In our study, Rehoboth Bay was sandier (53%) and less muddy (17%). Indian River was previously described as approximately equal proportions of muddy and sandy sediments (Chrzastowski 1986); our study found a higher proportion of mixed sediments and a lesser percent of sandy sediments. These minor differences could result from changes in conditions over the last decade, but more likely result from differences in the study design (previous studies did not use a probability-based sampling design) or from minor differences in how mud and sand were defined between studies.

3.5 COMPARISON TO SURROUNDING SYSTEMS

One design feature of the coastal bays study is that it was conducted using the same sampling design, methodologies, and quality assurance/ quality control procedures as EPA's EMAP, allowing comparisons between the coastal bays and other major estuarine systems in EPA Region III that are sampled by EMAP, such as Chesapeake Bay and the Delaware Bay. When such comparisons are conducted, the coastal bays are found to be shallower, saltier, and muddier than either the Chesapeake Bay or Delaware Bay. Average depths of 8.3 m in Chesapeake Bay and 7.0 m in Delaware Bay are approximately 5 m deeper than the coastal bays. Both of these deeper systems include areas which exceed 40 m in depth. In contrast, none of the 200 sample sites in the coastal bays exceeded 4 m in depth.

The average silt-clay content was higher in the coastal bays than in the other two systems. The silt-clay content for the coastal bays was 40%, compared to 34% for Chesapeake Bay and 24% for Delaware Bay. Mean bottom salinity in the coastal bays (30.6 ppt) was substantially higher than in either Chesapeake Bay (18.5 ppt) or Delaware Bay (22.5 ppt), reflecting the meager freshwater input to the coastal bays.

4.0 WATER QUALITY

4.1 BACKGROUND

Healthy aquatic ecosystems require clear water, acceptable concentrations of dissolved oxygen, limited concentrations of phytoplankton, and appropriate concentrations of nutrients. Clear water is a critical requirement for submerged aquatic vegetation (SAV), which provides habitat for many other aquatic organisms (Dennison et al. 1993). As large concentrations of suspended sediment or algal blooms reduce water clarity, the amount of sunlight reaching SAV is diminished and the plants fail to thrive; consequently, critical habitat for crabs, fish, and other aquatic organisms is lost (Magnien et al. 1995). Nutrient enrichment causes excessive algal growth in the water column and on the surfaces of plants. As bacteria metabolize senescent excess algae, they deplete dissolved oxygen in the water column and sediments causing hypoxia and, in extreme cases, anoxia.

Water quality in the coastal bays of Delaware and Maryland was evaluated using four classes of indicators: measures of algal productivity, dissolved oxygen (DO), water clarity, and nutrients. Measures of algal biomass included the concentrations of chlorophyll in the water column and sediment, and phaeophytin. Secchi depth, total suspended solids (TSS), and turbidity were measured to assess water clarity. Nutrient measures included dissolved inorganic nitrogen (DIN; nitrite, nitrate, and ammonium), dissolved inorganic phosphorus (DIP), total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), and particulate nitrogen and phosphorus.

Estimating the percent of area showing symptoms of eutriphication in the coastal bays requires identifying threshold levels for selected indicators that define eutrophication. While no such levels have been established for the coastal bays, the Chesapeake Bay Program has established thresholds for five water quality parameters to define critical habitat requirements for supporting SAV in a polyhaline environment (Dennison et al. 1993); these thresholds were used for our assessment (Table 4-1). All but one of the SAV restoration goal attributes were measured directly. The light attenuation coefficient was calculated from secchi depth measurements.

4.2 MAJOR SUBSYSTEMS

4.2.1 Measures of Algal Productivity

The mean concentration of chlorophyll a in the water column varied considerably among the

Table 4-1. Chesapeake Bay submerged aquatic vegetation habitat requirements for a polyhaline environment (Dennison et al. 1993).

Parameter	Critical Value
Light attenuation coefficient (k_d; m^{-1})	1.5
Total suspended solid (mg/l)	15
Chlorophyll *a* (μg/l)	15
Dissolved inorganic nitrogen (μM)	10
Dissolved inorganic phosphorus (μM)	0.67

coastal bays. The mean concentration in Chincoteague Bay was significantly less than the concentrations in any of the other three major subsystems (Table 4-2). Indian River had the largest mean concentration, almost four times that of Chincoteague Bay. Average phaeophytin concentrations were distributed similarly.

A significantly smaller portion of Chincoteague Bay had chlorophyll a concentrations exceeding the 15 ug/ml SAV restoration goal than any of the other systems (Figure 4-1). The percentage of area exceeding the threshold in the other systems ranged from four to six times that in Chincoteague Bay, and the differences were statistically significant (Figure 4-1). Almost 25% of the area in Indian River had chlorophyll a concentrations exceeding 30 ug/ml.

Average concentrations of chlorophyll in benthic sediment did not vary appreciably among coastal bays systems, except for Rehoboth Bay. Concentrations in Rehoboth Bay were two to four times greater than concentrations in the other systems (Table 4-2).

4.2.2 Dissolved Oxygen

Mean concentrations of DO ranged from 5.9 ppm to 6.7 ppm and did not vary appreciably among the four major subsystems (Table 4-2). Only Indian River had DO concentrations less than 5 ppm, (the state standard in both states) in more than 10% of its area (Figure 4-2). None of the major subsystems had measured DO concentrations less than 2 ppm, but the extent of low dissolved oxygen may be underestimated in this study because measurements were limited to daytime hours.

4.2.3 Measures of Water Clarity

Indicators of water clarity were consistently better in Chincoteague Bay than in the other systems. Chincoteague Bay had the highest mean secchi depth, approximately 1 m (Table 4-2). Average secchi depth is underestimated in our study for all of the major subsystems, except Assawoman Bay, because it included measurements when the secchi disk was readable on the bottom.

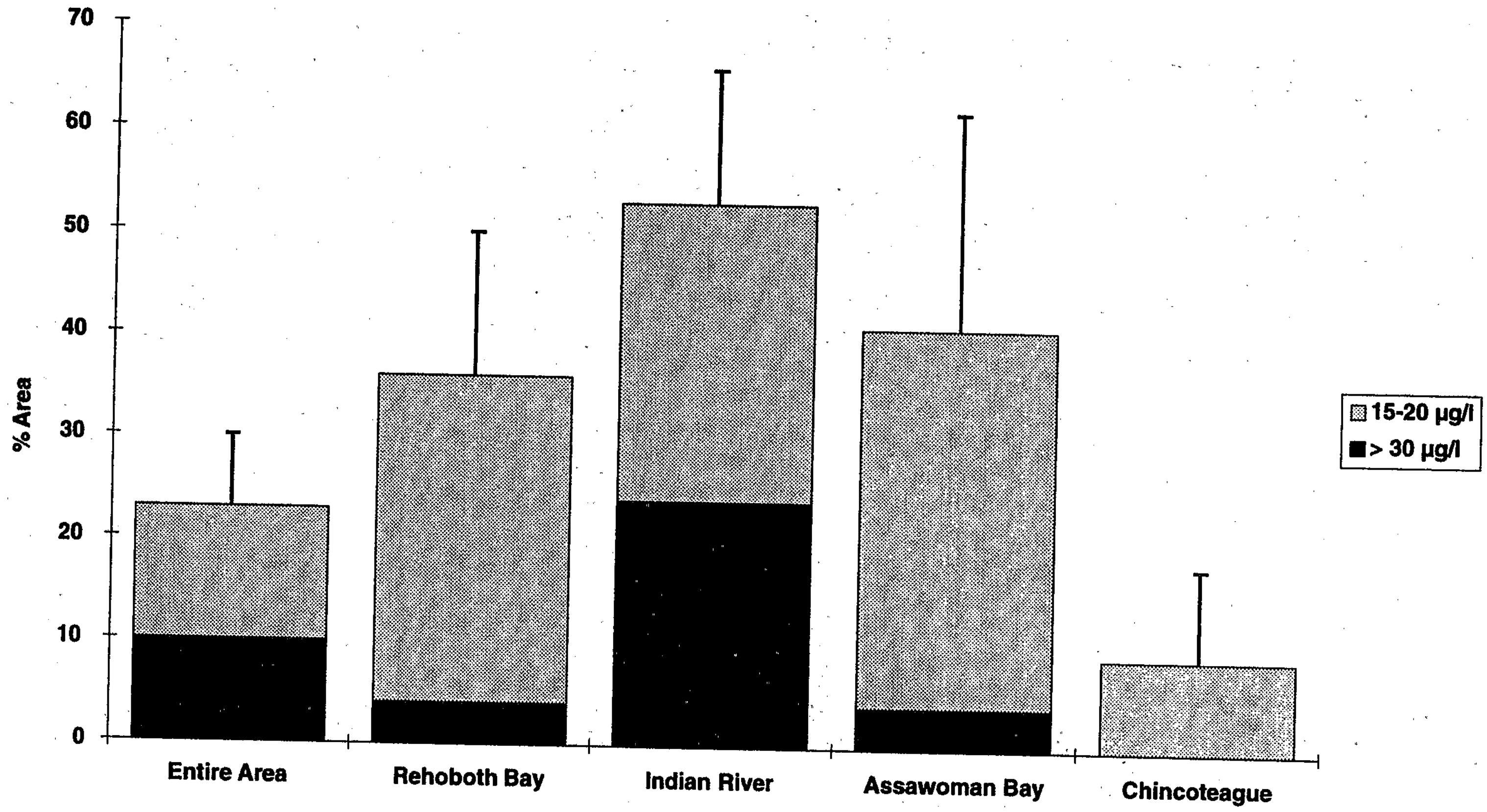

Figure 4-1. Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays which exceeded the SAV restoration.

Table 4-2. Area-weighted means of water quality parameters (90% confidence intervals)

		Major Subsystems				Target Areas			
Parameters	Entire Study Area	Rehoboth Bay	Indian River	Assawoman Bay	Chincoteague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
Measures of Primary Production									
Chlorophyll a (µg/l)	12.17 ± 1.97	13.31 ± 2.85	20.68 ± 4.21	15.78 ± 1.52	5.66 ± 1.31	35.22 ± 7.20	19.95 ± 2.03	45.81 ± 32.34	25.74 ± 7.57
Phaeophytin (µg/l)	4.39 ± 0.31	5.45 ± 0.91	9.94 ± 1.86	5.60 ± 0.50	2.61 ± 0.37	16.04 ± 3.16	8.96 ± 1.44	5.50 ± 1.16	7.90 ± 0.99
Benthic Chlorophyll (µg/g)	8.06 ± 1.40	22.10 ± 7.54	9.71 ± 2.29	6.22 ± 1.73	5.45 ± 2.02	12.15 ± 5.40	8.73 ± 3.35	7.67 ± 6.23	31.02 ± 16.61
Dissolved Oxygen (ppm)	6.3 ± 0.2	6.7 ± 0.4	5.9 ± 0.3	6.2 ± 0.4	6.3 ± 0.3	6.2 ± 0.6	5.7 ± 0.4	7.0 ± 1.0	3.8 ± 2.0
Nutrients									
Nitrite & Nitrate (µM)	0.79 ± 0.30	0.64 ± 0.44	3.38 ± 2.08	0.31 ± 0.21	0.35 ± 0.12	9.15 ± 6.20	0.10 ± 0.04	2.33 ± 3.42	0.57 ± 0.66
Ammonium (µM)	4.81 ± 1.07	4.19 ± 1.21	8.47 ± 2.77	6.07 ± 3.09	4.12 ± 1.74	10.82 ± 4.69	3.69 ± 1.40	3.71 ± 1.58	6.33 ± 4.94
Total Dissolved Nitrogen (µM)	28.73 ± 1.34	21.19 ± 1.99	27.57 ± 3.23	33.41 ± 4.38	27.43 ± 1.72	41.72 ± 5.65	32.34 ± 2.48	38.52 ± 5.18	32.62 ± 3.95
Orthophosphate (µM)	0.40 ± 0.06	0.60 ± 0.13	0.53 ± 0.08	0.27 ± 0.07	0.34 ± 0.07	0.46 ± 0.16	0.30 ± 0.08	0.87 ± 0.82	0.33 ± 0.16
Total Dissolved Phosphorus (µM)	0.93 ± 0.06	1.17 ± 0.15	0.98 ± 0.11	0.82 ± 0.04	0.88 ± 0.07	1.06 ± 0.11	1.08 ± 0.09	1.35 ± 0.67	1.03 ± 0.16
Total Particulate Nitrogen (µg/l)	357 ± 27	367 ± 70	421 ± 60	620 ± 56	209 ± 30	637 ± 78	755 ± 81	775 ± 321	658 ± 105
Total Particulate Phosphorus (µg/l)	47.91 ± 3.66	51.75 ± 6.20	63.97 ± 8.45	77.10 ± 5.41	28.72 ± 4.46	90.10 ± 11.15	102.73 ± 10.48	100.62 ± 44.21	91.32 ± 16.43
Total Particulate Carbon (µg/l)	2,245 ± 180	2,342 ± 463	2,479 ± 341	3,968 ± 412	1,277 ± 203	3,686 ± 475	4,825 ± 605	5,251 ± 2,212	4,333 ± 790
Water Clarity									
Secchi Depth (m)	0.8 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	1.0 ± 0.1	0.6 ± 0.1	0.6 ± 0.1	0.6 ± 0.1	0.7 ± 0.1
Total Suspended Solids (mg/l)	30.2 ± 4.5	33.8 ± 8.0	39.7 ± 10.0	28.9 ± 9.6	27.4 ± 7.4	33.59 ± 9.82	37.71 ± 10.58	36.69 ± 10.97	27.39 ± 14.31
Turbidity (NTU)	12 ± 2	12 ± 2	12 ± 3	15 ± 4	10 ± 3	15 ± 2	16 ± 3	19 ± 4	9 ± 1

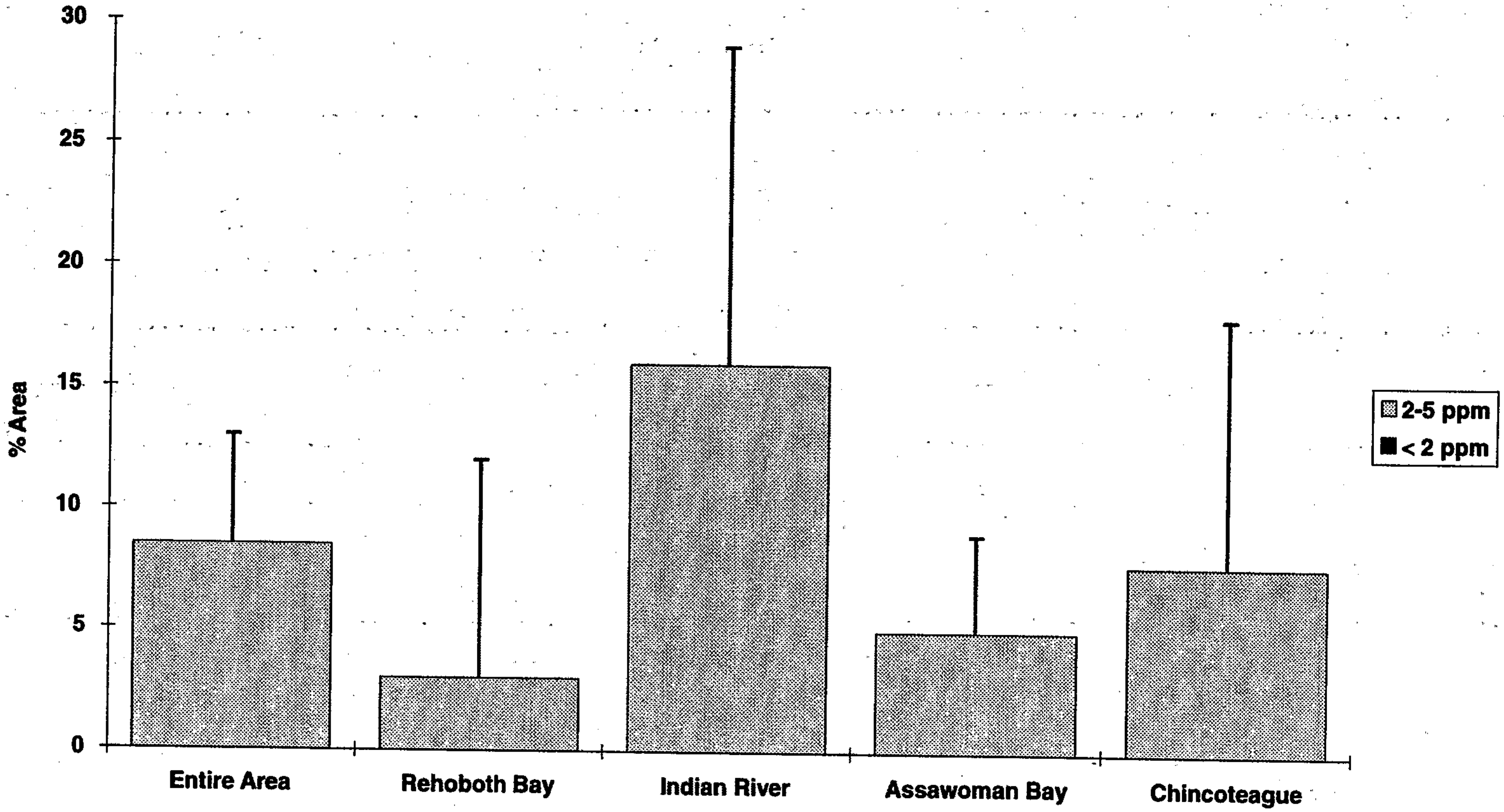

Figure 4-2. **Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays with dissolved oxygen levels below the State water quality standard (5 ppm) for Maryland and Delaware.**

The light attenuation coefficient (Kd) was calculated as 1.65/secchi depth (m) (Giesen et al. 1990). More than 55% of the area in each of the major subsystems exceeded the SAV restoration goal K_d threshold of 1.5 m^{-1} (Figure 4-3). No portion of the area in Assawoman Bay had a K_d value below the critical threshold.

Consistent with the light attenuation results, average concentrations for both total suspended solids and turbidity measurements were lowest in Chincoteague Bay (Table 4-2). Chincoteague Bay also had the largest proportion of area with TSS concentrations below the 15 mg/l SAV restoration goal (Figure 4-4). The percentage of area below this value was significantly smaller in Chincoteague than in either major system in Delaware, but was not significantly different than Assawoman Bay.

4.2.4 Nutrients

Mean concentrations of nitrate/nitrite and ammonium were highest and total dissolved nitrogen was second-highest in Indian River (Table 4-2). For nitrate/nitrite, average concentration in Indian River was 5 to 10 times and significantly greater than in any other major subsystem. Almost 15% of the area in the coastal bays failed the SAV restoration goal of 10 μM for DIN (Figure 4-5). This percentage was highest, exceeding 30%, in Indian River.

Mean DIP concentration in the two Delaware systems was approximately twice as high, and significantly greater, than the levels in both Maryland systems (Table 4-2). The difference between states was also apparent in the percent of area exceeding the 0.67 μ M SAV restoration goal for DIP (Figure 4-6). Thirty percent of the area in each of the Delaware systems exceeded that goal; in contrast, only 1% of the area in Assawoman Bay was above the DIP SAV restoration goal.

Mean concentrations of particulate nitrogen, carbon, and phosphorus were significantly higher in Assawoman Bay than in the other three major subsystems (Table 4-2). Levels were lowest in Chincoteague Bay, where they were about three times lower than in Assawoman Bay.

4.2.5 SAV Restoration Goals

Less than 25% of the area in the coastal bays met all of the SAV restoration goals (Figure 4-7). This percentage was significantly higher in Chincoteague Bay, which is the only major subsystem with substantial SAV currently growing (Orth et al. 1994, Orth and Moore 1988), than any of the other coastal bays systems (Figure 4-8). The percentage was lowest in Assawoman Bay, where none of the sampled locations met all of the SAV restoration goals.

Two of the SAV restoration goal parameters, TSS and light attenuation coefficient, are strongly influenced by physical mixing characteristics of the system and are not easily controlled by management action. The action of the wind and waves combined with the average shallow depth and poor flushing characteristics of the coastal bays cause the bays to retain and resuspend fine sediments, making the water turbid. Because of this, the amount of area in the system meeting SAV goals was reassessed considering only the parameters that are most controllable by management actions: chlorophyll a, DIN, and DIP. When examined in this fashion, almost half the area in the coastal bays still fails to meet the goals; however, the

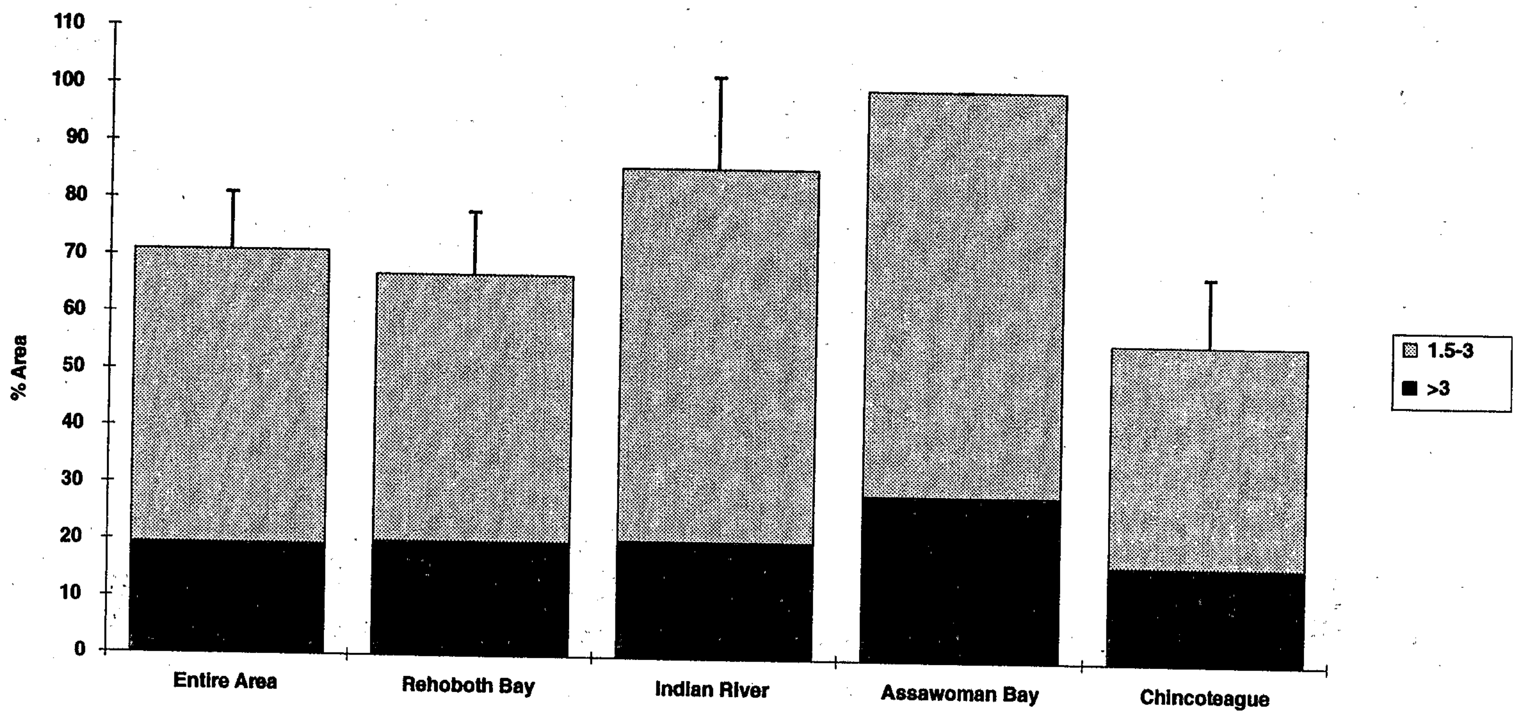

Figure 4-3. Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays which exceeded the SAV restoration goals for light attenuation coefficient (kd = 1.5 m^{-1}).

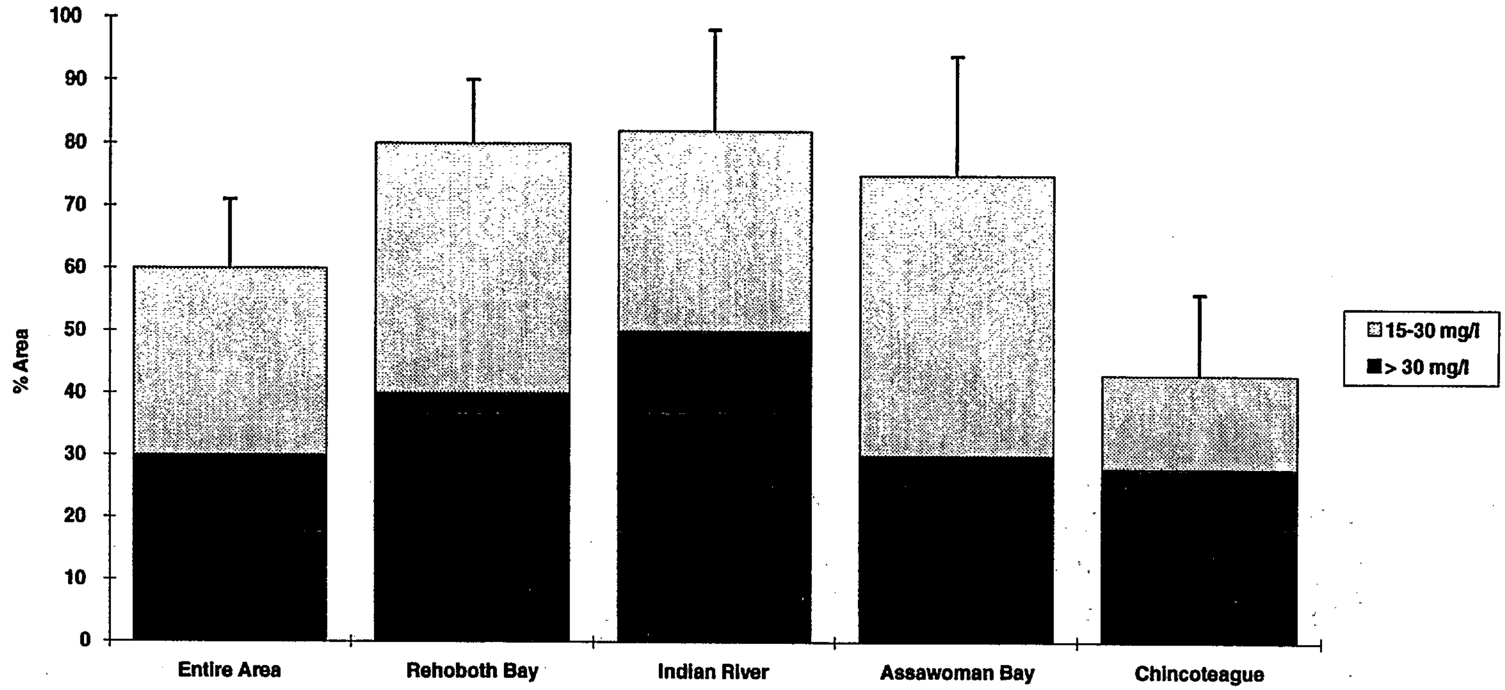

Figure 4-4. Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays which exceeded the SAV restoration goals for total suspended solids (15 mg/l).

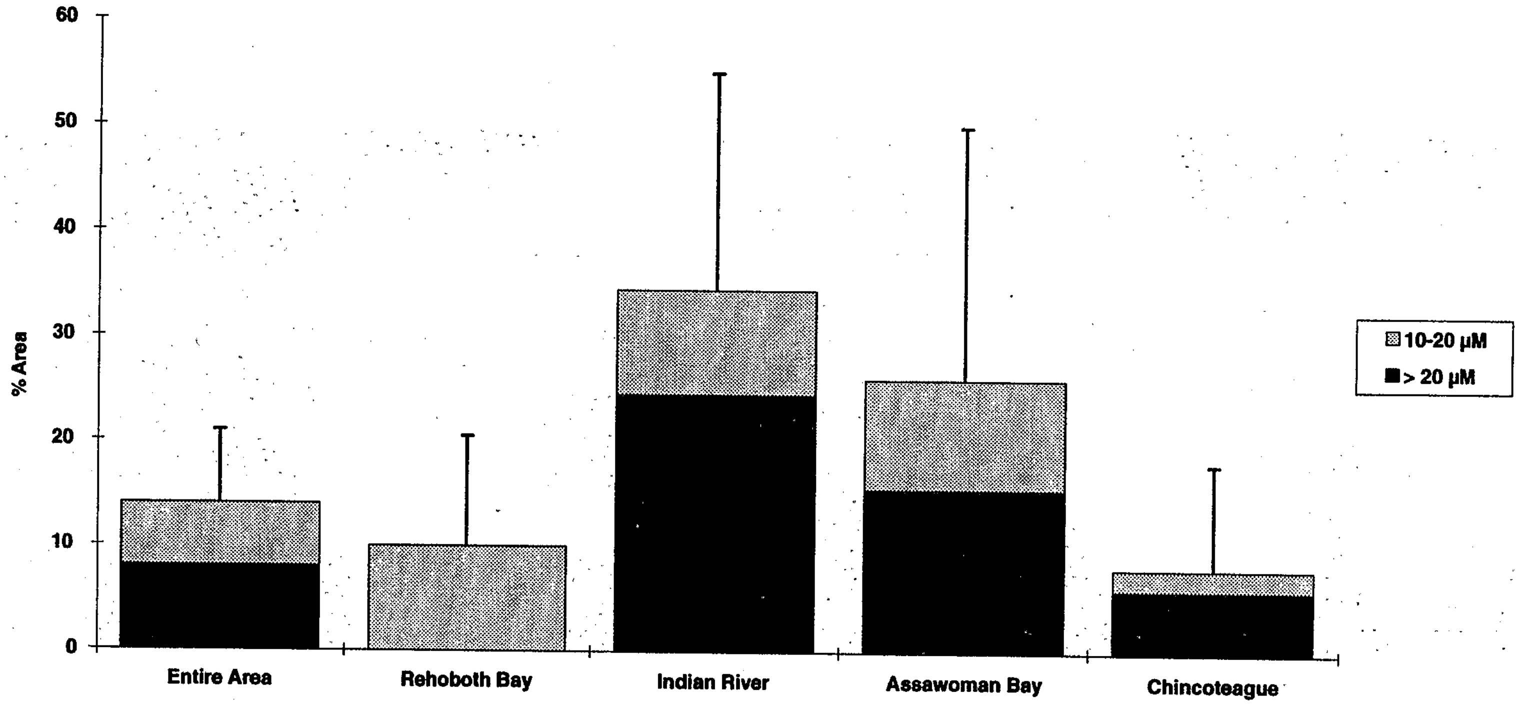

Figure 4-5. Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays which exceeded the SAV restoration goals for dissolved organic nitrogen (10 μM).

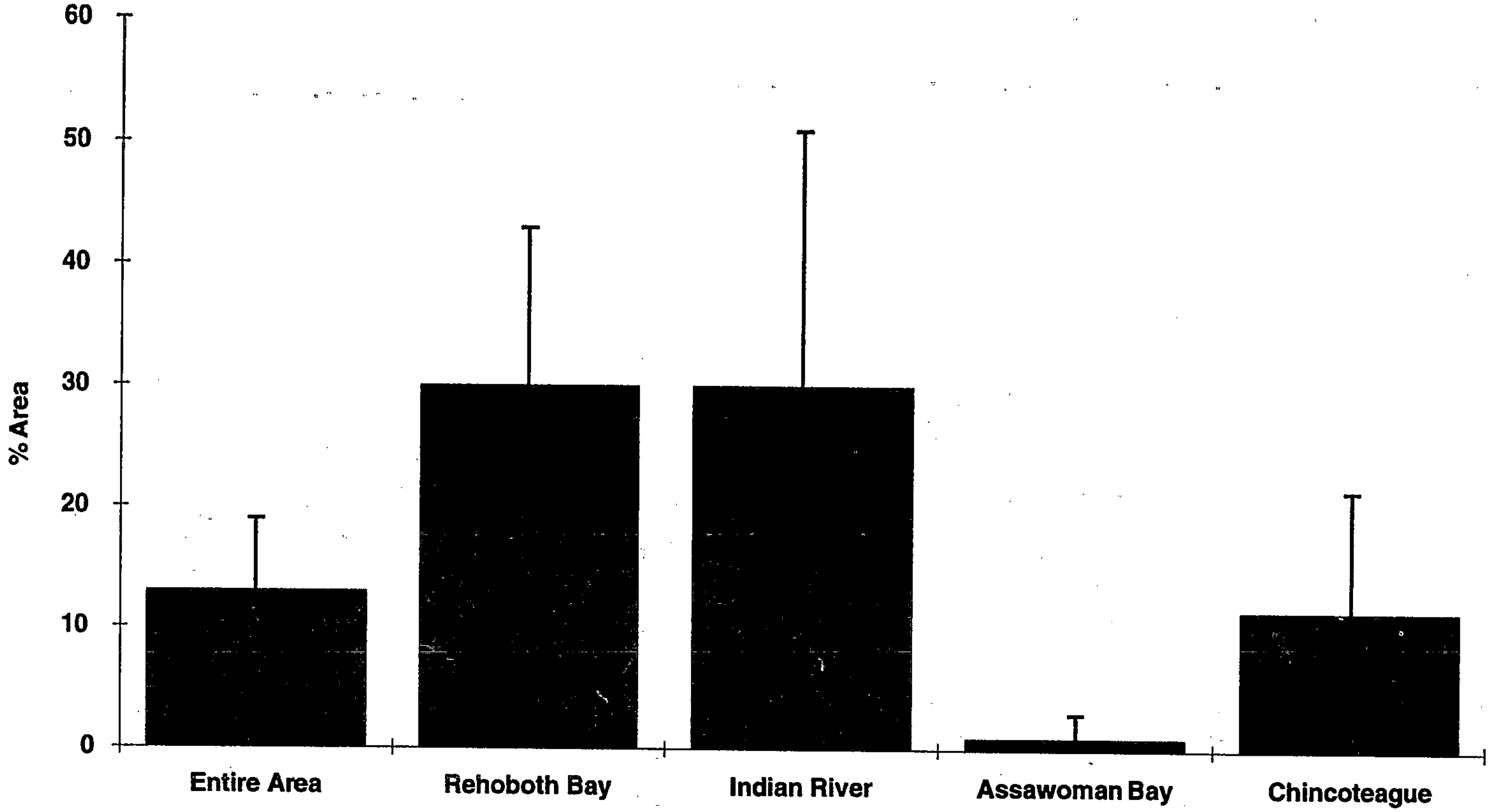

Figure 4-6. Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays which exceeded the SAV restoration goals for dissolved inorganic phosphorus (0.67 μM).

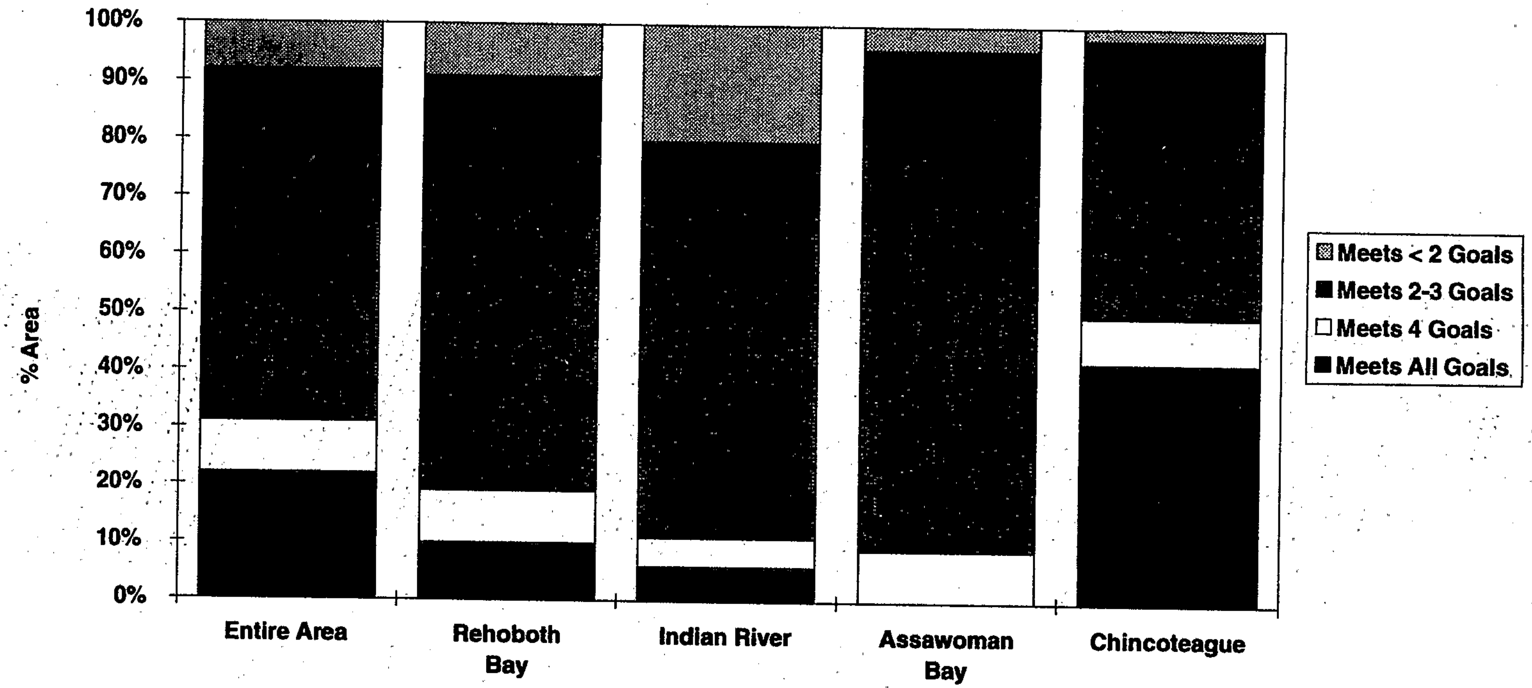

Figure 4-7. Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays which meets SAV restoration goals attributes.

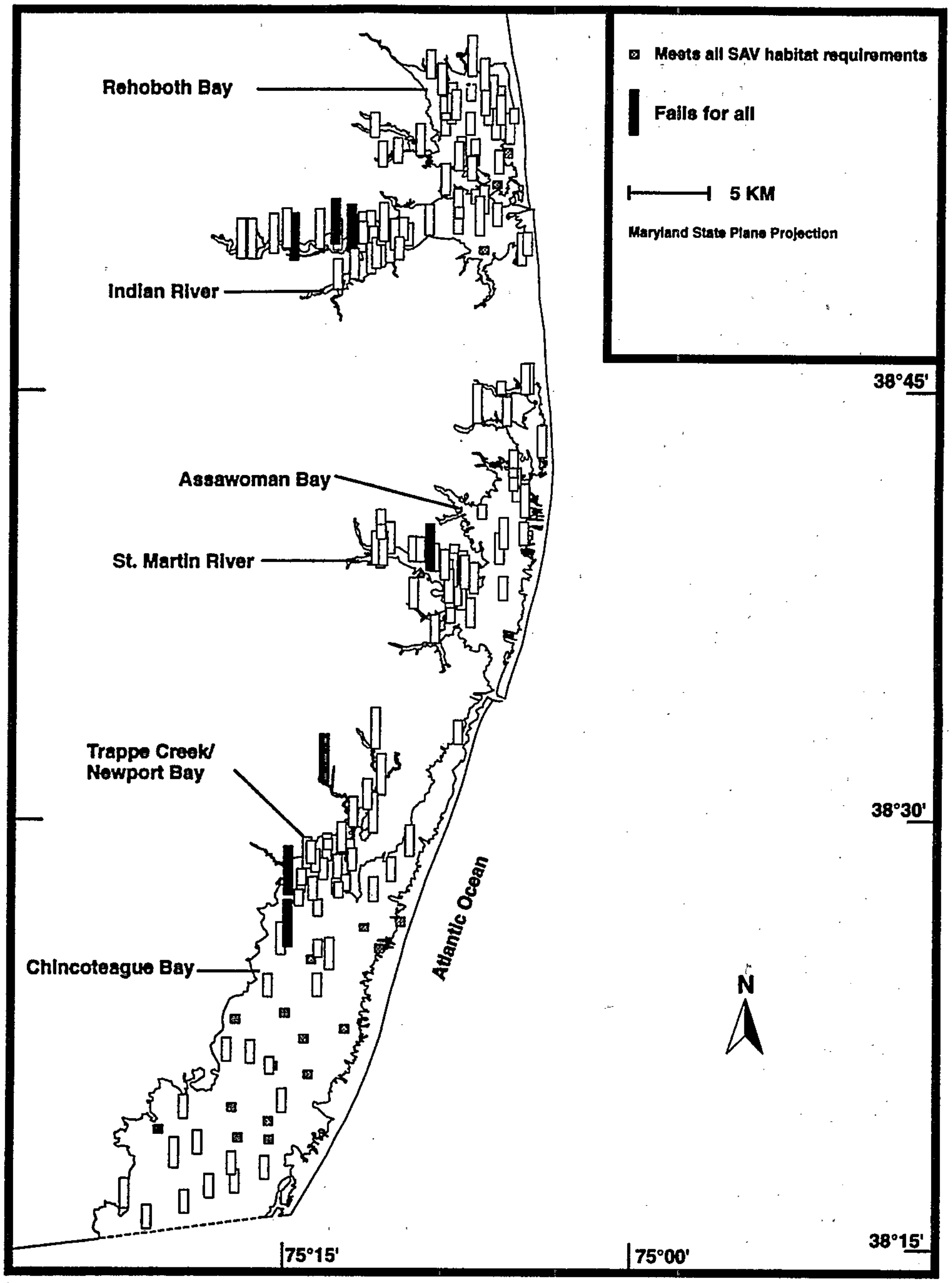

Figure 4-8. Spatial distribution of non-lagoon sites in the Delaware/Maryland coastal bays study area which met the SAV restoration goals. Cross-hatched bars represent sites where all goals attributes were met; clear bars represent sites where a subset of attributes were met, with height of the bar proportional to the number of attributes failed; and solid bars represent sites where no attributes were met.

proportion of area in Chincoteague Bay which meets the goals for the three attributes increases to more than 80% (Figure 4-9).

4.3 TARGET AREAS

4.3.1 Measures of Algal Productivity

Mean concentrations of chlorophyll *a* were significantly higher in all special target areas than in the study area as a whole (Table 4-2). Trappe Creek/Newport Bay had the highest concentration, four times that of the entire study area. At least two sites in the upper portion of Trappe Creek had concentrations of chlorophyll *a* exceeding 350 μ g/l (Figure 4-10); algal blooms were evident at both sites. Mean phaeophytin concentration patterns differed, however, with average concentrations two to four times higher in the other systems than in Trappe Creek/Newport Bay.

More than 70% of the area in upper Indian River, St. Martin River, and the dead-end canals had chlorophyll *a* concentrations exceeding 15 μ g/l (Figure 4-11)). Almost the entire area of upper Indian River had levels exceeding 15 μ g/l; more than 50% of the area exceeded 30 μ g/l.

Average measured concentrations of benthic chlorophyll in most of the special target areas were similar to the average concentration in the entire study area (Table 4-2). The dead-end canals were a large exception to the results; average concentrations of benthic chlorophyll were more than five times larger in the canals than in the remaining study area.

4.3.2 Dissolved Oxygen

Except for the dead-end canals, mean concentrations of DO in the special target areas did not vary appreciably from the average DO concentration in the entire study area (Table 4-2). The canals had a mean dissolved concentration less than 4 ppm, significantly lower than the entire study area.

Differences in DO concentrations were more pronounced when evaluated by proportion of area. The percentage of area with DO less than the state standard of 5 ppm was three to seven times greater in the special target areas than in the entire study area (Figure 4-12). Dead-end canals were the most hypoxic systems. More than 55% of the area in dead-end canals had DO less than 5 ppm; more than 30% of that area had concentrations less than 2 ppm.

4.3.3 Measures of Water Clarity

Water clarity and TSS did not differ significantly between any of the special target areas and the coastal bays as a whole (Table 4-2). The pattern was similar when looking at the proportion of area with TSS concentrations greater than the SAV restoration goal of 15 mg/l. The percentages for all special target areas, except dead-end canals, were slightly higher than for the entire study area, but the differences were not statistically significant.

4.3.4 Nutrients

Mean concentrations of nitrate/nitrite varied considerably among special target areas, ranging from 0.10 to 9.15 μ M (Table 4-2). St. Martin River had the lowest concentration; upper Indian

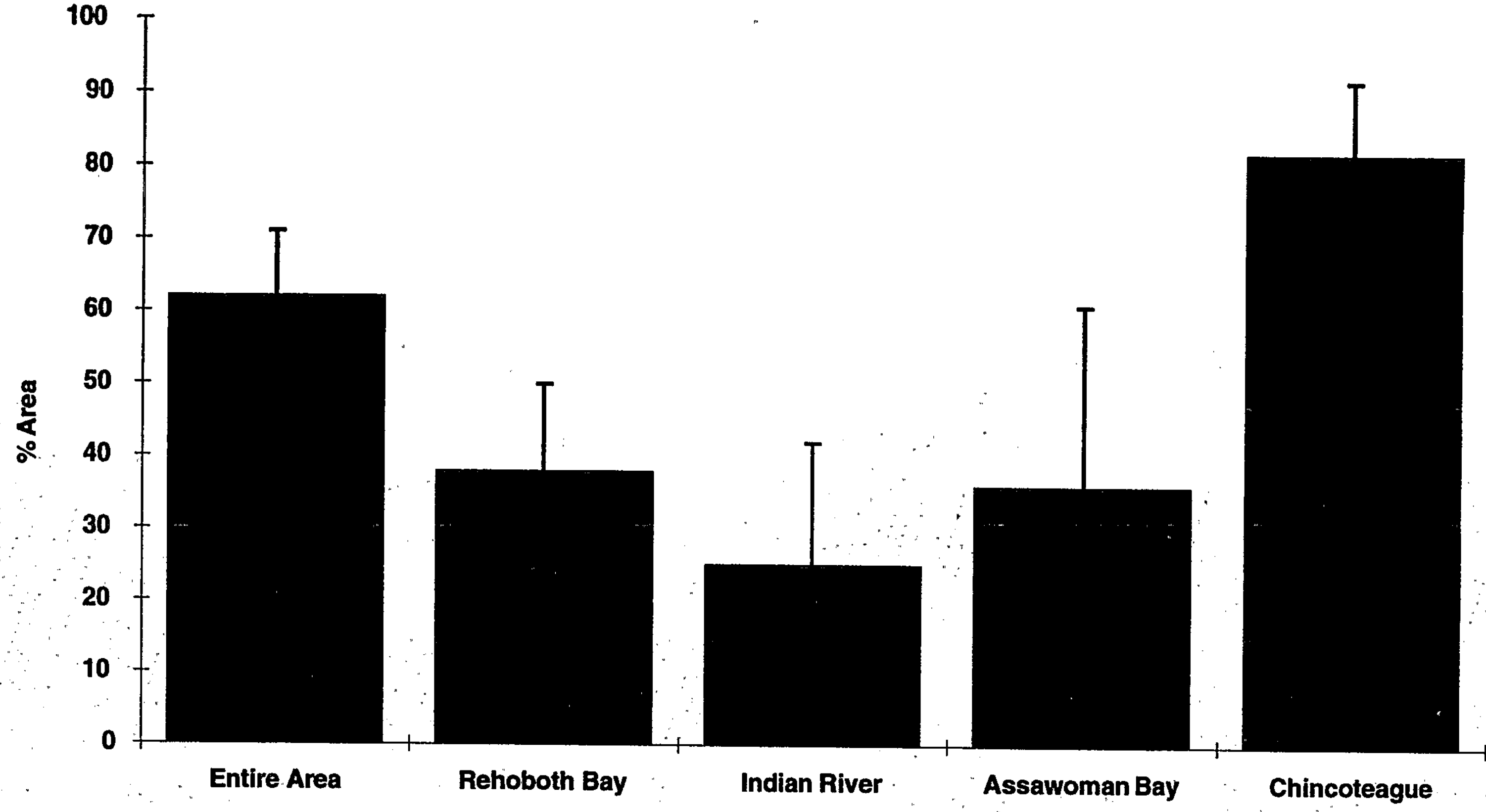

Figure 4-9. Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays which met the SAV restoration goals for chlorophyll and nutrients.

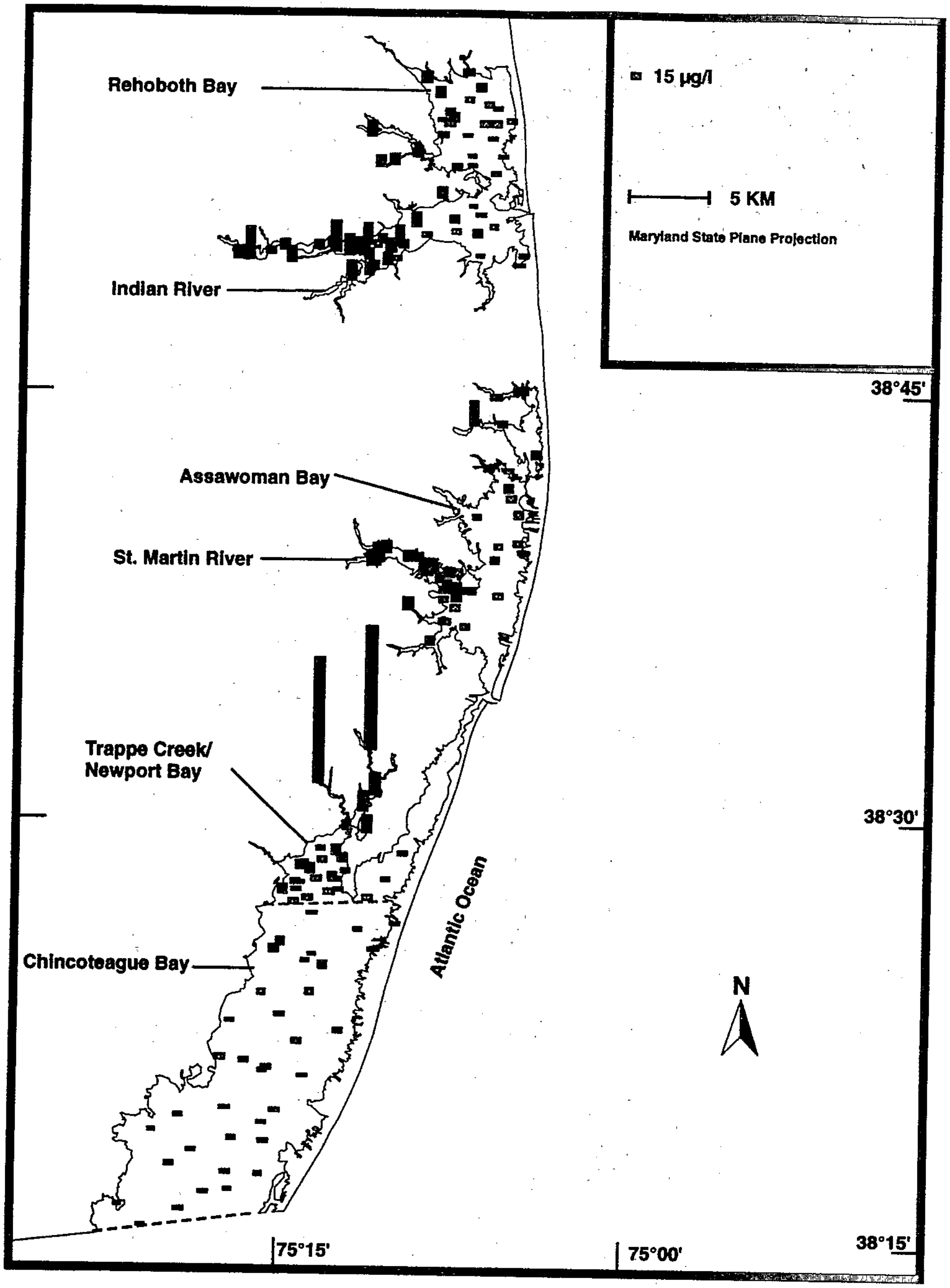

Figure 4-10. Spatial distribution of chlorophyll *a* concentrations at non-lagoon sites in the Delaware/Maryland coastal bays study area. Black-shaded bars represent concentrations which exceeded the SAV restoration goal for chlorophyll *a* (15 μg/l.)

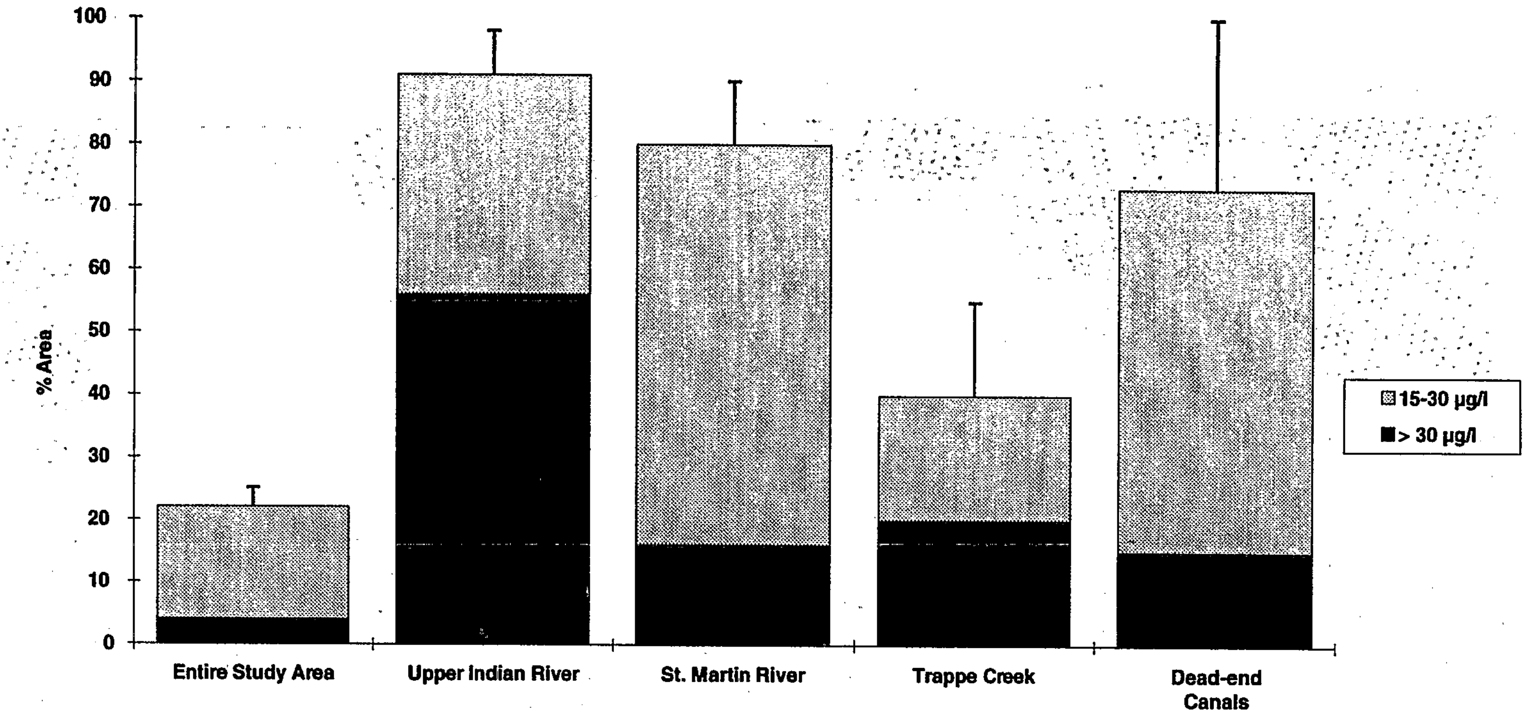

Figure 4-11. Percent of area (90% C.I.) in special target areas in the Delaware/Maryland coastal bays which exceeded the SAV restoration goals for chlorophyll *a* (15 μg/l).

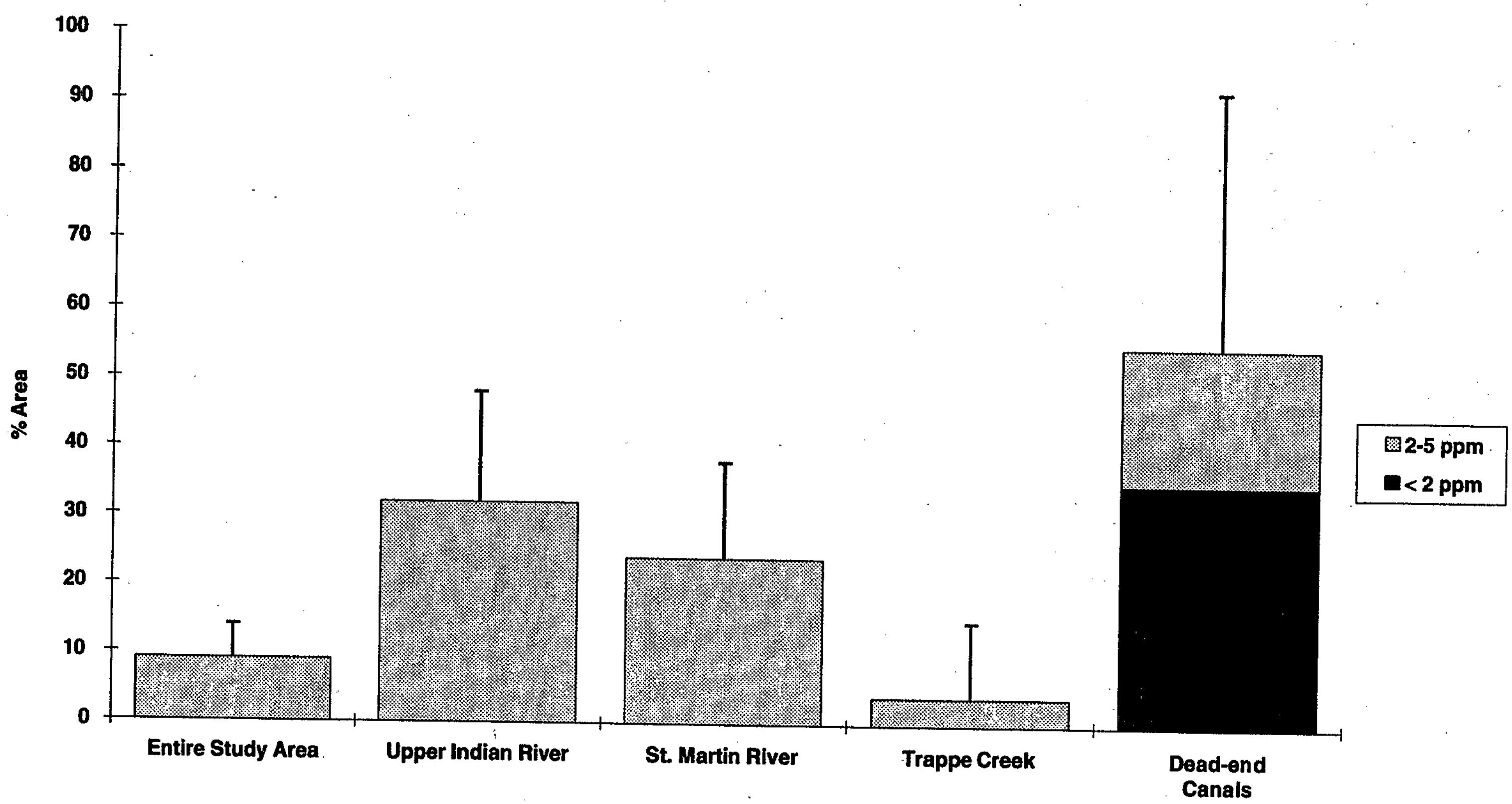

Figure 4-12. Percent of area (90% C.I.) in special target areas in the Delaware/Maryland coastal bays with dissolved oxygen levels below the state water quality standard (5 ppm) for Maryland and Delaware.

River had the highest concentrations, and both concentrations were significantly different than the average for the entire study area. Upper Indian River also had a significantly higher average concentration of ammonium than the entire study area.

Average DIN did not vary appreciably between three of the four special target areas and the entire study area, but upper Indian River had significantly greater levels, more than three times higher than the entire study area and the other three systems (Table 4-2). The proportion of area that failed to meet the SAV restoration goal for DIN was more than 50% in upper Indian River, almost three times greater than in the remaining coastal bays (Figure 4-13).

All special target areas had mean concentrations of total dissolved nitrogen greater than the average for the entire study area; however, only Trappe Creek/Newport Bay and upper Indian River were significantly higher then the entire study area (Table 4-2).

Mean concentrations of DIP in the upper Indian River, St. Martin River, and the dead-end canals were similar to the mean for the entire study area (Table 4-2). The mean concentration in Trappe Creek/Newport Bay was twice as high as the mean for the entire study area, but the difference was not statistically significant. The pattern was somewhat different when expressed as areal extent. Both upper Indian River and Trappe Creek/Newport Bay had approximately twice the proportion of area with DIP concentrations greater than 0.67 μ M, compared to the entire study area (Figure 4-14).

The mean concentration of particulate nitrogen, phosphorus, and carbon were all significantly higher in the special target areas than in the coastal bays as a whole (Table 4-2). No significant differences among the special target areas were found for any of the particulate parameters (Table 4-2).

4.3.5 SAV Restoration Goals

None of the samples collected in the special target areas met the SAV restoration goals. Even when considering only the nitrogen, phosphorus, and chlorophyll goals, less than 20% of the area in three of the systems met the goals (Figure 4-15).

4.4 COMPARISON WITH PREVIOUS STUDIES

Consistent with previous characterizations of the coastal bays (Weston 1993, Boynton et al. 1993), we found moderate eutrophication in the system with the highest nutrient/-chlorophyll concentrations occurring in the tributaries. Consistent with Weston (1993), we observed a significant inverse salinity:nutrient correlation, suggesting that the tributaries are a significant nutrient source for the coastal bays. While we found eutrophication to be widespread in the coastal bays, we found that eutrophication has not translated into a widespread hypoxia problem. Oxygen concentrations less than 5 ppm were observed in only 8% of the area of the coastal bays, though it was as high as 25% in upper Indian River and St. Martin River. This is consistent with previous studies in which concentrations of dissolved oxygen less than 5 ppm were rarely measured and were spatially limited to known target areas of management concern.

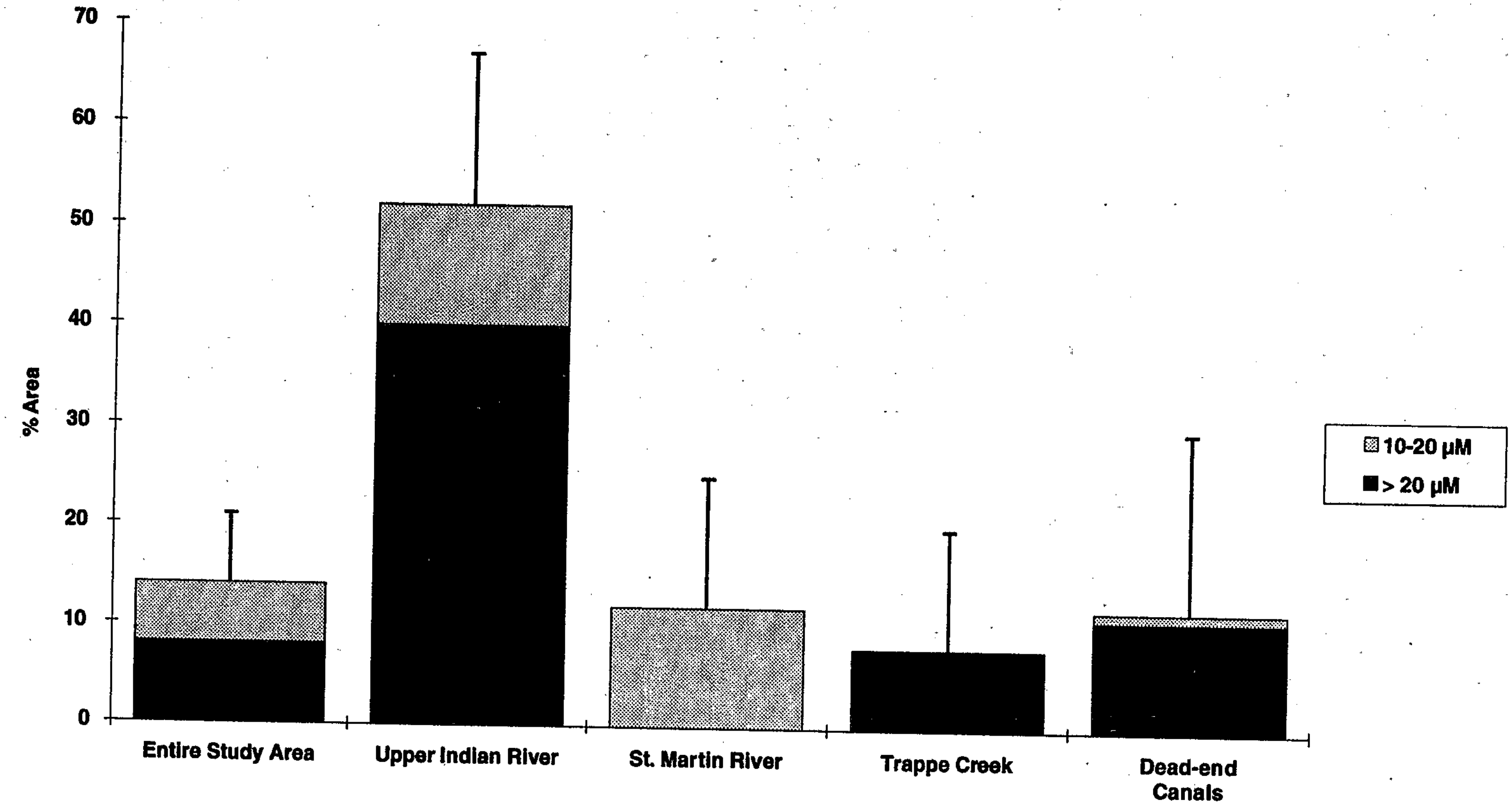

Figure 4-13. Percent of area (90% C.I.) in special target areas in the Delaware/Maryland coastal bays which exceeded SAV restoration goals for dissolved inorganic nitrogen (10 μM).

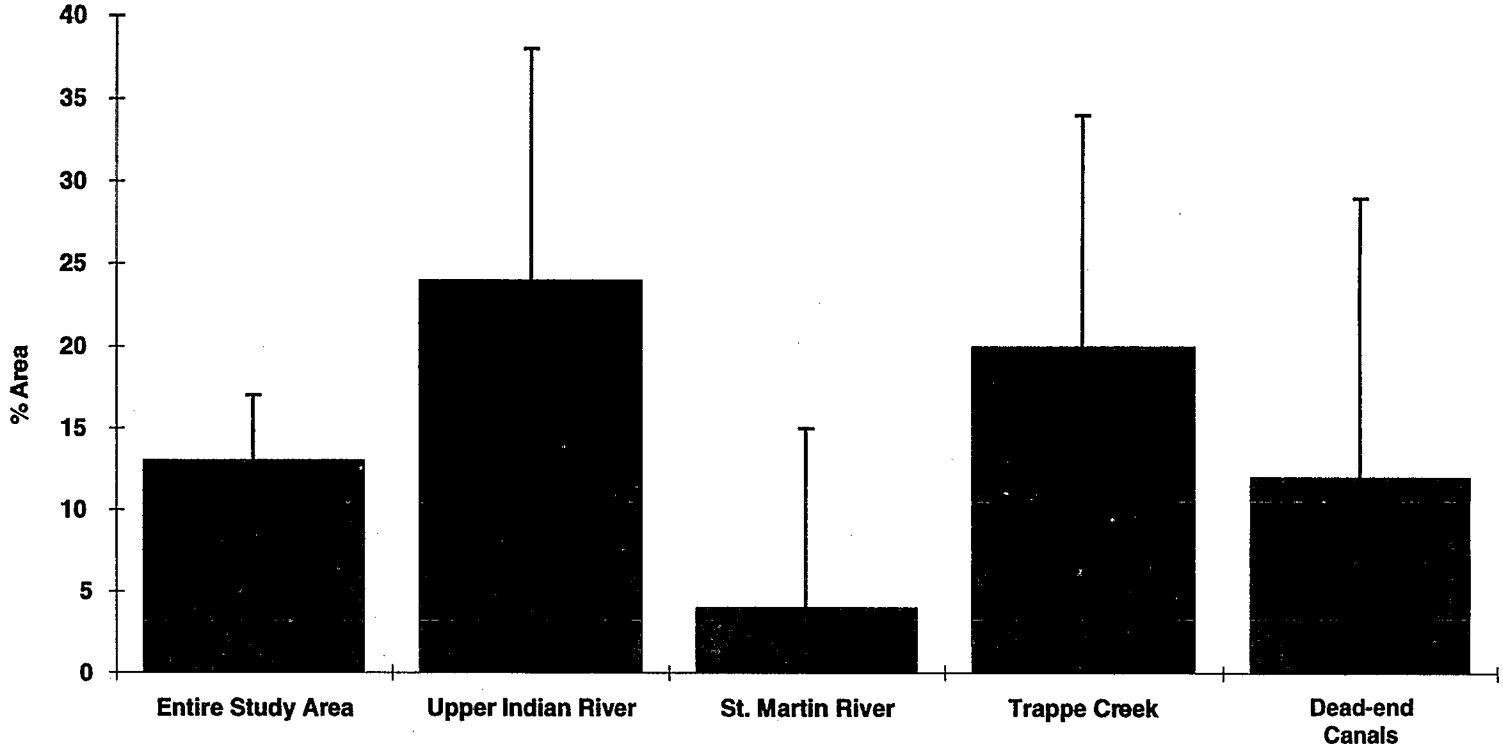

Figure 4-14. Percent of area (90% C.I.) in special target areas in the Delaware/Maryland coastal bays which exceeded SAV restoration goals for dissolved inorganic phosphorus (0.67 μM).

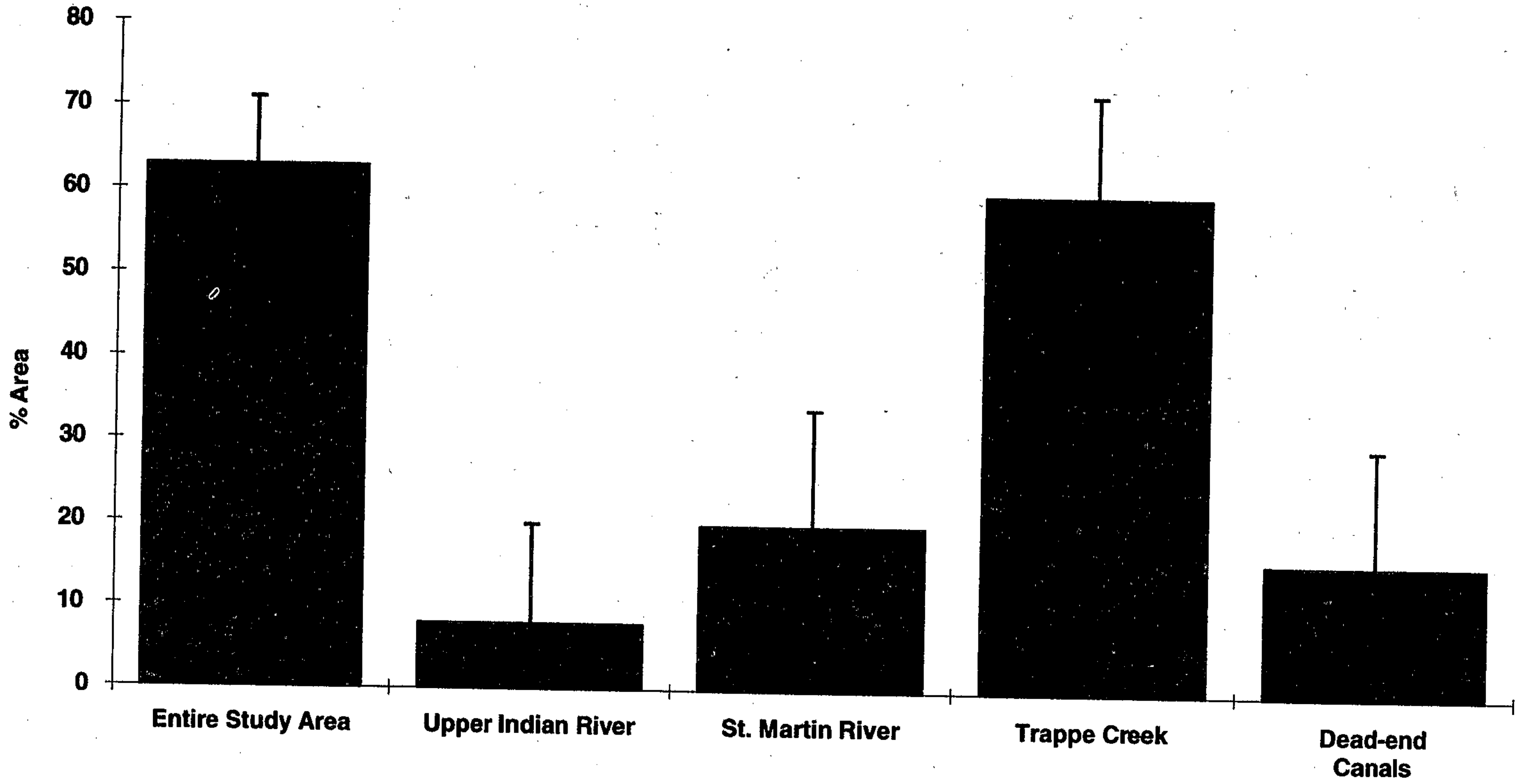

Figure 4-15. Percent of area (90% C.I.) in special target areas in the Delaware/Maryland coastal bays which met SAV restoration goals for dissolved nutrients and chlorophyll.

The amount of hypoxic area in the coastal bays may be underestimated because our measurements were limited to daytime hours. A part of this study, continuously recording dissolved oxygen meters were deployed for up to three weeks at 15 sites in the coastal bays. Detailed analyses of those data will be a future part of the joint assessment, but initial observations are that diurnal oxygen patterns in the coastal bays, with the exception of Trappe Creek are small. This is consistent with historic diurnal measurements in the coastal bays (Boynton et al. 1993) and suggests that our spatial estimate of hypoxia in the coastal bays is not a severe underestimate.

The apparent conflict between widespread eutrophication, as measured by the SAV Restoration Goals, and the apparent limited spatial extent of hypoxia may be explained by the physical characteristics of the system. The coastal bays are shallow and well mixed, which serves to reaerate the system quickly. The presence of hypoxia under these conditions, as occurs in 25% of the area in St. Martin River and upper Indian River, is indicative of substantial eutrophication concern.

While it was not the goal of this report to assess historical data for trend analysis, both previous characterizations of the coastal bays (Weston 1993, Boynton et al. 1993) noted that both chlorophyll and nutrient concentrations have declined throughout the coastal bays during the last two decades. Our data are consistent with that pattern. Summer chlorophyll concentrations in the Maryland coastal bays have declined by more than 50% since 1975 (Figure 4-16) and similar declines have occurred in the Delaware coastal bays (Lacoutre and Sellner 1988). Nitrogen concentrations in our study were approximately one-half of the values reported by Boynton et al. (1993) and Weston (1993) for historic studies, consistent with Weston's suggestion that nitrogen inputs to the system have declined during the last two decades. While these temporal patterns are consistent across a number of studies and parameters, more extensive examination of these trends needs to be conducted to ensure that the concentration differences observed among years do not result from inconsistencies in sampling design or measurement methodologies.

4.5 COMPARISON TO SURROUNDING SYSTEMS

Nutrient concentrations are not measured typically as part of the EMAP sampling and comparisons of these parameters to other Delaware and Chesapeake data sets is beyond the scope of this data summary report. Recent assessment reports by the Chesapeake Bay Program (Magnien et al. 1995) have identified that about 75% of the area in Chesapeake Bay meets the SAV restoration goals, which is triple the proportion of area in the coastal bays. In Chesapeake Bay, 90% of the area meets four of the five SAV goal attributes, whereas only 32% of the area in the coastal bays meets the same goals. The Chesapeake Bay estimate is not based on probability-based sampling and may include multiple months of data for each site. Thus, the estimate may not be directly comparable to that from this study, but the magnitude of the difference between estimates for the systems appears to transcend minor methodological differences between studies.

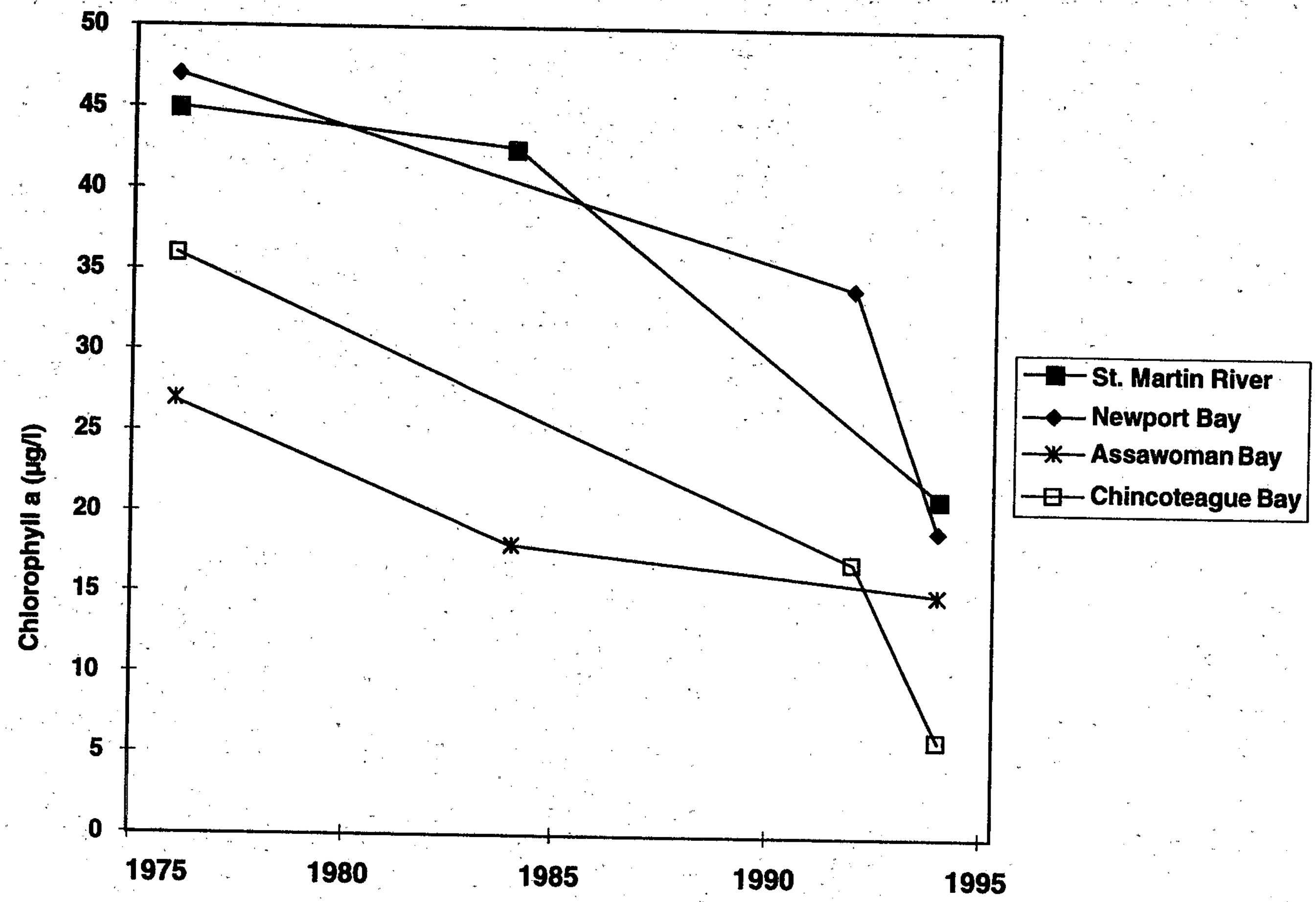

Figure 4-16. Summer average chlorophyll a concentrations for major subsystems of the Delaware/Maryland coastal bays. Sources: Fang et al. (1977), Maryland Department of the Environment (1983), National Park Service (1991), and the present study.

5.0 SEDIMENT CONTAMINANTS

5.1 INTRODUCTION

The scientific and popular presses have identified the presence of contaminants in estuaries as a problem contributing to degraded ecological resources and concerns about the safety of consuming fish and shellfish (Broutman and Leonard 1988, NOAA 1990, OTA 1987, O'Connor 1990). Reducing contaminant inuts and concentrations, therefore, is often a major focus of regulatory programs for estuaries. Contaminants include inorganic (metals) and organic chemicals originating from many sources such as atmospheric deposition, freshwater inputs, land runoff, and point sources. These sources are poorly characterized except in the most well-studied estuaries. Most contaminants that are potentially toxic to biological resources tend to bind to particles and ultimately are deposited in the bottom of estuaries (Santschi et al. 1980, Santschi 1984). This binding removes contaminants from the water column. Consequently, contaminants accumulate in estuarine sediments (Santschi et al. 1984).

Because of the complex nature of sediment geochemistry, and possible additive, synergistic, and antagonistic interactions among multiple pollutants, the ecological impact of elevated contaminant levels in bottom sediments is not well understood. Several strategies for estimating biological effects from contaminated sediments include the EPA Sediment Quality Criteria approach (U.S. EPA 1993a-d), the Long and Morgan approach (Long and Morgan 1990, Long et al. 1995), and the SEM/AVS (simultaneously extracted metals/acid volatile sulfides) approach (DiToro et al. 1989, 1990 and 1992). Because these various techniques result in different estimates, definitive estimates of those areas of the coastal bays with contaminant concentration high enough to cause ecological impacts cannot be provided with confidence (Strobel et al. 1995). For this reason, the analyses presented in this Section are provided for screening purposes only.

The guideline values developed by Long and Morgan (1990) and recently updated by Long et al. (1995) were used to screen contaminant levels in coastal bay sediments with respect to potential biological effects. These values were selected because they include values for most of the chemicals we measured, thus allowing us to provide the most complete evaluation of the data. Two values were identified for each contaminant: an effects range-low (ER-L) value corresponding to contaminant concentrations below which adverse effects to benthic organisms "rarely" occur, and an effects range-

Table 5-1. ER-L and ER-M guideline values for trace metals and organic compounds in sediments. Sources: Long and Morgan (1990), Long et al. (1995).

Chemical Analyte	ER-L Concentration	ER-M Concentration
Trace Elements (ppm)		
Antimony	2	25
Arsenic	8.2	70
Cadmium	1.2	9.6
Chromium	81	370
Copper	34	270
Lead	46.7	218
Mercury	0.15	0.71
Nickel	20.9	51.6
Silver	1	3.7
Zinc	150	410
Polychlorinated Biphenyls (ppb)		
Total PCBs	22.7	180
DDT and Metabolites (ppb)		
DDT	1	7
DDD	2	20
DDE	2	15
Total DDT	1.58	46.1
PPDDE	2.2	27
Other Pesticides (ppb)		
Chlordane	0.5	6
Dieldrin	0.02	8
Endrin	0.02	45
Polynuclear Aromatic Hydrocarbons (ppb)		
Acenaphthene	16	500
Acenaphthylene	44	640
PAH (high mol. wt.)	1700	9600
PAH (low mol. wt.)	552	3160
Anthracene	85.3	1100
Benzo(a)anthracene	261	1600
Benzo(a)pyrene	430	1600
Chrysene	384	2800
Dibenz(a,h)anthracene	63.4	260
Fluoranthene	600	5100
Fluorene	19	540
2-methylnaphthalene	70	670
Naphthalene	160	2100
Phenanthrene	240	1500
Pyrene	665	2600
Total PAH	4022	44792

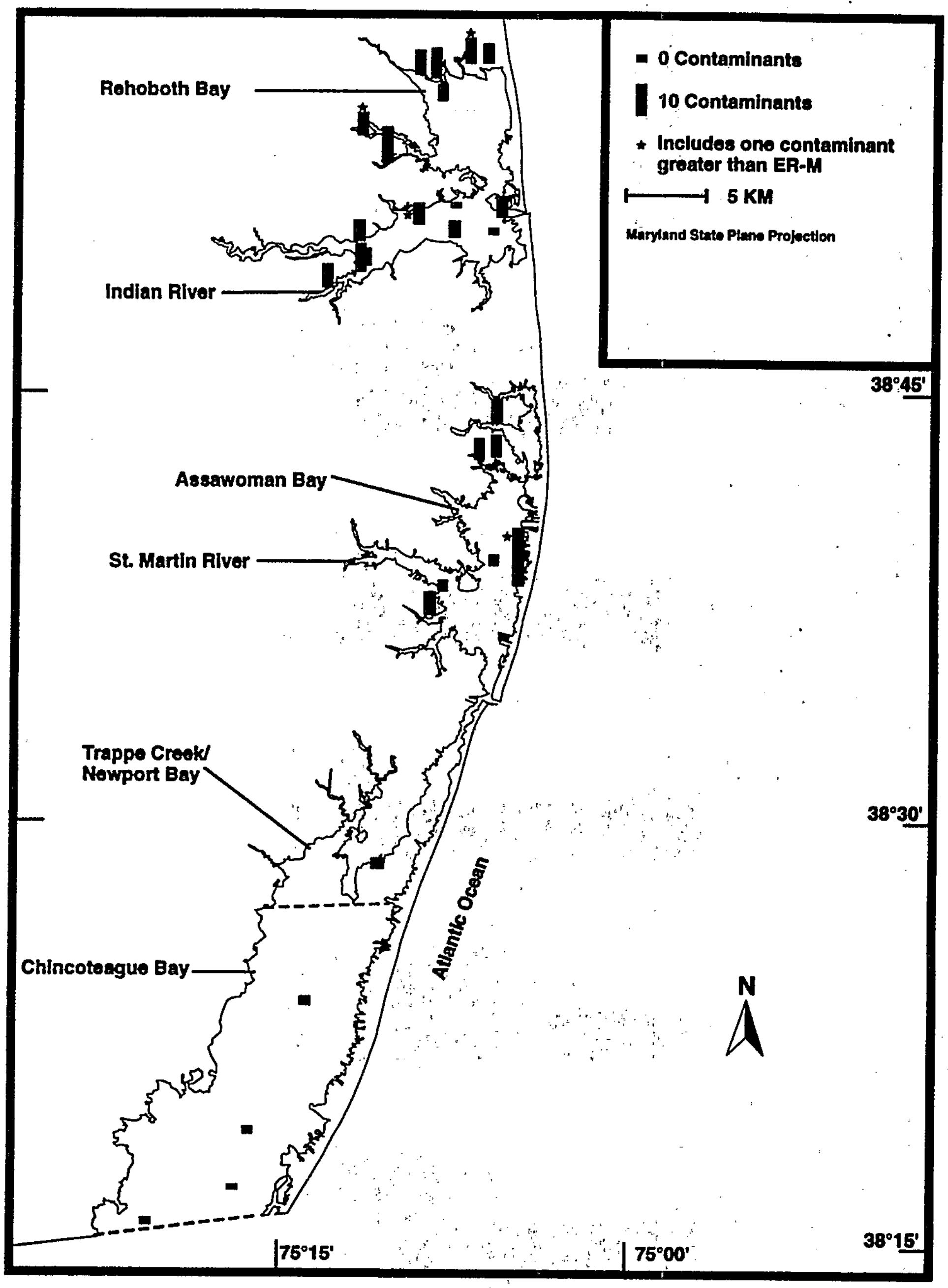

Figure 5-1. Spatial distribution of sites (including dead-end canals) for which sediment contaminants were analyzed. Bar height is directly proportional to number of sediment contaminants which exceeded ER-L threshold concentrations. Asterisk indicates sites where a contaminant exceeded ER-M concentration.

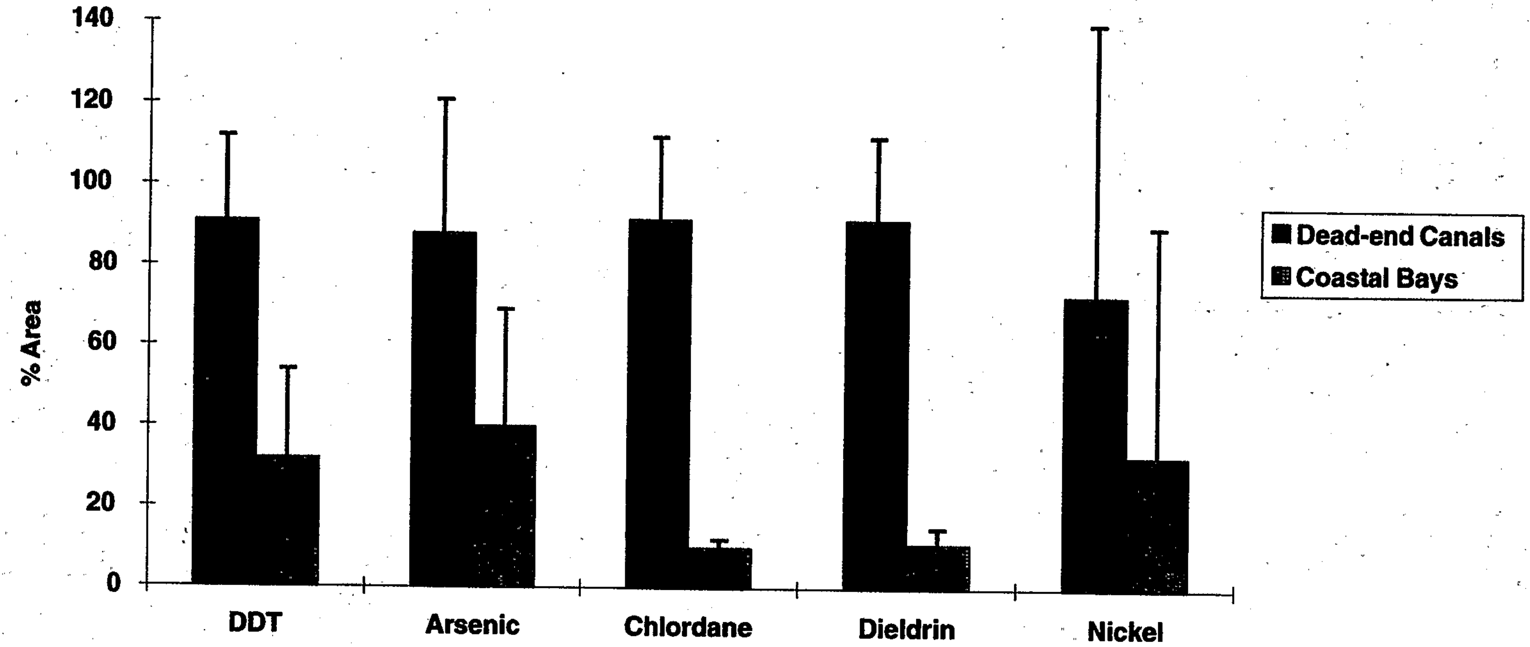

Figure 5-2. Percent of area with concentrations exceeding ER-L values for the five most prevalent contaminants in the Delaware/Maryland coastal bays.

Table 5-2. Area-weighted mean concentrations (± 90% C.I.) of sediment contaminants in the Coastal Bays and Dead-End Canals

	Coastal Bays	Dead-end Canals
Metals (ppm)		
Silver	0.05 ± 0.02	0.1 ± < 0.1
Arsenic	7.03 ± 1.91	10.6 ± 2
Cadmium	0.14 ± 0.05	0.2 ± < 0.1
Chromium	41.98 ± 10.58	56.1 ± 21.7
Copper	9.52 ± 2.81	40.6 ± 10.3
Lead	24.14 ± 5.83	34.4 ± 6.6
Nickel	13.93 ± 4.65	21.1 ± 9.2
Zinc	64.53 ± 16.35	107.9 ± 28.9
Pesticides (ppb)		
Chlordane	0.41 ± 0.39	1.8± 0.7
Total DDT	2.15 ± 0.87	3.1± 2.9
Lindane	0.20 ± 0.15	0.9± 0.2
Mirex	0.12 ± 0.17	0
Endrin	0.04 ± 0.02	0.5± 0.1
Dieldrin	0.13 ± 0.07	1.7± 1.8
Total PAHs (ppb)	232.33 ± 92.43	2060.9 ± 1099.7
Total PCBs (ppb)	2.89 ± 1.04	19.8 ± 5.5

median (ER-M) concentration above which adverse effects "frequently" occur (Long et al. 1995). Adverse effects could be expected to "occasionally" occur when the measured concentration falls between the ER-L and ER-M (Long et al. 1995). According to Long and Morgan (1990), sites with the greatest number of ER-L and ER-M exceedences have the highest potential for cause adverse biological effects. In those situations where there is a high potential for adverse effects based upon exceedences of ER-Ls and ER-Ms, EPA and others have suggested follow-up testing such as solid phase toxicity testing to directly measure biological effects (Adams et al. 1992, Chapman et al. 1992, EPA 1992). Future activities may include these additional analyses.

Only a subset of the sediment samples collected were processed for contaminants because of cost constraints. Consequently, comparisons were limited to dead-end canals (10 sites) and the coastal bays as a whole (24 sites).

5.2 CONDITION OF THE COASTAL BAYS

At least 1 contaminant exceeded its ER-L concentration at 70% of the 24 sites in the coastal bays (excluding sites in the dead-end canals) where contaminant samples were processed. This corresponded to 68% (± 23%) of the total area of the system. Only four sites (representing 4% of the area in the system) had at least one contaminant that exceeded its ER-M concentration.

Many sites had more than one contaminant that exceeded its ER-L concentration. A dead-end canal on the east side of Assawoman Bay contained the most contaminants that exceeded their ER-L concentrations (20). The number of contaminants that exceeded ER-L in the coastal bays increased from south to north. Indian River had the most sites with multiple contaminants exceeding ER-L and had one site with a contaminant exceeding ER-M (Figure 5-1). The majority of sites in Rehoboth Bay with multiple contaminants were located in dead-end canals. Five of the seven sites in Rehoboth Bay were canal sites containing more then five contaminants exceeding ER-L concentrations.

The most ubiquitous contaminants (measured as the estimated area in which the contaminant exceeded its ER-L concentration), were DDT, arsenic, and nickel, with each found to exceed ER-L in more than a quarter of the bottom of the area of the system (Figure 5-2). DDT and its principal metabolites were 4 of the top 10 contaminants. The only ER-M concentration exceedances were for chlordane, dieldrin, DDE, and benzo(a)anthracene, which were exceeded at single, separate sites (Figure 5-1).

In this study, Long et al. (1995) and Long and Morgan (1990) ER-L and ER-M thresholds were used as a means of estimating the areal extent of contaminants in the coastal bays; however, other authors have suggested alternative approaches for identifying thresholds of biological concern (DiToro et al. 1990, 1991, 1992; EPA 1993). Long et al. values were selected because they included thresholds for most of the chemicals that we measured, allowing us to provide an integrated contaminant response, whereas other approaches for identifying thresholds have been developed for a relatively small number of chemicals. These alternative thresholds, when applied to the coastal bays data set, lead to a smaller estimate of areal extent (Greene 1995), suggesting that the ER-L thresholds are more protective of the environment. Future CBJA activities may include analyses to relate the biological responses reported in this chapter with the sediment contaminant data reported here.

5.3 CONDITION OF DEAD-END CANALS

Concentrations of contaminants generally were higher in the sediments of dead-end canals than in the rest of the coastal bays. Fifteen of the 45 contaminants measured had significantly higher mean concentrations in the canals. No contaminants had significantly higher concentrations in the rest of the coastal bays than in the canals (Table 5-2). The difference in concentration between canals and the coastal bays was greatest for the polynuclear aromatic hydrocarbons (e.g., chrysene and pyrene); the concentrations of many of these contaminants were 10 times higher in the dead-end canals than in the rest of the coastal bays (Appendix C).

The difference between the dead-end canals and the rest of the coastal bays was also apparent in the spatial extent of contamination. Of the five most ubiquitous contaminants in the coastal bays, none exceeded ER-L concentrations for more than 42% of the total area of the coastal bays; however, these contaminants each exceeded their ER-L concentrations in more than 70% of the area of the dead-end canals (Figure 5-2). Seventy-five percent of the area of dead-end canals had more than six contaminants that exceeded their ER-L concentrations (Figure 5-3). In contrast, only 10% of the area in the rest of coastal bays had more than five contaminants above ER-L, and 30% had no contaminants that exceeded ER-L concentrations.

5.4 COMPARISON TO PREVIOUS STUDIES

The Delaware/Maryland coastal bays study represents to the best of our knowledge the first substantive assessment of sediment contaminants in the coastal bays. Although only a subset of the sediment samples collected for contaminant analysis were processed, the data presented in this report represent a ten-fold increase in available data over the last 15 years. No data were reported in the Delaware Inland Bays Estuary Program's characterization report (Weston 1993) because the data found were insufficient for a status determination. The Maryland report (Boynton et al. 1993) contained three years of data for a single site at Chincoteague Inlet, VA. Three-year average concentrations were found to be elevated relative to detection levels but only dieldrin was measured at concentrations of biological concern (NOAA 1991).

5.5 COMPARISON TO SURROUNDING SYSTEMS

Sixty-eight percent of the area in the coastal bays had at least one sediment contaminant exceeding the Long et al. (1995) ER-L concentration, which is a threshold of biological concern. This was significantly greater than the spatial extent which was observed for the same threshold of concern in either Chesapeake Bay (46%) or Delaware Bay (34%).

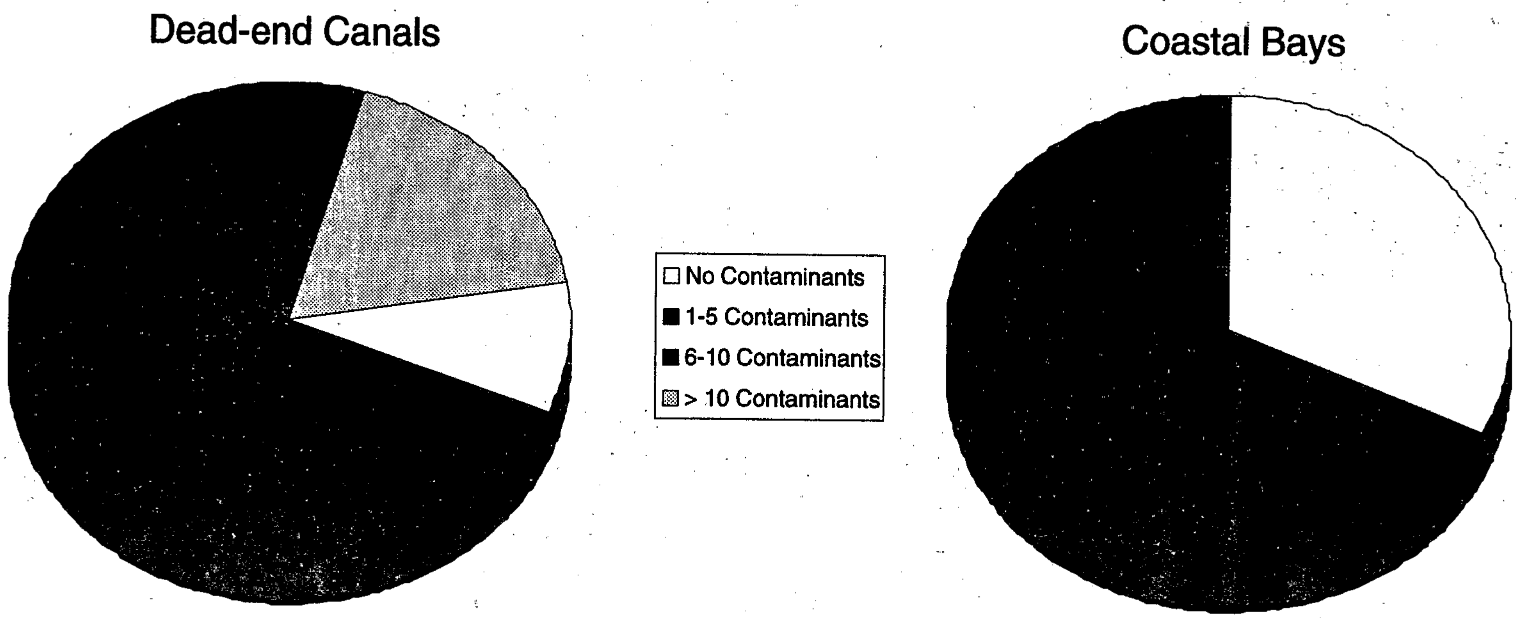

Figure 5-3. Areal distribution of number of sediment contaminants which exceeded ER-L values.

6.0 BENTHIC MACROINVERTEBRATES

6.1 BACKGROUND

Benthic assemblages have many attributes that make them reliable and sensitive indicators of ecological condition (Bilyard 1987). Benthic macroinvertebrates live in sediments, where exposure to contaminants and low concentrations of dissolved oxygen generally is most severe. Their relative immobility prevents benthic organisms from avoiding exposure to pollutants and other environmental disturbances (Gray 1982). Benthic assemblages are composed of a diverse array of species that display a wide range of physiological tolerances and respond to multiple kinds of stress (Pearson and Rosenberg 1978, Rhoads et al. 1978, Boesch and Rosenberg 1981). The life spans of benthic macroinvertebrates are long enough (a few months to several years) to enable researchers to measure population- and community-level responses to environmental stress (Wass 1967). This combination of attributes enables benthic assemblages to integrate environmental conditions prevalent during the weeks and months before a sampling event.

Four measures of biological response were used to evaluate the condition of benthic assemblages in the coastal bays of Delaware and Maryland: abundance, biomass, diversity, and the EMAP benthic index. Abundance and biomass are measures of total biological activity at a location. The diversity of benthic organisms supported by the habitat at a location often is considered a measure of the relative "health" of the environment. Diversity was evaluated using the number of species (i.e., species richness) at a location and the Shannon-Wiener diversity index, which incorporates both species richness and evenness components (Shannon and Weaver 1949). The EMAP benthic index integrates measures of species richness, species composition, and biomass/abundance ratio into a single value that distinguishes between sites of good or poor ecological condition (Schimmel et al. 1994). A value of 0 or less denotes a degraded site at which the structure of the benthic community is poor, and the number of species, abundance of selected indicator species, and mean biomass are small.

6.2 MAJOR SUBSYSTEMS

6.2.1 Abundance and Biomass

Indian River had significantly more benthic invertebrates than any of the other three major subsystems (Table 6-1). Much of this difference was due to a greater number of amphipods. Amphipods accounted for about 50% of total abundance in the coastal bays as a whole; however, in Indian River, amphipods accounted for more than 75% of total abundance (Figure 6-1). Biomass followed a different pattern than abundance among the major subsystems. Biomass was greatest in Chincoteague Bay and smallest in Indian River (Table 6-1). The very small ratio of biomass to abundance observed in Indian River often is associated with degraded habitat (Wilson and Jeffrey 1994).

6.2.2 Species Richness and Diversity

The average number of species was significantly higher and about 50% greater in Chincoteague Bay than in any of the other three major subsystems (Table 6-1). Species diversity as measured by the Shannon-Wiener diversity index was significantly greater in Chincoteague than in Rehoboth and Indian River, but the difference between Chincoteague and Assawoman was not statistically significant. The presence of several rare species that did not contribute significantly to the Shannon-Wiener index for Chincoteague Bay was responsible for the smaller difference in diversity than in number of species between Chincoteague Bay and the other major subsystems.

6.2.3 EMAP Benthic Index

Based on mean EMAP benthic index values, benthic communities in Indian River were degraded and in significantly worse condition than in any of the other major subsystems. Benthic communities in Chincoteague Bay were nondegraded and in significantly better condition than in any other system (Table 6-1). The average index in Rehoboth Bay indicated significant degradation of benthic communities; Assawoman Bay was nondegraded.

The estimated proportion of degraded area in the major subsystems ranged from 77% in Indian River to 11% in Chincoteague Bay (Figure 6-2). Indian River had a significantly higher proportion of degraded area than any of the other systems. Chincoteague Bay had a significantly smaller proportion of degraded area than Rehoboth Bay (Figures 6-2 and 6-3). The difference in proportion of degraded area between Chincoteague and Assawoman was not statistically significant. Although the average index value indicated that Rehoboth Bay was degraded, the difference in proportion of nondegraded area between Rehoboth and Assawoman was not statistically significant.

6.3 TARGET AREAS

6.3.1 Abundance and Biomass

Abundance and biomass were an order of magnitude less in dead-end canals than in the rest of the coastal bays (Table 6-1). The composition of benthic communities in the dead-end canals differed substantially from the composition in the rest of the coastal bays. Amphipods constituted almost 50% of the benthos throughout the coastal bays; however, approximately 85% of the benthos collected in dead-end canals were polychaetes (Figure 6-4), of which 90% were *Streblespio benedicti* (Appendix C), a pollution-tolerant species (Ranasinghe et al. 1994). Bivalves, which are generally less pollution tolerant, constituted 12% of the benthos in the rest of the coastal bays as a whole, but less than 5% of that in each of the special target areas. Differences in species composition between the dead-end canals and

Table 6-1. Area-weighted means of benthic macroinvertebrate parameters (90% confidence intervals)

		Major Subsystems				Target Areas			
Parameters	Entire Study Area	Rehoboth Bay	Indian River	Assawoman Bay	Chincoteague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
Abundance (#/m²)	18,724 ± 2,551	17,556 ± 5,030	34,889 ± 8,741	13,646 ± 5,488	15,478 ± 2,892	58,498 ± 16,520	30,200 ± 11,032	16,859 ± 4,721	1,917 ± 1,354
Biomass (g/m²)	10.57 ± 3.03	10.72 ± 9.87	5.05 ± 1.38	5.19 ± 1.39	13.97 ± 5.53	6.66 ± 1.72	6.07 ± 3.41	9.08 ± 3.23	0.43 ± 0.33
Number of Species (#/sample)	24.25 ± 1.19	18.73 ± 1.77	17.30 ± 2.51	20.53 ± 3.30	27.58 ± 1.98	18.56 ± 1.70	19.20 ± 2.90	22.76 ± 2.59	3.6 ± 2.6
Shannon-Wiener Index	2.73 ± 0.10	2.41 ± 0.19	1.79 ± 0.36	2.85 ± 0.31	3.02 ± 0.15	1.96 ± 0.17	2.10 ± 0.37	2.54 ± 0.22	0.59 ± 0.49
EMAP Index	0.48 ± 0.25	-0.20 ± 0.49	-2.30 ± 0.88	0.35 ± 0.45	1.41 ± 0.25	-4.80 ± 1.68	-1.68 ± 1.35	0.24 ± 0.47	-0.57 ± 0.25

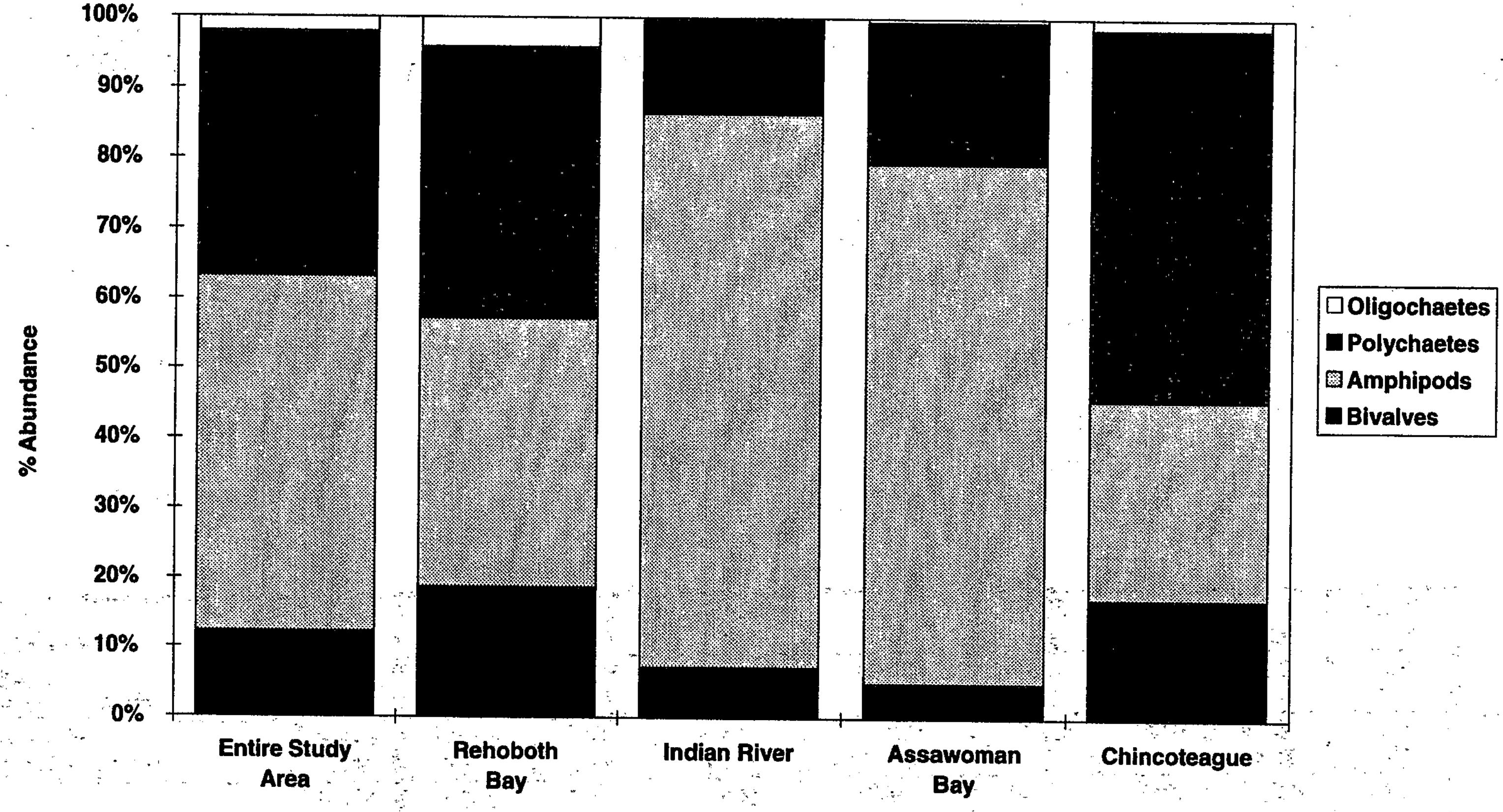

Figure 6-1. Composition of benthic assemblages in the major subsystems of the Delaware/Maryland coastal bays.

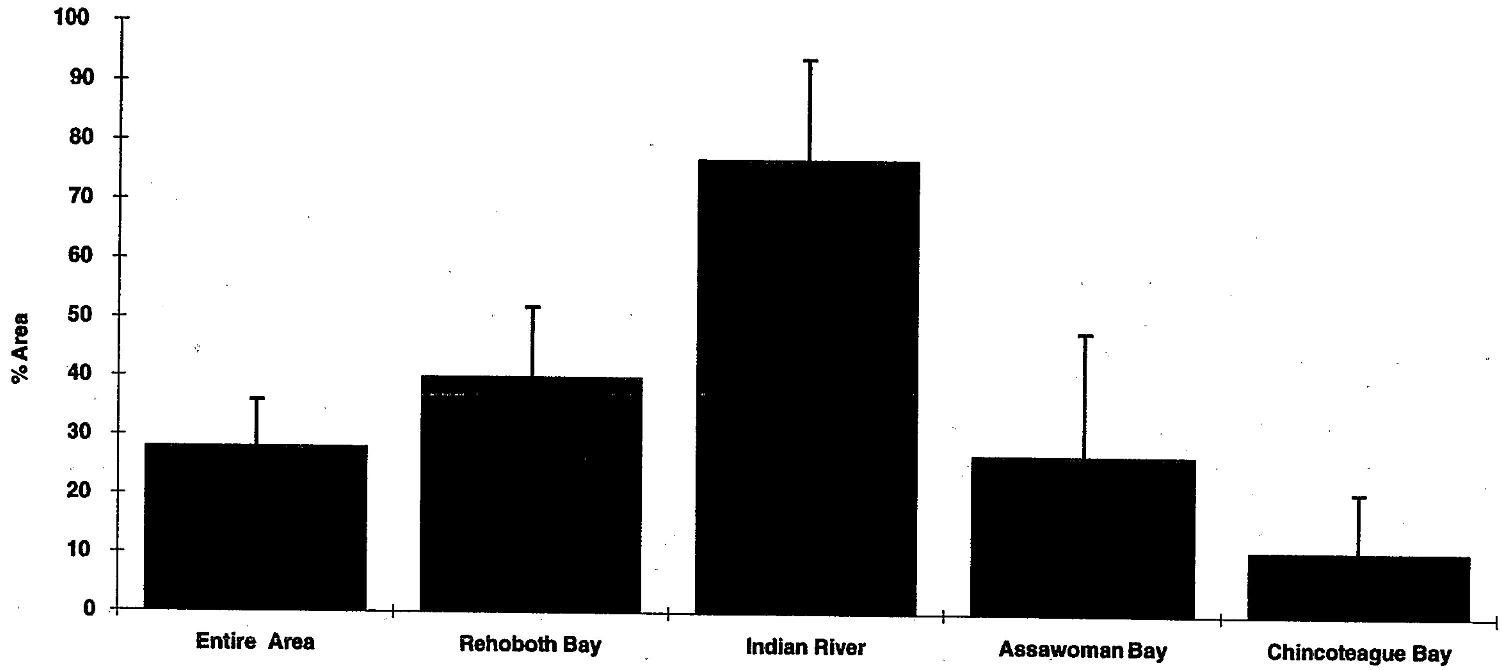

Figure 6-2. Percent of degraded area in the major subsystems of the Delaware/Maryland coastal bays, based on the EMAP benthic index.

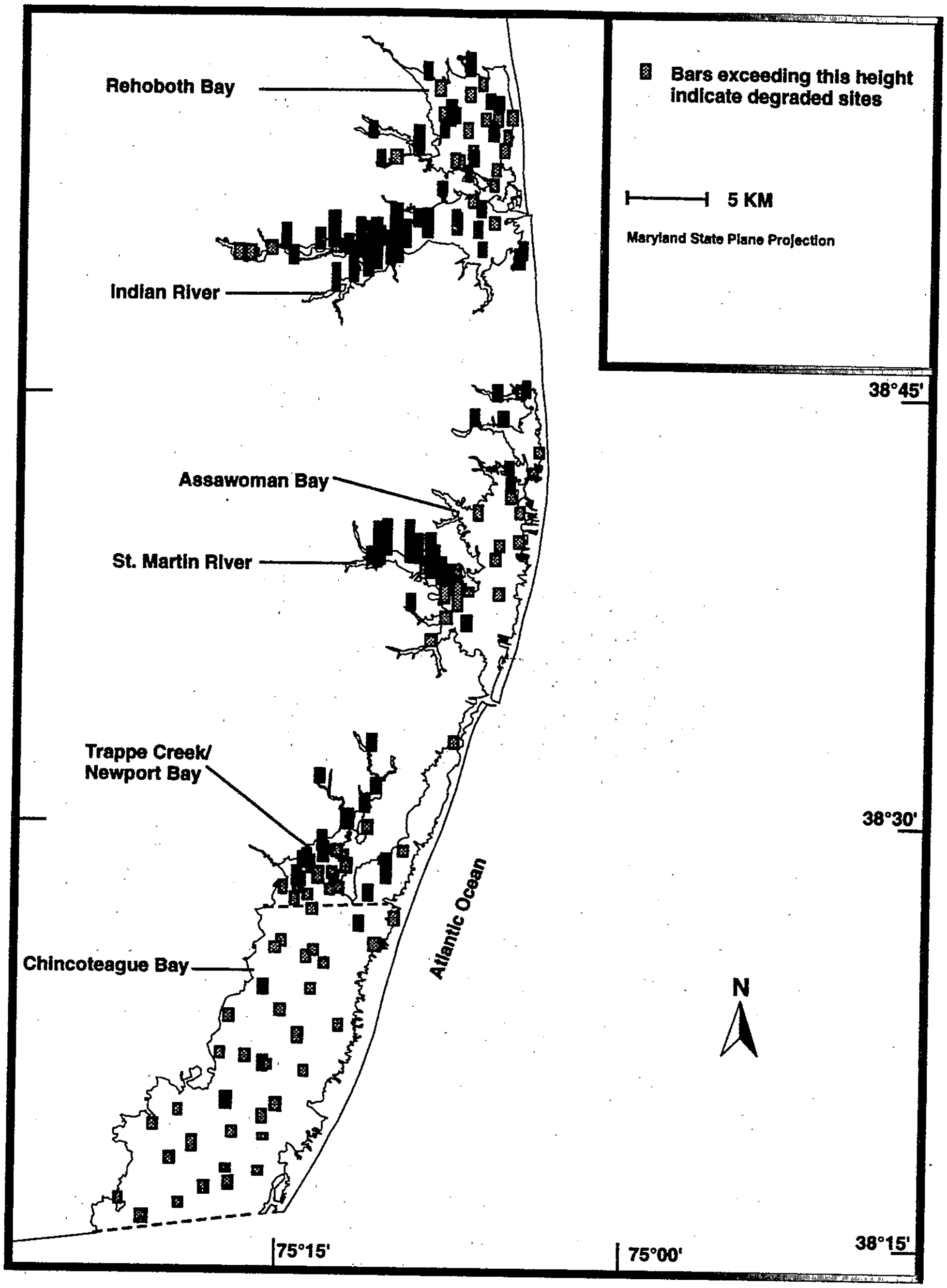

Figure 6-3. Benthic index values at non-lagoon sites in the Delaware/Maryland coastal bays study area. Bar height is inversely proportional to the index value; black-shaded bars indicate a degraded condition.

the rest of the coastal bays are reflected in the significantly lower biomass in the dead-end canals. Approximately 81% of the area in dead-end canals had a mean biomass less than 0.5 g/m^2 compared to 4% in the rest of the coastal bays (Figure 6-5).

6.3.2 SPECIES RICHNESS

The upper Indian River, St. Martin River, and the dead-end canals all had significantly fewer species per sample than the rest of the coastal bays (Table 6-1). The difference was particularly notable in dead-end canals, where the number of species was nearly seven times less than in the entire study area and approximately five or six times less than in any of the other special target areas. Whereas, 70% of the area in the coastal bays had at least 20 species per 440 cm^2 grab, 78% of the area in the canals produced less than 5 species per sample (Figure 6-6).

Similar patterns were observed with the Shannon-Wiener diversity index; the values for the upper Indian River, St. Martin River, and the dead-end canals all were significantly lower than for the entire study area. The index value for the dead-end canals was five times lower than for the entire study area and three to four times lower than for the other special target areas. Diversity in Trappe Creek/Newport Bay did not differ significantly from diversity in the rest of the coastal bays but was low in the Trappe Creek portion of this stratum.

of the coastal bays (Table 6-1, Figure 6-3). The index value for Trappe Creek/ Newport Bay was not significantly different than the value for the rest of the coastal bays, but the Trappe Creek portion of the stratum, where pollution sources were most prevalent historically, was degraded.

The extent of degradation was greatest in the dead-end canals and upper Indian River. More than 80% of the area of these two systems had degraded benthic communities as measured by the EMAP benthic index (Figures 6-7 and 6-3); this proportion was significantly greater than in the rest of the coastal bays.

6.4 COMPARISON WITH PREVIOUS STUDIES

Recent characterizations of the coastal bays (Boynton et al. 1993, Weston 1993) made little use of benthic macroinvertebrates in their assessment. The principal limitations they cited were that most benthic data for these systems were collected more than 20 years ago and were spatially limited. Moreover, the sampling efforts were conducted primarily to characterize species composition and habitat distribution, and did not focus on using benthos as indicators of ecological condition. Thus, this report represents the first ecological assessment of benthic invertebrate condition in the Maryland/Delaware coastal bays.

Comparisons to these historical studies is difficult because of differences in sampling gear and because original data are no longer available. The most comprehensive characterization of the system was conducted by Maurer (1977), but he used a 1 mm sieve which is not easily comparable to our 0.5 mm sieve. DP&L (1976)

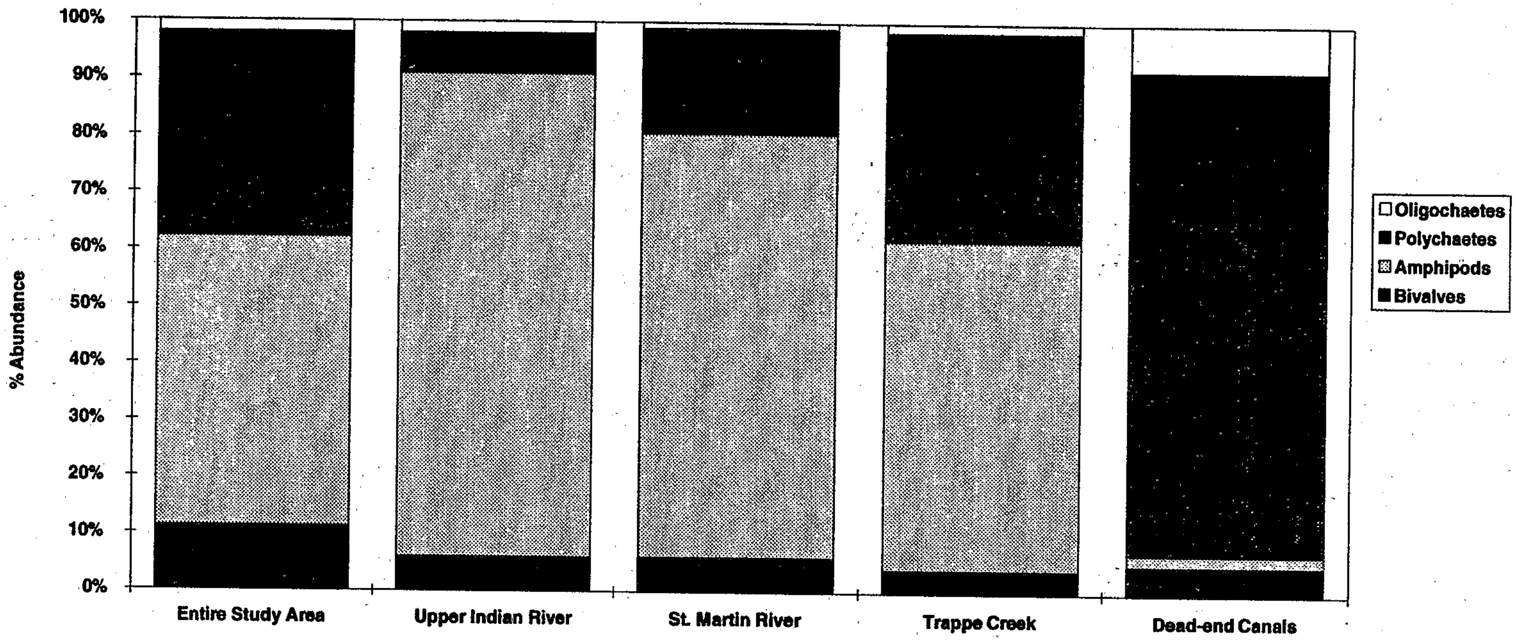

Figure 6-4. Composition of benthic assemblages in special target areas in the Delaware/Maryland coastal bays.

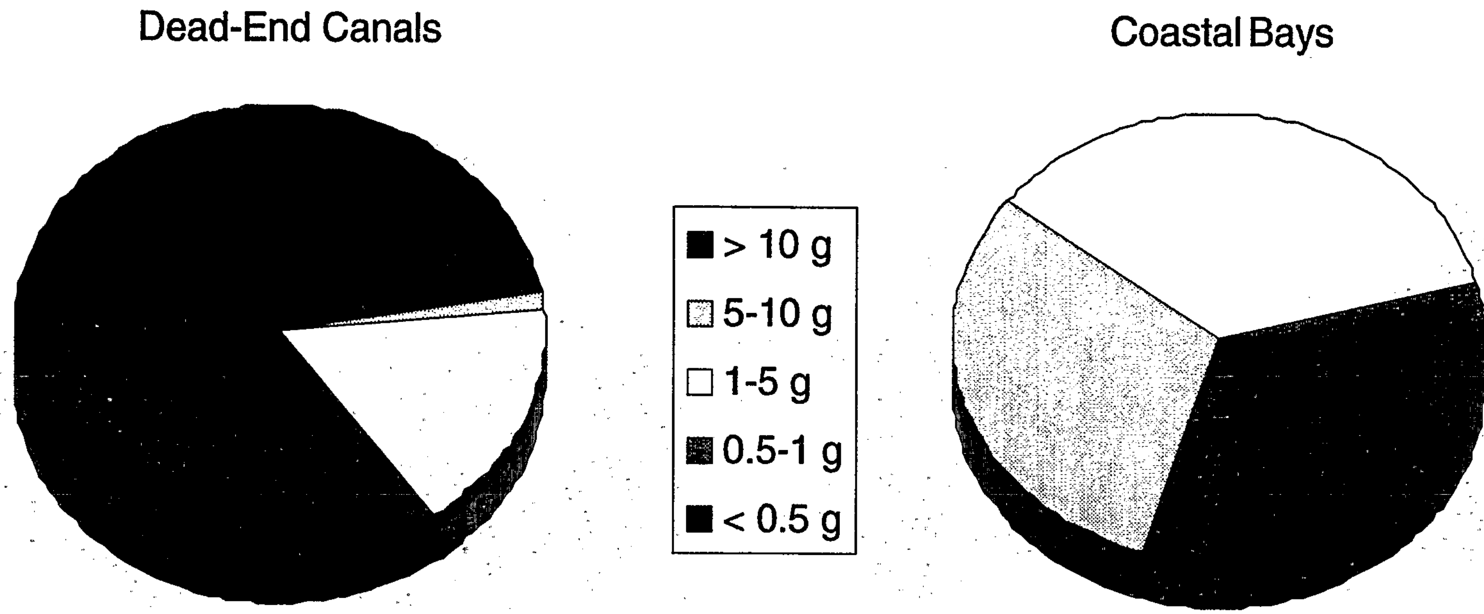

Figure 6-5. Percent of area for biomass (g/m^2) of benthic macroinvertebrates.

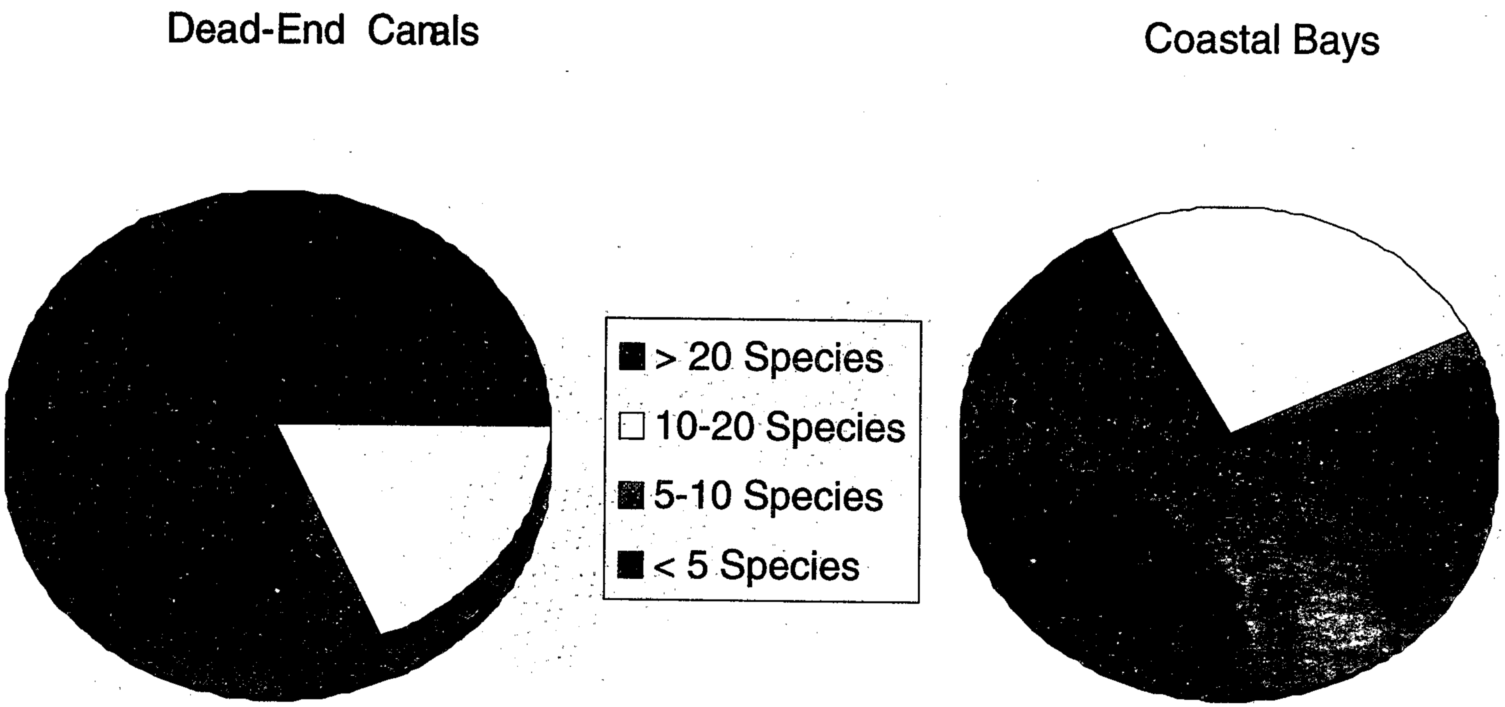

Figure 6-6. Percent of area for species richness of benthic macroinvertebrates.

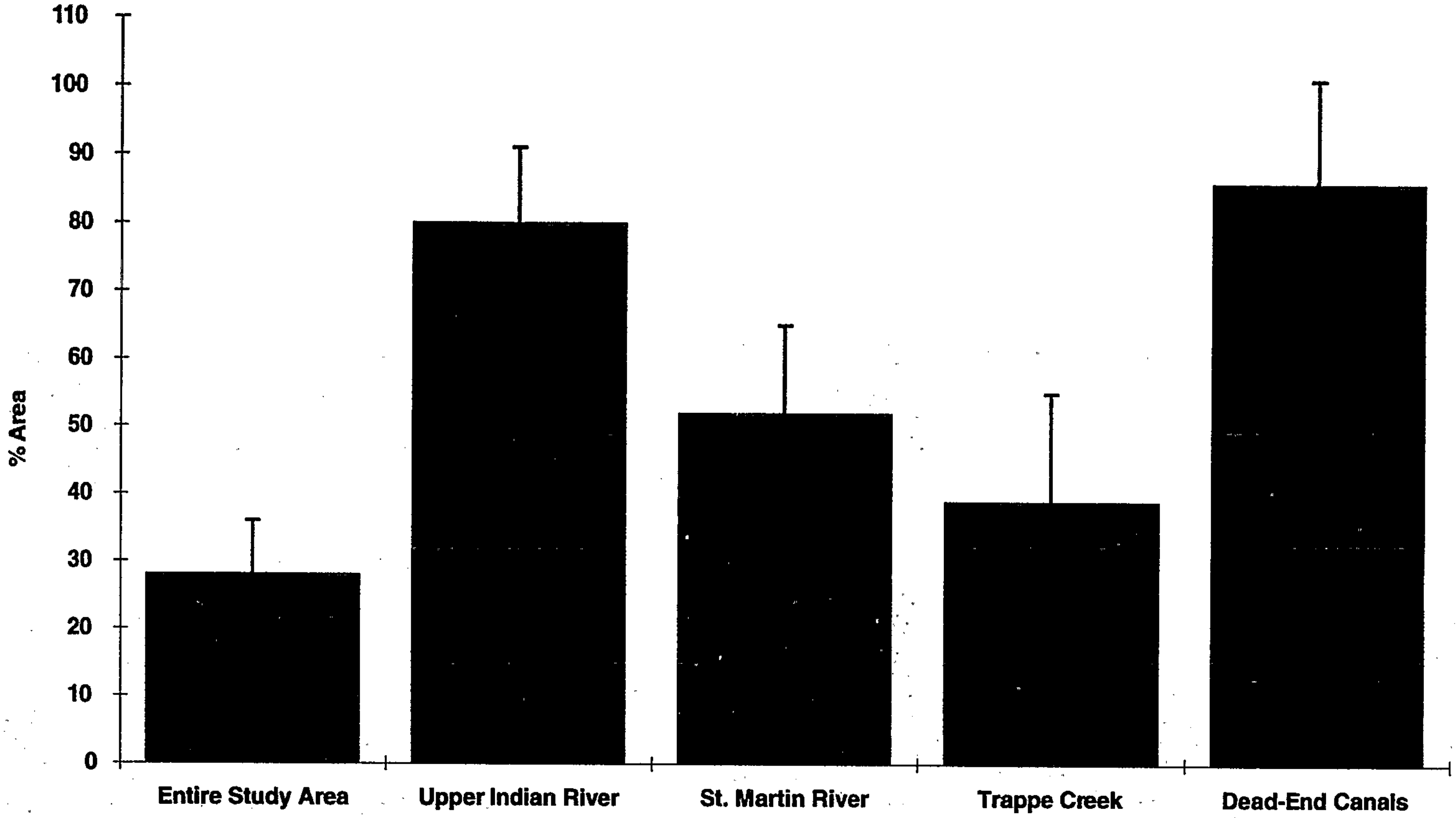

Figure 6-7. Percent of degraded area in special target areas in the Delaware/Maryland coastal bays, according to the EMAP benthic index.

conducted the most comprehensive historic study in Indian River, one that used the same sieve size as the coastal bays study. Mean invertebrate density in their study was almost an order of magnitude less than in our study for both the upper Indian River and the entire Indian River. Average species density did not vary appreciably between the two studies. The 1993 benthic community in Indian River was dominated by amphipods, which accounted for 75% of the total abundance. In the polyhaline stratum of the DP&L study, percent abundance was equally divided among polychaetes, amphipods, and bivalve molluscs. Together, these differences suggest that the quality of the benthic community has changed in the last two decades, but more substantial analyses based on original, rather than summarized, historic data are required to better characterize these changes.

6.5 COMPARISON TO SURROUNDING SYSTEMS

Benthic invertebrate communities may be in poorer condition in the coastal bays than in either Chesapeake or Delaware Bays. Twenty-eight percent of the area in the coastal bays had degraded benthic communities as measured by EMAP's benthic index. Using the same sampling methods and benthic index, 26% of the area in Chesapeake Bay and 16% of the area in Delaware Bay had degraded benthos.

7.0 CONCLUSIONS

The probability-based sampling design used in the Delaware/Maryland coastal bays joint assessment allows for two types of estimates that were not previously available for these systems. First, it allows estimation of areal extent of selected indicators exceeding threshold levels of concern to managers. Second, it allows unbiased comparisons among various subsystems of the coastal bays, since the same sampling design, sampling methodologies and quality assurance/quality control procedures were employed throughout the study area. The results of the study support the following conclusions:

1. Major portions of the coastal bays have degraded environmental quality.

Major portions of the coastal bays were found to have degraded environmental conditions. Twenty-eight percent of the area in the coastal bays had degraded benthic communities, as measured by EMAP's benthic index. More than 75% of the area in the coastal bays failed the Chesapeake Bay Program's Submersed Aquatic Vegetation (SAV) restoration goals, which are a combination of measures that integrate nutrient, chlorophyll, and water clarity parameters. Most areas failed numerous SAV goal attributes. About 40% of the area failed the nutrient and chlorophyll components of the SAV Restoration Goals. Sixty-eight percent of the area in the coastal bays had at least one sediment contaminant with concentrations exceeding published guidelines for protection of benthic organisms (Long and Morgan 1990, Long et al. 1995). Further study is needed to assess whether the biological effects we observed are the direct result of contamination.

2. Eutrophication threatens recolonization of SAV in the coastal bays, but is not severe enough to cause widespread hypoxia.

Eutrophication, as measured by the SAV restoration goals, is widespread in the coastal bays. With the exception of some limited areas of management concern, eutrophication has not yet resulted in a severe hypoxia problem that threatens biota. Oxygen concentrations less than 5 ppm were measured in only 8% of the study area, though it was as high as 25% of the study area in Indian River and St. Martin River. Oxygen concentrations less than 2 ppm were measured only in dead-end canals. This is consistent with previous studies, in which concentrations of dissolved oxygen less than 5 ppm were measured rarely and were spatially limited to known areas of management concern. While we measured only 8% of the area as hypoxic, this amount may be larger during nighttime hours and is a significant amount of area, given the shallow, well-mixed nature of the system.

3. The sediment contaminants detected in this study are primarily persistent chlorinated hydrocarbons and are probably a remnant of historic inputs.

The sediment contaminants detected in this study are primarily persistent pesticides, such as DDT, chlordane, and dieldrin, that are no longer commercially available or are strongly regulated, and whose input into the system has undoubtedly declined. The prevalence of these chemicals in the sediments probably result, to a large extent, from the unique physical characteristics of the coastal bays: (1) land use in the coastal bays is largely agricultural, and a source of non-point pollution; (2) the system has a large perimeter to area ratio, enhancing the potential impact of non-point source inputs; and (3) the low flushing rate of the system enhances the likelihood that chemicals entering the system will be retained in the system for long periods of time.

4. Chincoteague Bay is in the best condition of the major subsystems within the coastal bays Indian River is in the worst condition.

Of the four major subsystems that comprise the coastal bays, Chincoteague Bay was in the best condition. Only 11% of the area in Chincoteague Bay had degraded benthos. Almost 45% of the area in Chincoteague Bay met the Chesapeake Bay Program's SAV restoration goals, a figure which increased to almost 85% when only the nutrient and chlorophyll components of the goals were considered. In comparison, 77% of the area in Indian River had degraded benthos and less than 10% of its area met the SAV restoration goals.

5. The tributaries to the coastal bays are in poorer condition than the mainstems of the major subsystems.

Previous studies have suggested that the major tributaries to the system: upper Indian River, St. Martin River, and Trappe Creek are in poorer condition than the mainstem water bodies. Our study confirms that finding. The percentage of area containing degraded benthos was generally two to three times greater in the tributaries compared to the other coastal bays. The percent of area with DO less than the state standard of 5 ppm was three to seven times greater in the tributaries. More than 70% of the area in upper Indian River and St. Martin River and in the dead-end canals had chlorophyll a concentrations exceeding the SAV goal of 15 μg/l. None of the samples collected in the tributaries met the SAV restoration goals.

Among these systems, Trappe Creek contained the sites in the worst condition. Two sites in the upper portion of Trappe Creek had concentrations of chlorophyll *a* exceeding 350 μg/l; algal blooms were evident at each site. In addition, dissolved oxygen levels exceeding 14 ppm were measured at both sites. It appears, however, that degraded conditions in the Trappe Creek system are spatially limited to Trappe Creek and have not spread to Newport Bay. Undoubtedly, this results from the low freshwater flow from this tributary compared to the other tributaries.

6. Dead-end canals are the most severely degraded areas in the coastal bays.

Ninety-one percent of the area in dead-end canals had sediment contaminant concentrations exceeding published guideline values. Fifty-six percent of their area had dissolved oxygen concentrations less than state standards of 5 ppm. Canals were the only locations from all the coastal bays sites where concentrations less than 2 ppm were measured. These stresses appear to have biological consequences: more than 85% of the area in the dead-end canals had degraded benthic communities. Dead-end canals averaged fewer than 4 benthic species per sample compared to 26 species per sample in the remaining portions of the coastal bays.

7. Based on percent areal extent, the coastal bays are in as poor or worse condition than either Chesapeake Bay or Delaware Bay with respect to sediment contaminant levels, water quality, and benthic macroinvertebrate community condition.

The consistency of the sampling design and methodologies between our study and EMAP allows unbiased comparison of conditions in the coastal bays with that in other major estuarine systems in EPA Region III that are sampled by EMAP. Based on comparison to EMAP data collected between 1990 and 1993, the coastal bays were found to have a similar or higher frequency of degraded benthic communities than surrounding systems. Twenty-eight percent of the area in the coastal bays had degraded benthic communities as measured by EMAP's benthic index, which was significantly greater than the 16% EMAP estimated for Delaware Bay using the same methods and same index, and was statistically indistinguishable from the 26% estimated for Chesapeake Bay. The coastal bays also had a prevalence of chemical contamination in the sediments that was higher than in either Chesapeake Bay or Delaware Bay. Sixty-eight percent of the area in the coastal bays exceeded published guideline values for at least one contaminant, compared to 46% for Chesapeake Bay and 34% for Delaware Bay (Long and Morgan 1990, Long et al. 1995). While the percent of area having poor benthic and sediment conditions is higher in the coastal bays, the absolute amount of area having these conditions is greater in the Delaware and Chesapeake Bays, because of their larger size.

Nutrients were not measured by EMAP and statistically unbiased estimates of average concentrations are unavailable for either Chesapeake or Delaware Bays. The Chesapeake Bay Program, though, recently estimated that about 75% of the area in Chesapeake Bay meets SAV Restoration Goals. This is more than three times the percent of area meeting SAV Restoration Goals in the coastal bays. Even when the turbidity and TSS components of the SAV Restoration Goals, which are naturally high in shallow systems, are ignored, almost half of the area in the coastal bays, or twice that in Chesapeake Bay, still fails the SAV Restoration Goal estimates for nutrients and chlorophyll.

8. The fish assemblages in Maryland's coastal bays have remained relatively unchanged during the past twenty years, while those of similar systems in Delaware have changed substantially.

Fish assemblages of the Maryland coastal bays, as sampled by shallow-water seines, are dominated by Atlantic silversides, bay anchovy, Atlantic menhaden, and spot. This assemblage is similar to that of the Delaware coastal bays 35 years ago. The fish fauna in Delaware's coastal bays has shifted toward species of the Family Cyprinodontidae (e.g., killifish and sheepshead minnow) which are more tolerant to low oxygen stress, and salinity and temperature extremes.

8.0 REFERENCES

Academy of Natural Sciences of Philadelphia (ANSP). 1988. Phytoplankton, nutrients, macroalgae and submerged aquatic vegetation in Delaware's inland bays, 1985-1986. Prepared for Delaware Department of Natural Resources and Environmental Control.

Adams, W.J., R.A. Kimerle, and J.W. Barnett, Jr. 1992. Sediment quality and aquatic life assessment. *Environmental Science and Technology*. 26 (10).

American Public Health Association. 1981. Standard Methods for the Examination of Water and Wastewater. 15th ed.

Andriot, J.C. 1980. Population abstracts of the United States. Andriot Associates, McLean, Virginia.

Aspilla, I.H. Agemian, and A.S.Y. Chau. 1976. A semi-automated method for the determination of inorganic, organic and total phosphate in sediments. *Analyst* 101:187-197.

Bartberger, C.E., and R.B. Biggs. 1970. Sedimentation in Chincoteague Bay. *In*: Natural Resources Institute, University of Maryland. 1970 October. Assateague ecological studies, Part II: Environmental threats. Contribution No. 446. Chesapeake Biological Lab, Solomons, MD.

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

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

Boynton, W.R., L. Murray, W. M. Kemp, J. D. Hagy, C. Stokes, F. Jacobs, J. Bowers, S. Souza, B. Rinsky, and J. Seibel. 1993. Maryland's Coastal Bays: An assessment of aquatic ecosystems, pollutant loadings, and management options. Prepared for Maryland Department of the Environment.

Brenum, G. 1976. A comparative study of benthic communities of dredged lagoons, tidal creeks, and areas of open bays in Little Assawoman, Indian River, and Rehoboth Bays, Delaware. M.S. thesis, College of Marine Studies, University of Delaware, Newark, DE.

Broutman, M. A., and D. L. Leonard. 1988. National estuarine inventory: The quality of the shellfish growing waters in the Gulf of Mexico. National Oceanic and Atmospheric Administration, Strategic Assessment Branch, Rockville, MD.

Casey, J.F., S. B. Doctor, and A.E. Wesche. 1993. Investigation of Maryland's Atlantic Ocean and coastal bay finfish stocks. Federal aid project no. F-50-R-3. Maryland Department of Natural Resources.

Chapman, P.M., E.A. Power, and G.A. Burton, Jr. 1992. Integrated assessments in aquatic systems"; Chapter in Sediment Toxicity Assessment, edited by G.A. Burton Jr.; Lewis Publishers.

Chrzatowski, M.L. 1986. Statigraphy and geologic history of a Holocene lagoon; Rehoboth and Indian River Bay, Delaware. Ph.D. Dissertation, Geology Department, University of Delaware, Newark, DE. 337 p.

Cochran, W. G. 1977. Sampling Techniques. 3rd ed. New York: John Wiley and Sons.

D'Elia, C.F., P.A. Steudler, and N. Corwing. 1977. Determination of total nitrogen in aqueous samples using persulfate digestion. *Limnol. Oceanogr*. 22:760-764.

Delmarva Power and Light Company. 1976. Ecological studies in the vicinity of the Indian River power plant for the period June 1974 through August 1976. A section 316(a) demonstration.

Dennison, W.C., R.J. Orth, K.A. Moore, J.C. Stevenson, V. Carter, S. Kollar, P. Bergstrom, and R.A. Batiuk. 1993. Assessing water quality with submerged aquatic vegetation. *Bioscience*. 43:86-94.

Derickson, W. K. and K. S. Price, Jr. 1973. The fishes of the shore zone of Rehoboth and Indian River bays, Delaware. *Trans. Amer. Fish*. Soc. 102:552-562.

DiToro, D. M., J. D. Mahony, D. J. Hansen, K. J. Scott, A. R. Carlson, and G. T. Ankley. 1992. Acid volatile sulfide predicts the acute toxicity of cadmium and nickel in sediments. Environmental Science and Technology. 26: 96-101.

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. Environmental Toxicology and Chemistry. 9:1487-1502.

DiToro, D. M., N. A. Thomas, C. E. Herdendorf, R. P. Winfield, and J. P. Connolly. 1987. A post audit of a Lake Erie eutrophication model. J. Great Lakes Res. 13: 801-825.

Efron, B., and G. Gong. 1983. A leisurely look at the bootstrap, the jackknife and cross-validation. *Am. Sta.* 37:36-48.

Fang, C. S., A. Rosenbaum, J. P. Jacobson, and P. V. Hyer. 1977. Intensive hydrographical and water quality survey of the Chincoteague/Sinepuxent/Assawoman bays, Vol. II. Data report: Intensive hydrographical and water quality. Special Scientific Report No. 82. Virginia Institute of Marine Science, Gloucester Point, VA.

Frithsen, J. B., L. C. Scott, and M. Young. 1994. Methods for processing estuarine benthic macroinvertebrate samples from the EMAP Estuaries Virginian Province. Versar, Inc., Columbia, MD.

Giesen, W.B.J.T., M. M. van Katwijk, and C. den Hartog. 1990. Eelgrass condition and turbidity in the Dutch Wadden Sea. *Aquat. Bot.* 37:71-85.

Gray, J.S. 1982. Effects of pollutants on marine ecosystems. *Neth. J. Sea Res*. 16:424-443.

Greene, R. W. 1995. Preliminary assessment of the bioavailability and ecological risk of sediment-sorbed toxicants in the Delmarva coastal bays. Delaware Department of Natural Resources and Environmental Control, Division of Water Resources, Watershed Assessment Section, Dover, DE. Draft.

Heukelem, L. Van, A. J. Lewitus, T. M. Kana, and N. E. Croft. 1992. High-performance liquid chromatography of phytoplankton pigments using a polymeric reversed phase C_{18} column. *J. Phycol.* 28: 867-872.

Holland, A. F., ed. 1990. Near coastal program plan for 1990: Estuaries. EPA/600/4-90/033. U.S. Environmental Protection Agency, Environmental Research Laboratory, Narragansett, RI.

Holland, A.F., A.T. Shaughnessy, L.C. Scott, V.A. Dickens, J. Gerritsen, and J.A. Ranasinghe. 1989. Long term benthic monitoring and assessment program for the Maryland portion of Chesapeake Bay: Interpretive report. (CBRM-LTB/EST-2). Prepared for Maryland Department of Natural Resources, Annapolis, MD.

Hollander, M., and D. A. Wolfe. 1973. Nonparametric Statistical Methods. New York: John Wiley and Sons.

Holt, D., and T. M. F. Smith. 1979. Post stratification. *J. R. Statist.* Soc. A. 142:33-46.

Klemm, D. J., L. B. Lobring, J. W. Eichelberger, A. Alford-Stevens, B. B. Porter, R. F. Thomas, J. M. Lazorchak, G. B. Collins, and R. L. Graves. 1993. Environmental Monitoring and Assessment Program (EMAP) Laboratory Methods Manual: Estuaries. U.S. Environmental Protection Agency, Environmental Research Laboratory, Cincinnati, OH.

Lacoutre, P.V., and K.G. Sellner. 1988. Phytoplankton and nutrients in Delaware's inland bays. Report to Delaware Department of Natural Resources and Environmental Control, Dover, DE. 140 p.

Leeman Labs, Inc. 1988. The automated and advanced Model 240X-A Elemental Analyzer.

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. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Rockville, MD.

Long, E. R., D. D. MacDonald, S. L. Smith, and F. D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management* 19(1): 81-97.

Magnien, R., D. Boward, and S. Bieber, eds. 1995. The state of the Chesapeake Bay. Prepared by the Chesapeake Bay and Watershed Management Administration, Maryland Department of the Environment, for the Chesapeake Bay Program.

Maryland Department of the Environment. 1983. St. Martin River phytoplankton. Prepared by the Water Quality Monitoring Division, Baltimore, MD.

Maurer, D. 1977. Estuarine benthic invertebrates of Indian River and Rehoboth Bays, Delaware. *Int. Revue Ges. Hydrobiol.* 62:5, 591-629.

Menzel D.W., and R.F. Vaccaro. 1964. The measurement of dissolved organic and particulate carbon in seawater. *Limnol. Oceanogr.* 9:138-142.

National Park Service. 1991. Assateague Island National Seashore water quality monitoring, 1987-1990. Data summary report. Water Resources Division and Assateague Island Seashore. Tech. report NPS/NRWRD/NRTR 91/06. Washington, DC. pp. 86.

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*: Biogeochemical Processes at the Land-sea Boundary, 99-122. P. Lasserre and J. M. Martin, eds. Elsvier, NY.

NOAA. 1990. Estuaries of the United States: Vital statistics of a national resource base. A special NOAA 20th Anniversary Report. National Oceanic and Atmospheric Administration, Rockville, MD.

O'Connor, T. P. 1990. Coastal Environmental Quality in the United States, 1990: Chemical contamination in sediment and tissues. A special NOAA 20th Anniversary Report. National Oceanic and Atmospheric Administration, Rockville, MD.

Orth, R.J., and K.A. Moore. 1988. Submerged aquatic vegetation in Delaware's inland bays. *In:* Phytoplankton, nutrients, macroalgae, and submerged aquatic vegetation in Delaware's inland bays, 96-121. Academy of Natural Sciences in Philadelphia.

Orth, R. J., J. F. Nowak, G. F. Anderson, and J. R. Whiting. 1994. Distribution of submerged aquatic vegetation in the Chesapeake Bay and tributaries and Chincoteague Bay - 1993. Prepared for U.S. Environmental Protection Agency.

OTA (Office of Technology Assessment). 1987. Wastes in Marine Environments. Washington, DC.

Overton, W. S., D. White, and D. L. Stevens. 1990. Design report for EMAP: Environmental Monitoring Assessment Program. EPA/600/3-91/053. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.

Parsons, T. R., Y. Maita, and C. M. Lalli. 1984. A Manual of Chemical and Biological Methods for Seawater Analysis. Pergamon Press.

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.

Pritchard, D. W. 1960. Salt balance and exchange rate for Chincoteague Bay. *Ches. Sci.* 1:48-57.

Quinn, H., J. P. Tolson, C. J. Klein, S. P. Orlando, and C. Alexander. 1989. Strategic assessment of near coastal waters-susceptibility of east coast estuaries to nutrient discharges: Passamaquoddy Bay to Chesapeake Bay, summary report. Strategic Assessment Branch, Ocean Assessments Division, Office of Oceanography and Marine Assessment, National Ocean Service, National Oceanic and Atmospheric Administration. Rockville, MD.

Ranasinghe, J. A., S. B. Weisberg, D. M. Dauer, L. C. Schaffner, R. J. Diaz, and J. B. Frithsen. 1994. Chesapeake Bay benthic community restoration goals. Chesapeake Bay Program, U.S. Environmental Protection Agency. CBP/TRS 107/94. Annapolis, MD.

Rhoads, D. C. 1974. Organism-sediment relations on the muddy sea floor. *Oceanogr. Mar. Biol. Ann. 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.

Ritter, W.F. 1986. Nutrient budgets for the inland bays. Prepared for Delaware Department of Natural Resources and Environmental Control. Dover, DE.

Santschi, P.H. 1984. Particle flux and trace metal residence time in natural waters. *Limnol. Oceanogr.* 29:1100-1108.

Santschi, P.H., Y.H. Li, and S. Carson. 1980. The fate of trace metals in Narragansett Bay, Rhode Island: Radiotracer experiments in microcosms. Estuar. Coast Mar. Sci. 10:635-654.

Santschi, P. H., S. Nixon, M. Pilson, and C. Hunt. 1984. Accumulation of sediments, trace metals (Pb, Cu) and total hydrocarbons in Narragansett Bay, Rhode Island. *Estuar. Coast. Shelf Sci.* 19:427-449.

Schimmel, S.C., B.D. Melzian, D.E. Campbell, C.J. Strobel, S.J. Benyi, J.S. Rosen, and H.W. Buffum. 1994. Statistical summary: EMAP-Estuaries Virginian Province-1991. U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Narragansett, RI. EPA/620/R-94/005.

Seagraves, R. J. 1986. Survey of the sport fishery of Delaware Bay. Delaware Department of Natural Resources and Environmental Control. Document No. 40-05/86/04/02.

Shannon, C.E., and W. Weaver. 1949. The Mathematical Theory of Communication. Urbana: University of Illinois Press.

Snelgrove, P. V. R., and C. A. Butman. 1994. Animal-sediment relationships revisited: cause versus effect. *Oceanogr. Mar. Biol. Ann. Rev.* 32:111-177.

Strobel, C.J., H.W. Buffum, S.J. Benyi, E.A. Petrocelli, D.R. Reifsteck, and D.J. Keith. 1995. Statistical Summary - EMAP Estuaries: Virginia Province 1990 to 1993. U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, Narragansett, RI. EPA/620/R-94/026.

Symposium on the classification of brackish waters. 1958. The Venice System for the classification of marine waters according to salinity. *Oikos* 9:311-312.

U.S. EPA. 1992. Sediment classification methods compendium. EPA 823-R-92-006. Washington, D.C: U.S. Environmental Protection Agency, Office of Water.

U.S. EPA. 1993. Guidelines for deriving site-specific sediment quality criteria for the protection of benthic organisms. EPA /822/R-93/017. Washington, DC: U.S. Environmental Protection Agency, Office of Science and Technology, Health and Ecological Criteria Division.

U.S. EPA. 1993a. Proposed sediment quality criteria for the protection of benthic organisms: Acenaphthene. Washington, DC: U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology. In Review.

U.S. EPA. 1993b. Proposed sediment quality criteria for the protection of benthic organisms: Phenanthrene. Washington, DC: U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology. In Review.

U.S. EPA. 1993c. Proposed sediment quality criteria for the protection of benthic organisms: Fluoranthene. Washington, DC: U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology. In Review.

U.S. EPA. 1993d. Proposed sediment quality criteria for the protection of benthic organisms: Dieldrin. Washington, DC: U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology. In Review.

Wass, M.L. 1967. Indicators of pollution. *In*: Pollution and Marine Ecology, 271-283. Olsen, T.A. and F.J. Burgess, eds. New York: John Wiley and Sons.

Weisberg, S. B., A. F. Holland, K. J. Scott, H. T. Wilson, D. G. Heimbuch, S. C. Schimmel, J.B. Frithsen, J. F. Paul, J. K. Summers, R. M. Valente, J. Gerritsen, and R. W. Latimer. 1993. EMAP-Estuaries, Virginian Province 1990: Demonstration Project Report. EPA/600/R-92/100. U.S. Environmental Protection Agency, Washington, DC.

Weston, Inc. 1993. Characterization of the inland bays estuary. Prepared for Delaware Inland Bays Estuary Program.

Wilson, J. G., and D. W. Jeffrey. 1994. Benthic biological pollution indices in estuaries. *In*: Biomonitoring of Coastal Waters and Estuaries, 311-327. J. M. Kramer, ed. CRC Press, Boca Raton, FL.

APPENDIX A

1993 Delaware Fish Seine Study and Comparison to Delaware and Maryland Historical Studies

Contributing Authors:

Kent S. Price and Maryellen Timmons
University of Delaware, College of Marine Studies

Cecelia C. Linder, James F. Casey,
Steve Doctor, and Alan Wesche
Maryland Department of Natural Resources

Janis C. Chaillou
Versar, Inc.

DELAWARE COASTAL BAYS
SHORE ZONE FISH COMMUNITY TRENDS

Kent S. Price[1], Maryellen Timmons[1], and Janis C. Chaillou[2]

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INTRODUCTION

The general purpose of this study was to examine historical and current shore-zone fish community data to determine whether perceived changes in the fish community could be related to spatial or temporal trends in water quality in Delaware and Maryland's coastal inland bays. Generally, studies in fresh water have shown that moderate eutrophication increases fish biomass, but may shift the composition of the fish community from desirable colder water fish to rough fish such as carp (Lee, et al., 1991). The mechanism underlying the shift in community structure is poorly understood, but Lee, et al. (1991) suggests that it is related to such factors as reduced grazing ability of predatory fish brought about by increased turbidity from increased amounts of phytoplankton. Almost no studies of this type have been conducted for estuarine fish. Price, et al. (1985) suggested that the depression of striped bass stocks in the Chesapeake Bay may be related to eutrophication through (1) loss of habitat for adult fish through reductions in dissolved oxygen in deeper waters and (2) loss of habitat for juvenile fish through eutrophication mediated reductions in submerged aquatic vegetation. Price (U.S. EPA, 1983) also proposed that nutrient and toxic enrichment of low-salinity spawning and nursery areas may be related to declines in anadromous (fresh water) spawning estuarine species such as striped bass, white perch, yellow perch, herring, and others.

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[1] University of Delaware, College of Marine Studies, Lewes, DE

[2] Versar, Inc., Columbia, MD

THE SETTING IN DELAWARE

Delaware's inland bays (Fig. 1) consist of three interconnected water bodies--Rehoboth, Indian River, and Little Assawoman bays. The inland bays have a drainage area of about 300 square miles, a water surface area of 32 square miles, a marsh area of 9 square miles, a mean-low-water volume of 4 billion cubic feet, and a freshwater discharge of 300 cubic feet per second. Almost 30 square miles of the inland bays are classified as shellfish waters, of which 19 square miles presently are approved for shellfishing. There are about 126 people per square mile of the inland bays watershed, and the land is about 10 percent urban, 44 percent forested, and 46 percent agriculture. The inland bays are tidally flushed, with estimates typically converging on 90-100 days for Indian River Bay and 80 days for Rehoboth Bay. No flushing estimates are available for Little Assawoman Bay (Weston, 1993).

The inland bays are suffering from plant nutrient enrichment (eutrophication) that causes unwanted phytoplankton blooms with resulting declines in light penetration and oxygen levels. These changes in environmental quality have led to eradication of submerged aquatic vegetation (sea grasses) and to declines in desirable finfish and shellfish. Major sources of these nutrients are land runoff from intensive agribusiness operations, intrusion of nutrient-contaminated groundwater from agricultural and domestic sources, and sewage treatment plant effluents.

Overall, the inland bays are highly nutrient enriched (eutrophic), especially in the tidal creeks. Characterization efforts in the Chesapeake Bay yielded a classification system for bay waters based upon total nitrogen and total phosphorous concentrations. Under that classification system, the inland bays' combination of ambient total nitrogen concentrations, generally in excess of 1 part per million (ppm), and total phosphorous concentrations, generally in the range of 0.1 to 0.2 ppm, would rank the inland bays among the most enriched of the 32 sub-estuarine systems of the Chesapeake Bay. Based upon the Chesapeake classification system, the middle and upper segments of the Indian River estuary are more enriched than any segment of the Chesapeake Bay. Significant increases in tidal flushing rates over the past 20 years may have mediated the progression of advancing eutrophic conditions, especially in the lower, higher salinity reaches of the system (Weston, 1993).

For Rehoboth Bay, agriculture is the principal source of nitrogen, but point sources are the major source of phosphorus, almost all of which originates from the Rehoboth wastewater treatment plant (Cerco, et al., 1994). For Indian River and Assawoman bays, the principal source of both nitrogen and phosphorus is agriculture, through the application of inorganic fertilizers and manures. These practices, applied to the sandy, permeable soils of the watershed, have resulted in widespread contamination of the groundwater by nitrates (Andres, 1994).

Groundwater is a highly significant component of freshwater flow into the bays. About 70 to 80 percent of total freshwater stream flow is composed of groundwater discharge. Groundwater also flows under the bay shores and discharges directly into the bays. Nearly all of this groundwater originates as precipitation in the inland bays watershed (Andres, 1992).

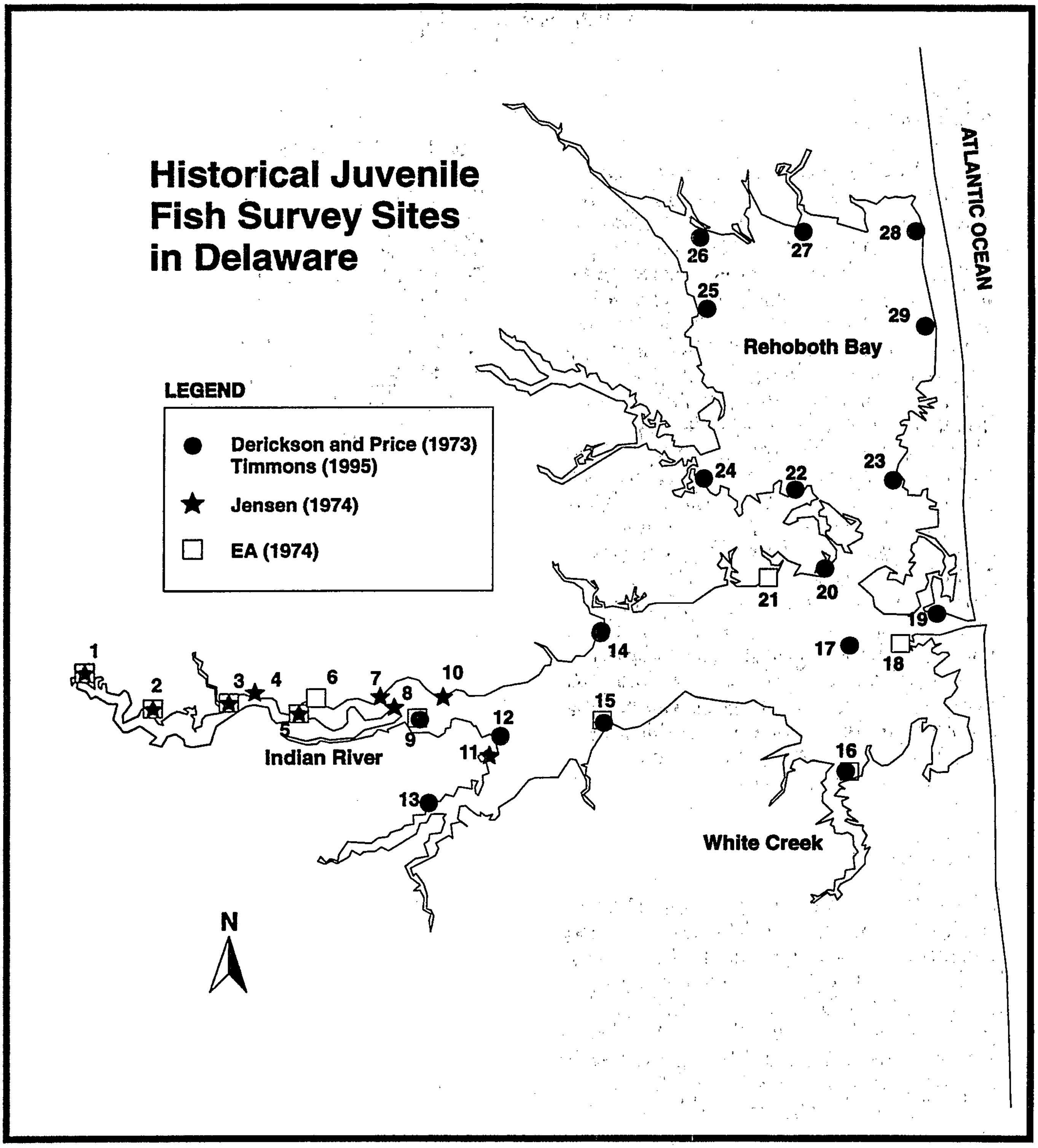

Figure 1. Historical juvenile fish survey sites which were revisited during the CBJA. Site 8, 17, and 23 could not be sampled due to lack of beach.

METHODOLOGY

Field Collection

During the CBJA, a beach seine survey of juvenile fish in the Delaware coastal bays was conducted monthly from July to September 1993 at 26 of 29 sites corresponding to those sampled in historical studies. Three sites could not be sampled due to lack of beach (Fig. 1). Two kinds of sampling gear were used to be consistent with the historical studies. Sites corresponding to those sampled by Edmunds and Jensen (1974) or Ecological Analysts (1976) were sampled with a 50-ft., nylon haul seine of 0.25-in mesh with a 6-ft. by 6-ft. center bag. Sites corresponding to those sampled by Derickson and Price (1973) were sampled with a 60-ft., nylon haul seine of 1-in stretch mesh with a 6-ft. by 6-ft. center bag. Two sites that were common to the studies by Derickson and Price (1973) and Ecological Analysts (1976) were sampled with the 60-ft gear only. At all sites, seines were deployed by holding one end on shore, towing the other end perpendicularly away from shore, walking parallel to shore for 50 yards, then sweeping the seine in a semicircular path towards the shore. All fish collected were identified, and up to 25 individuals of each species were measured to the nearest millimeter.

Data Analysis

Data sets for shore-zone fish were assembled from original data sets where possible. Otherwise, data summaries from reports, technical papers, and the Delaware inland bays characterization document (Weston, 1993) were utilized in the analysis. The principal studies used in this analysis are shown in Table 1. Original data sets were available only for the Coastal Bays Joint Assessment (CBJA) for 1993 and Edmunds and Jensen for 1971.

In an effort to determine how shore-zone fish community structure may have changed with time and allow comparisons to Maryland's coastal bays, percent abundances for each species were calculated based on the two summer months' collections that most closely approximated the CBJA 1993 collecting times and the Maryland coastal bays' finfish investigations (Casey, et al., 1994) in either June/July or August/September. Because of possible differences in sampling gear and intensity, no special attempt was made to analyze differences in total abundance. Fish species were ranked by percent abundance for the summer season by aggregating two sampling periods (June/July or August/September) for each body of water sampled.

RESULTS

Indian River Bay and Rehoboth Bay

Results from Derickson and Price (1973) are shown in Figure 2 and indicate that for the summer of 1968 the five most dominant fish species in order of percent abundance were *Menidia menidia* (30.6%), *Fundulus majalis* (29.2%), *Fundulus heteroclitus* (20.2%), *Pseudopleuronectes americanus* (7.6%), and *Anchoa mitchilli* (4.6%) representing a total of 92.2% of the total shore-zone fish community. The same authors (Derickson and Price, 1973) report for the summer of 1969 (Fig. 3) that the most dominant fish species were *Fundulus majalis* (35.8%), *Menidia menidia* (22.0%), *Fundulus heteroclitus* (21.3%), *Bairdiella chrysoura* (9.1%), and *Pseudopleuronectes americanus* (3.5%) for a total of 91.7% of the shore-zone fish community. In 1992, Timmons (1995) captured shore-zone fishes reporting *Menidia menidia* (34.8%), *Fundulus heteroclitus* (16.4%), *Fundulus majalis* (16.3%), *Pseudopleuronectes americanus* (5.2%), and *Anchoa mitchilli* (4.6%) for a total of 77.3% of the shore-zone fish community (Fig. 4). In 1993, the CBJA duplicated the Derickson and Price (1973) and Timmons (1995) studies and reported dominance in order of percent abundance to be *Fundulus majalis* (49.4%), *Fundulus heteroclitus* (31.2%), *Cyprinodon variegatus* (3.1%), *Mugil curema* (2.9%), and *Leiostomus xanthurus* (1.9%) for a total of 88.5% of the shore-zone fish community. In this case, the two *Fundulus* sp. accounted for over 80% of the total (Fig. 5).

Table 1. Sampling methodology of several studies on the shore-zone finfish community of the Delaware inland bays.					
Study	**Study Period**	**Study Location**	**Sampling Gear**	**Length of Haul**	**Sampling Frequency**
CBJA	1993	Rehoboth--7 Stations Lower Indian River--8 stations	60' x 6' Haul Seine; 0.5" Square Mesh	~150'	July, August, September
		Indian River--7 Stations	50' x 6' Beach Seine; 0.25" Square Mesh		
Timmons & Price	1992	Rehoboth--8 Stations	20' x 3'; 0.25" Str. Mesh	~100'	June, August
		Indian River-- 7 Stations			
Price & Schneider	1991	Little Assawoman Bay--5 Stations	33' x 4' Seine; 0.25" Str. Mesh	~100'	Single Event-- June
DNREC	1986-1988	Rehoboth--8 Stations	50' x 6' Beach Seine; 0.25" Square Mesh	~150'	Monthly
		Indian River-- 7 Stations			May-November
22DP&L	1974-1976	Indian River--Millsboro to the Inlet--7 Stations	50' x 6' Beach Seine; 0.25" Square Mesh	~150'	Semi-Monthly-- 1974-1975; Monthly--1975-1976
Campbell & Price	1973	White Creek-- 8 Stations	25' Beach Seine; 0.25" Square Mesh	~150'	Weekly
Edmunds & Jensen	1970-1971	Upper Indian River--9 Stations	50' x 6' Beach Seine; 0.25" Square Mesh	~220'	Monthly
Derickson & Price	1968-1970	Rehoboth--8 Stations	60' x 6' Haul Seine; 0.50" Square Mesh	~150'	Monthly
		Indian River-- 9 Stations			
Pacheco & Grant	1957	White Creek-- 8 Stations	25' x 6' Beach Seine; 0.25" Square Mesh	~150'	Semi-Weekly

The rank and relative abundance of the top ten shore-zone fish collected by seine in the above studies are shown in Table 2. The average rank of the five most abundant shore-zone fish in order are *Fundulus majalis* (1), *Fundulus heteroclitus* (2), *Menidia menidia* (3), *Pseudopleuronectes americanus* (4), and *Cyprinodon variegatus* (5) which allows members of the Cyprinodon family to comprise

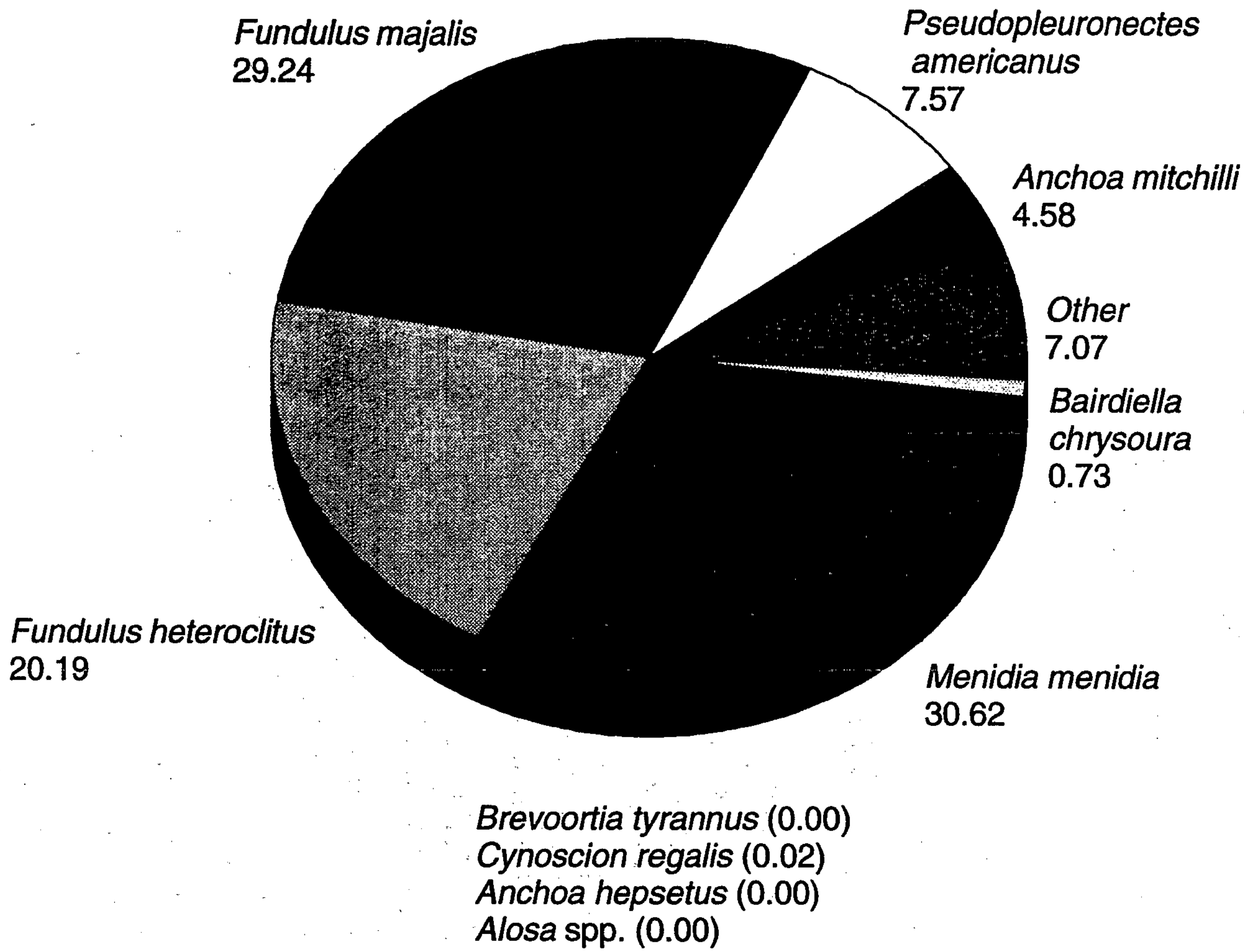

Figure 2. 1968 percentages of total fish captured in the inland bays.

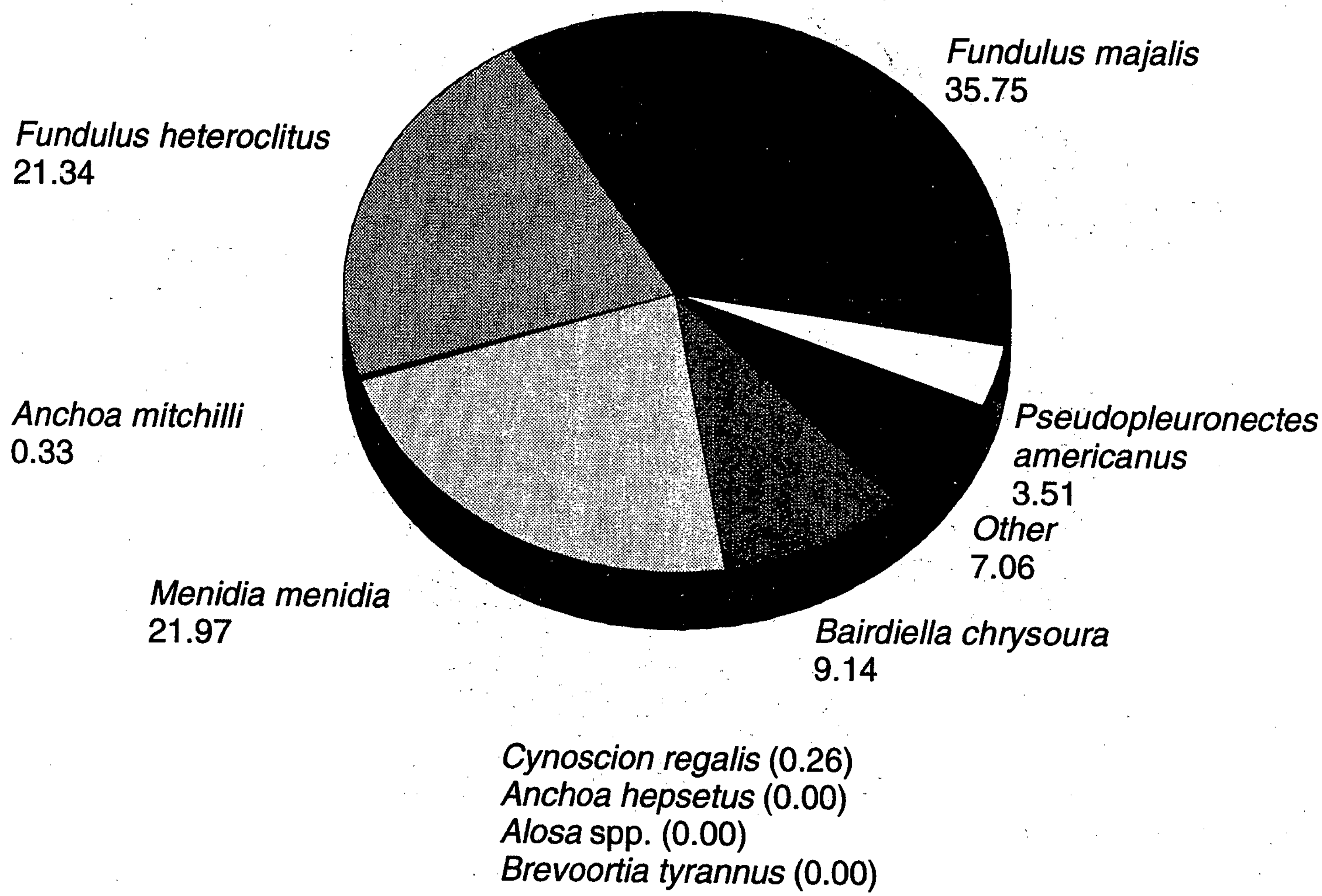

Figure 3. 1969 percentages of total fish captured in the inland bays.

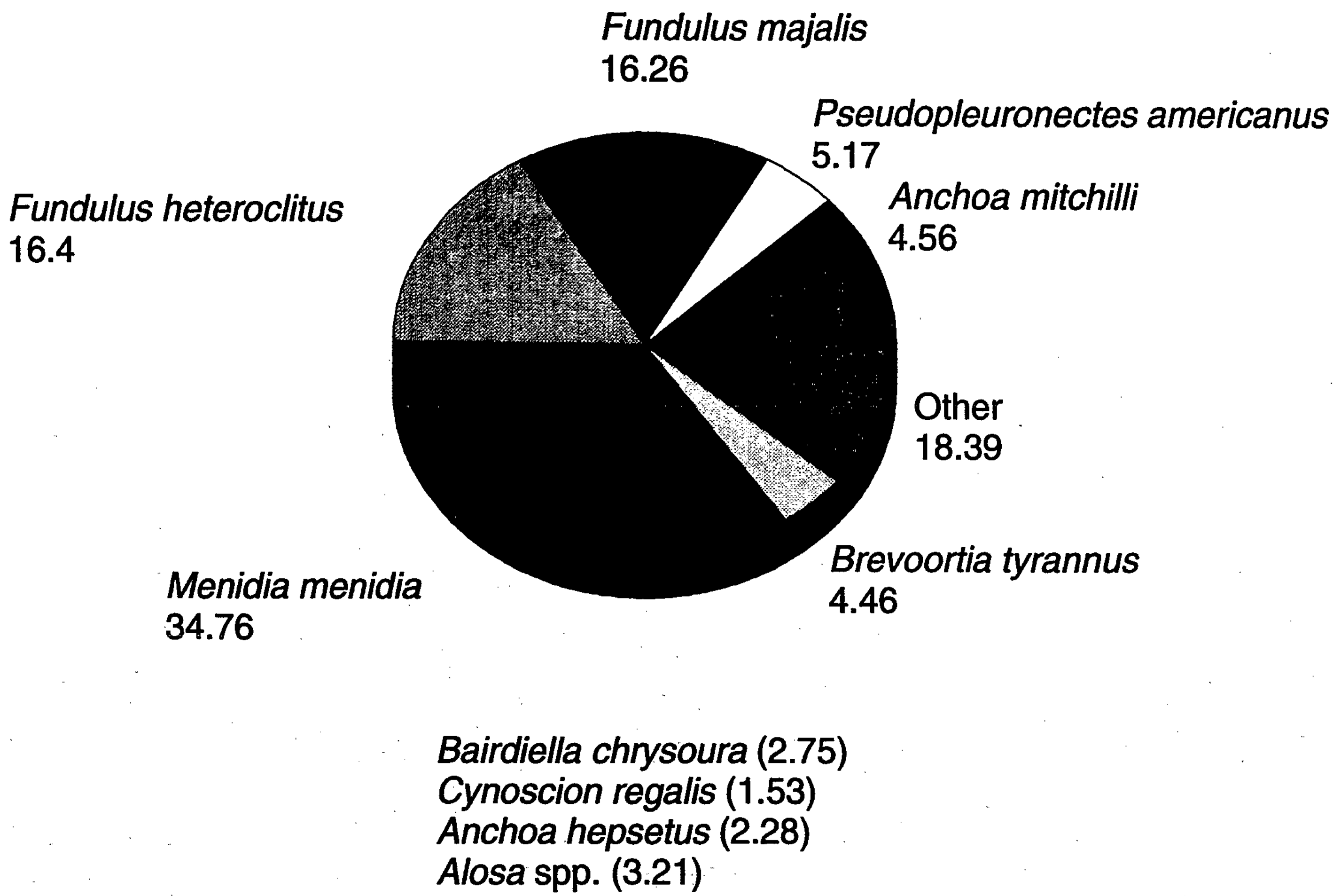

Figure 4. 1992 percentages of total fish captured in the inland bays, DE.

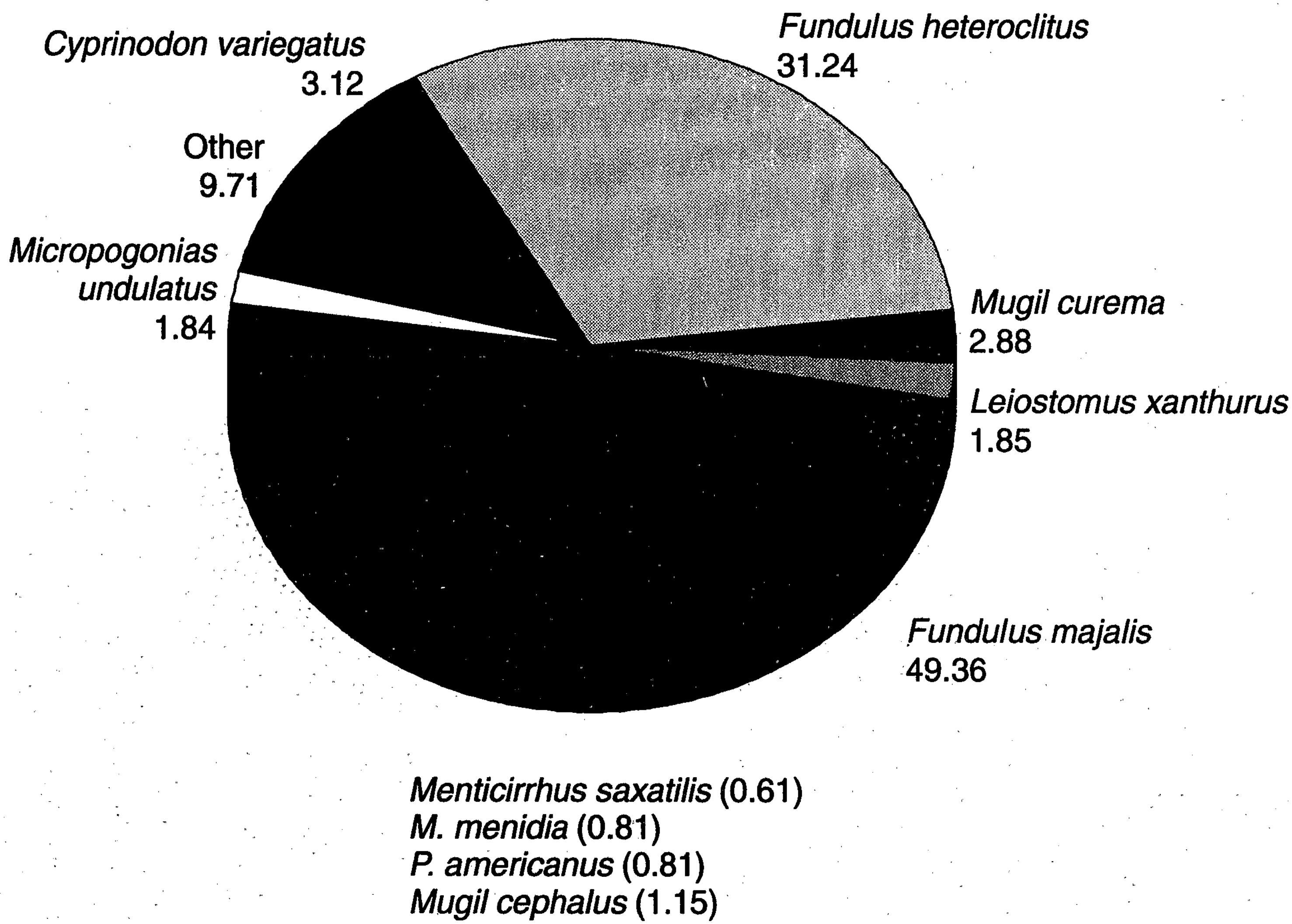

Figure 5. 1993 percentages of total fish captured in the inland bays, DE.

three of the top five rankings for Rehoboth Bay and Indian River Bay.

Upper Indian River

Edmunds and Jensen (1974) collected shore-zone fish at 9 stations from the base of the Millsboro dam on upper Indian River to the mouth of Island Creek near the DP&L Indian River power plant. In 1971, they found the dominant fish species to be *Brevoortia tyrannus* (69.6%), *Fundulus heteroclitus* (8.5%), *Pomoxis nigromaculatus* (6.8%), *Menidia menidia* (4.7%), and *Leiostomus xanthurus* (3.3%) for a total of 92.9% of the fish community (Fig. 6). In 1993, the CBJA duplicated this study and reported dominance in abundance by percent to be *Menidia menidia* (60.9%), *Fundulus heteroclitus* (21.7%), *Fundulus majalis* (8.9%), *Morone saxatilis* (2.2%), and *Leiostomus xanthurus* (1.4%) for a total of 95.1% of the shore-zone fish community (Fig. 7). The 1971 study reported a number of primarily freshwater species including *Notemigonus crysoleucas*, *Fundulus diaphanus*, *Pomoxis nigromaculatus*, and *Esox niger*. *Lepomis macrochirus* and *Lepomis gibbosus* were reported both in 1971 and 1993, but in larger numbers in 1971.

Base of the Millsboro Dam

Station 1 from the 1971 study by Edmunds and Jensen (1974) was the most up-river station in Indian River and, therefore, should experience the lowest salinities. In 1971, the most dominant species by percent abundance were *Pomoxis nigromaculatus* (45.2%), *Menidia beryllina* (19.2%), *Fundulus diaphanus* (10.7%), *Notemigonus crysoleucas* (9.5%), and *Leiostomus xanthurus* (7.4%) for a total of 92.0% of the shore-zone fish community (Fig. 8). In 1993 (Versar, 1995), the dominant species at that station were *Fundulus heteroclitus* (48.1%), *Morone saxatilis* (16.9%), *Fundulus majalis* (13.5%), *Menidia menidia* (9.9%), and *Menidia beryllina* (5.2%) for a total of 93.6% of the total shore-zone fish population (Fig. 9). In 1971, three of the top five species were freshwater fish with *Fundulus* sp. comprising only 10.7%, while in 1993 all were brackish/estuarine forms with the two *Fundulus* sp. comprising a total of 61.6% of the total assemblage.

White Creek

In 1957, Pacheco and Grant (1965) conducted a shore-zone fish survey of White Creek (Fig. 10) and reported that the dominant species in order of percent abundance were *Brevoortia tyrannus* (32.5%), *Menidia beryllina* (19.5%), *Menidia menidia* (18.2%), *Fundulus heteroclitus* (13.5%), and *Anchoa mitchilli* (5.9%) for a total of 89.6% of the shore-zone fish community (Fig. 11). Campbell (1975) duplicated the study 16 years later and showed that the dominant species captured in White Creek included *Menidia menidia* (39.7%), *Fundulus heteroclitus* (13.6%), *Leiostomus xanthurus* (13.0%), *Menidia beryllina* (11.6%), and *Fundulus majalis* (8.8%) for a total of 86.7% of the shore-zone fish community (Fig. 12). In 1957, the two *Fundulus* sp. comprised 15.6% of the total assemblage. By 1973, that had increased to 22.4% of the total assemblage.

Table 2.	Rank and relative abundance of top ten shore zone fish collected by seine from Indian River and Rehoboth bays, Delaware--1968-1993.									
	1968		1969		1992		1993		1968-1993
	Rank	%	Rank	%	Rank	%	Rank	%	Average Rank
Atlantic Silversides	1	30.6	2	22.0	1	34.8	8	0.8	3
Striped Killifish	2	29.2	1	35.8	3	16.3	1	49.4	1
Mummichog	3	20.2	3	21.3	2	16.4	2	31.2	2
Winter flounder	4	7.6	5	3.5	4	5.2	9	0.8	4
Menhaden					6	4.5			9
Bay Anchovy	5	4.6			5	4.6			6*
Sheepshead Minnow	6	2.5	7	1.2			3	3.1	5
Spot			6	1.6			5	1.9	8
Silver Perch	9	0.7	4	9.1	8	2.8			6*
Atlantic Croaker							6	1.8	
White Mullet	10	0.6	10	0.5			4	2.9	10
Rainwater Fish	8	1.2							
Striped Mullet			9	0.8			7	1.6	
Weakfish					10	1.5			
Northern Puffer	7	1.5	8	1.1					
Atlantic Herring					7	3.2			
Striped Anchovy					9	2.3			
Kingfish							10	0.6	
Total No. of Species	36		40		34		31		*Tied

Indian River Bay

The only additional data for Indian River Bay are from a study conducted by Ecological Analysts for Delmarva Power and Light (Ecological Analysts, 1976). The study included seven shore-zone stations spaced approximately equidistantly from Millsboro Dam to Indian River Inlet (Fig. 1). Original data were not available for this study. The semi-monthly (74-75) data or monthly (76) data were aggregated by year (74-75, 75-76, 76) and, therefore, are not directly comparable to the two monthly summer collections selected from the other studies. However, these data do provide some insight into the shore-zone fish community and are included in Table 3 for completeness. The rankings of dominant species for White Creek (1957 and 1973) and Indian River (1974-1976) are strikingly similar (Table 3) and show that the dominant species in order are *Menidia menidia* (1), *Fundulus heteroclitus* (2), *Brevoortia tyrannus* (3), *Menidia beryllina* (4), and *Leiostomus xanthurus* (5).

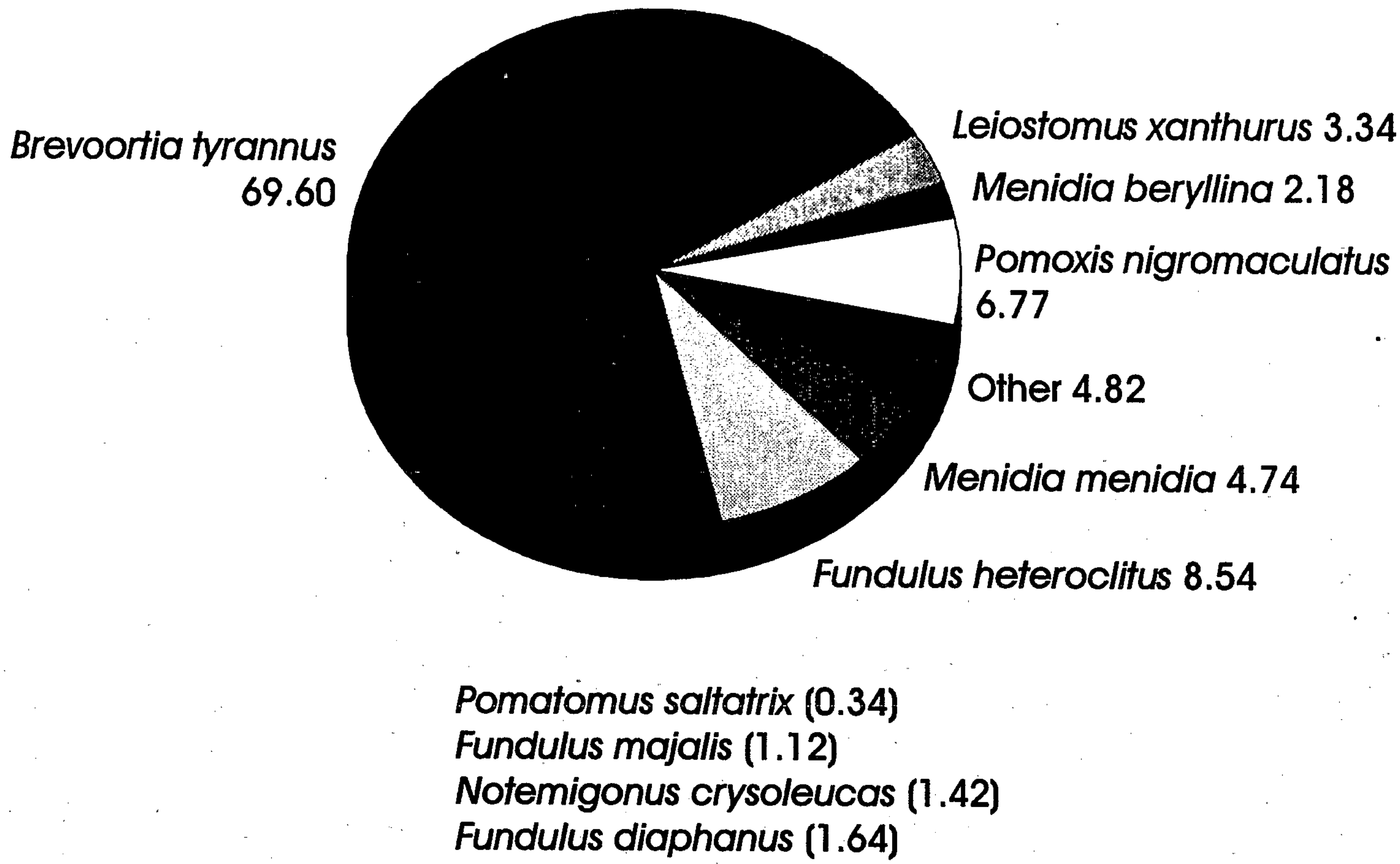

Figure 6. 1971 percentages of fish captured in upper Indian River, DE.

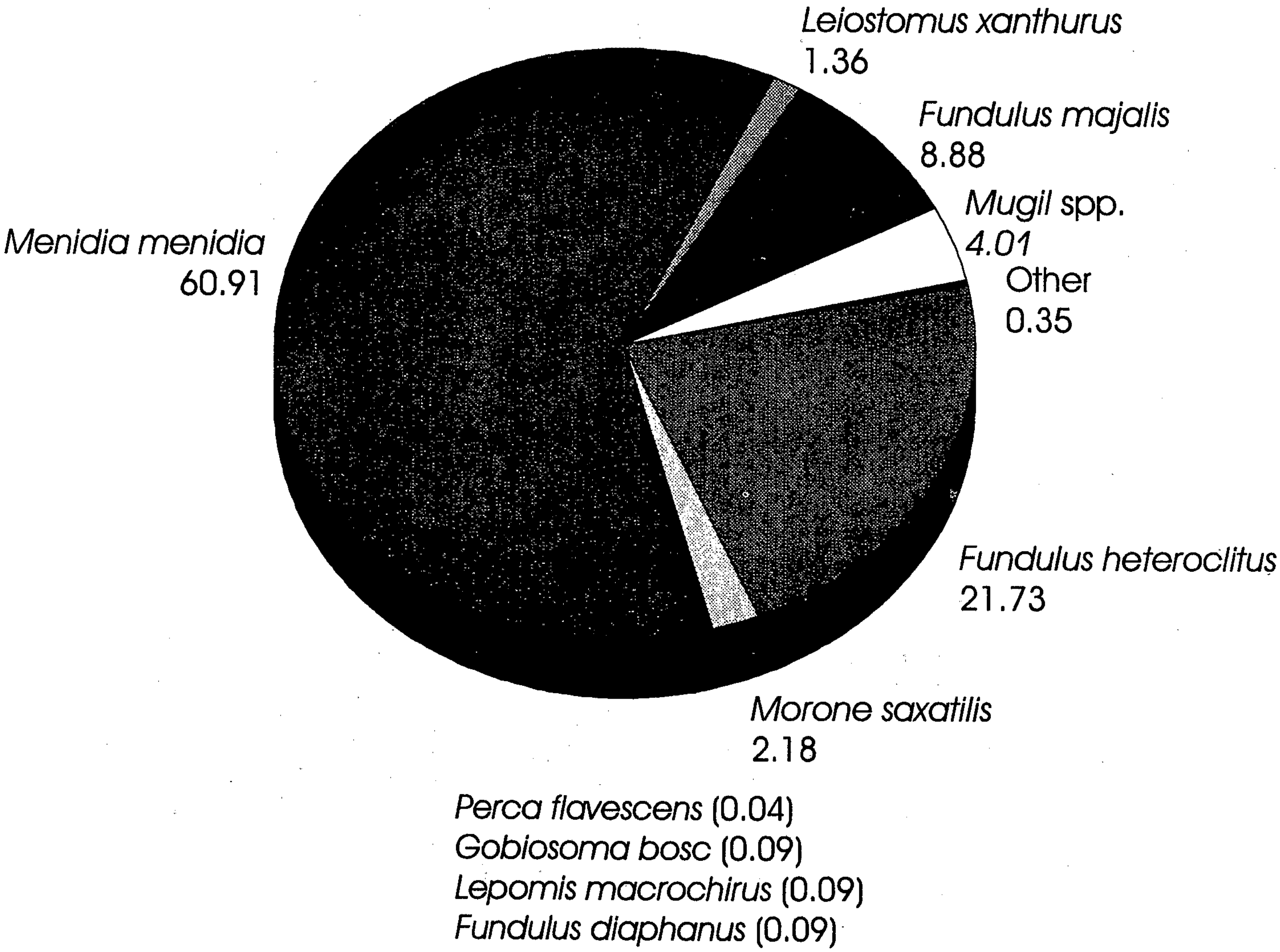

Figure 7. 1993 percentages of fish captured in upper Indian River Bay, DE.

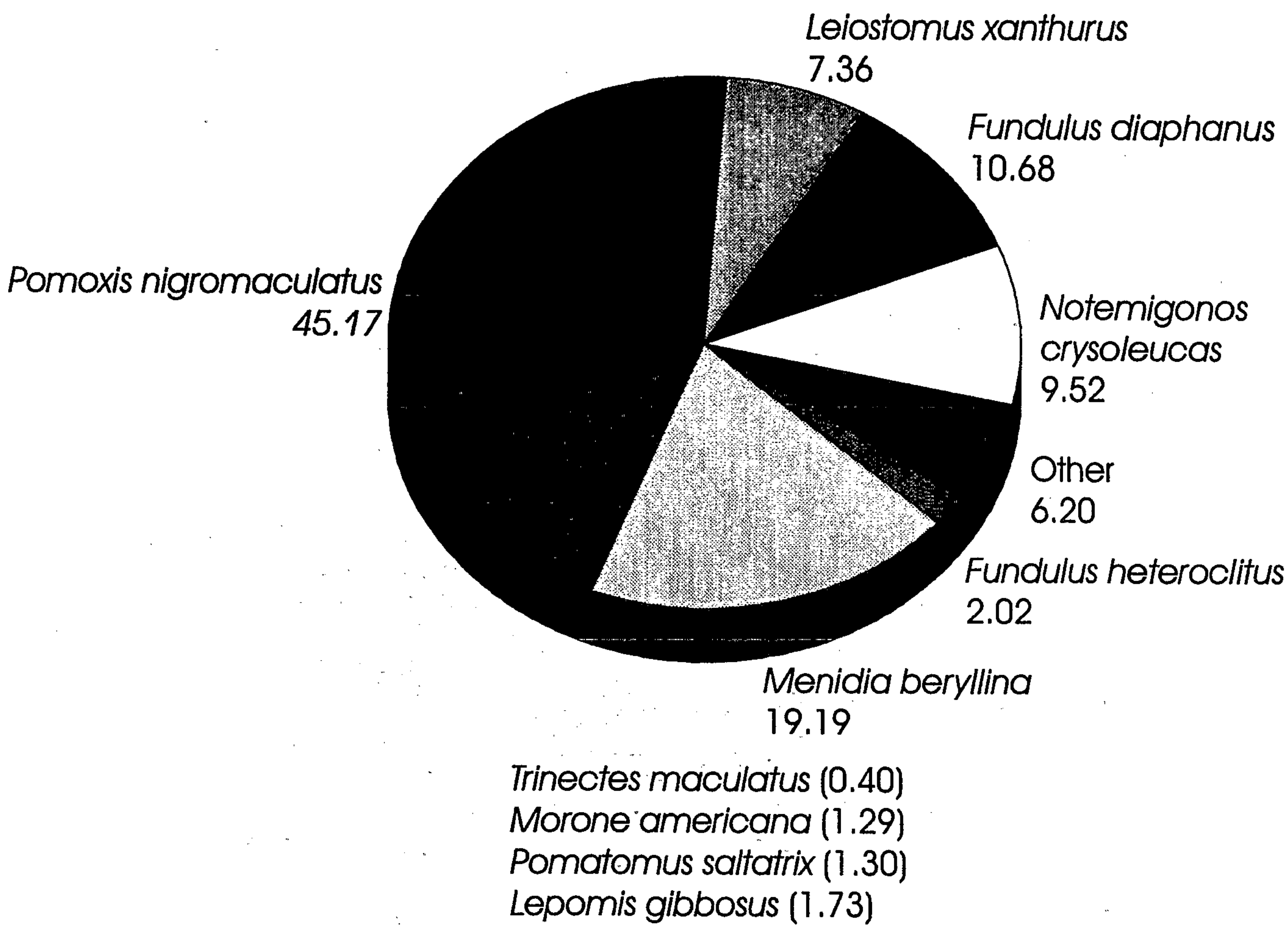

Figure 8. 1971 percentages of total fish captured in the base of Millsboro Dam, Indian River, DE.

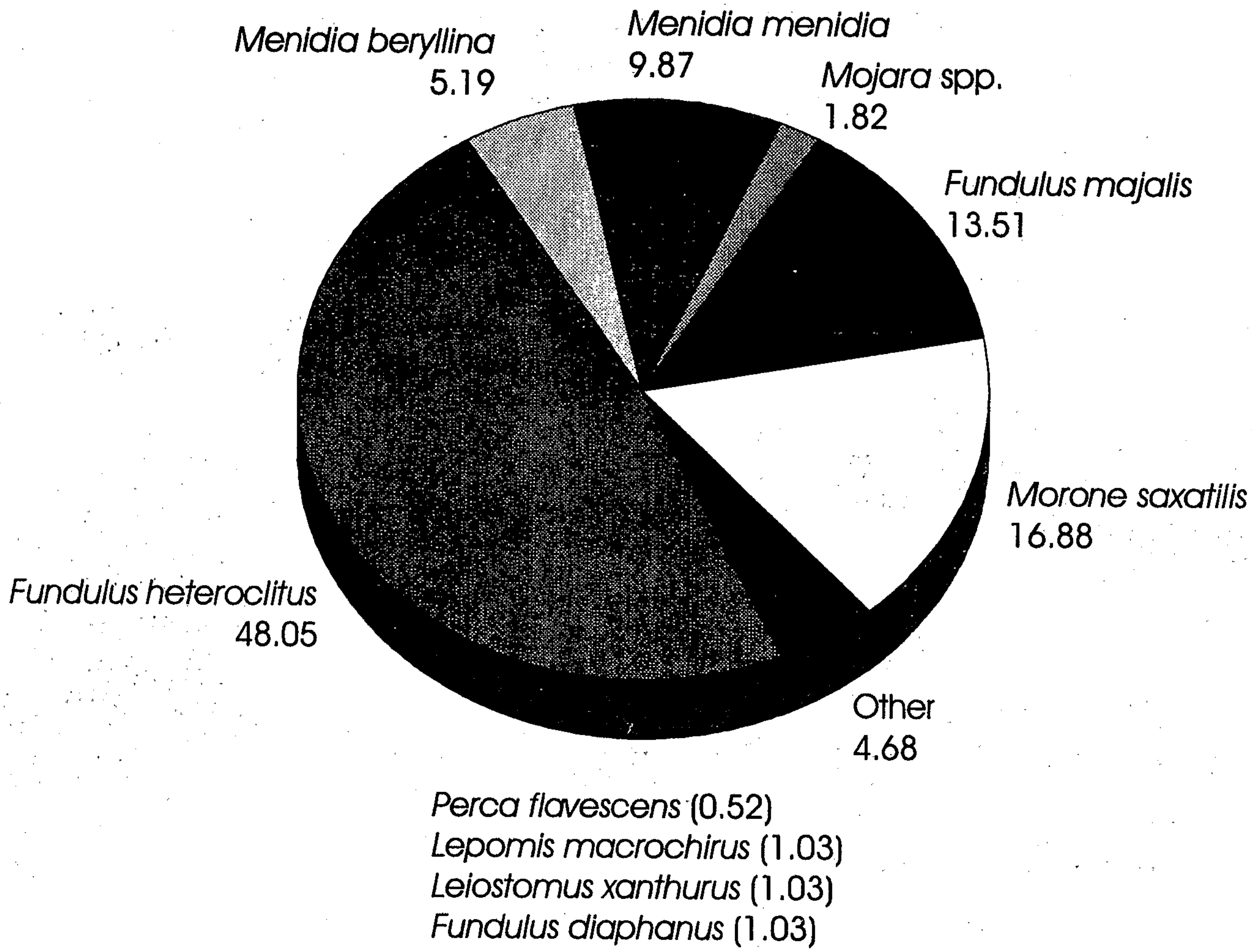

Figure 9. 1993 percentages of total fish captured in the base of Millsboro Dam, Indian River, DE.

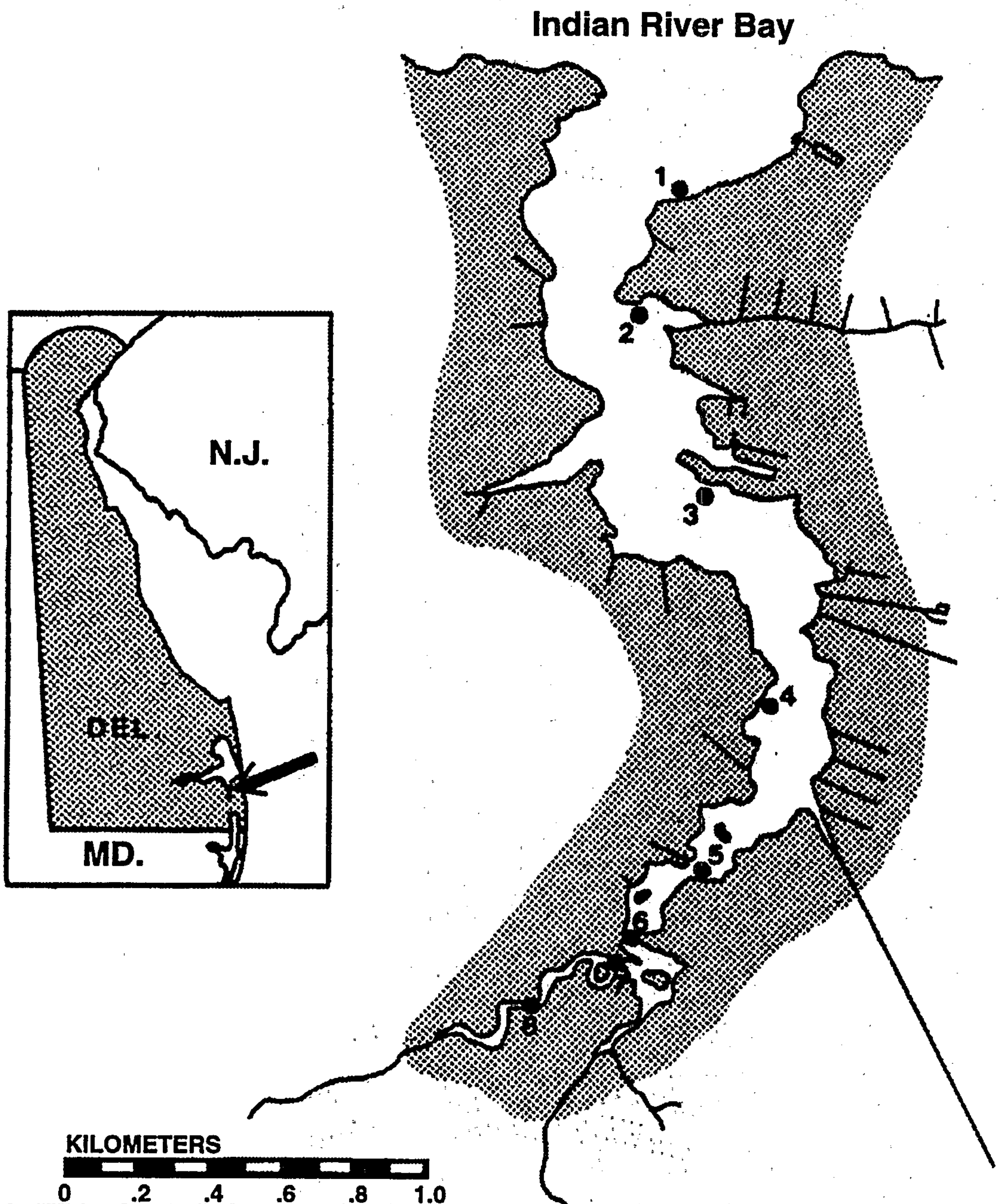

Figure 10. White Creek, Delaware, with the eight sampling stations indicated. Inserts shows location of White Creek relative to the Atlantic coast.

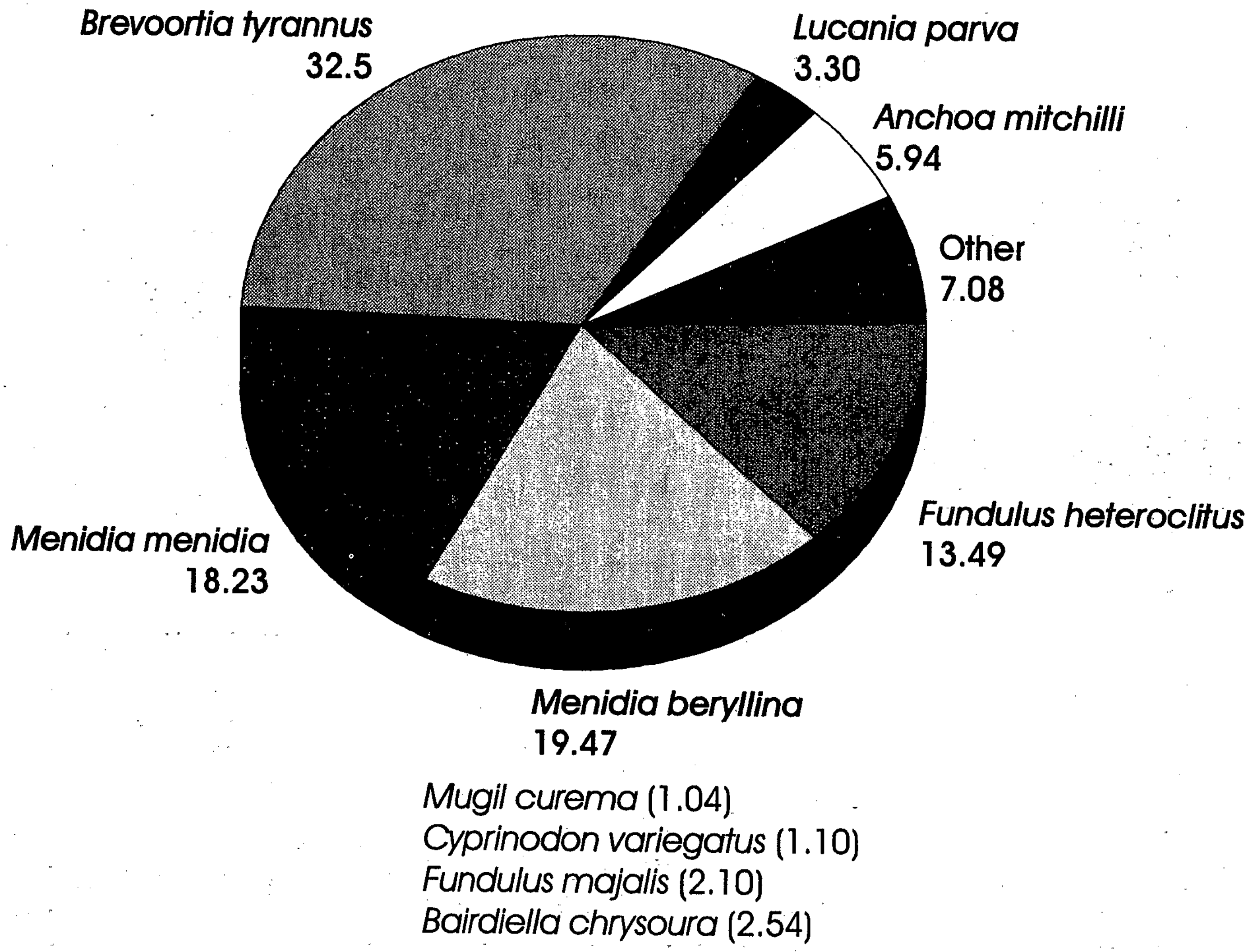

Figure 11. 1957 percentages of total fish captured in White Creek, Indian River, DE.

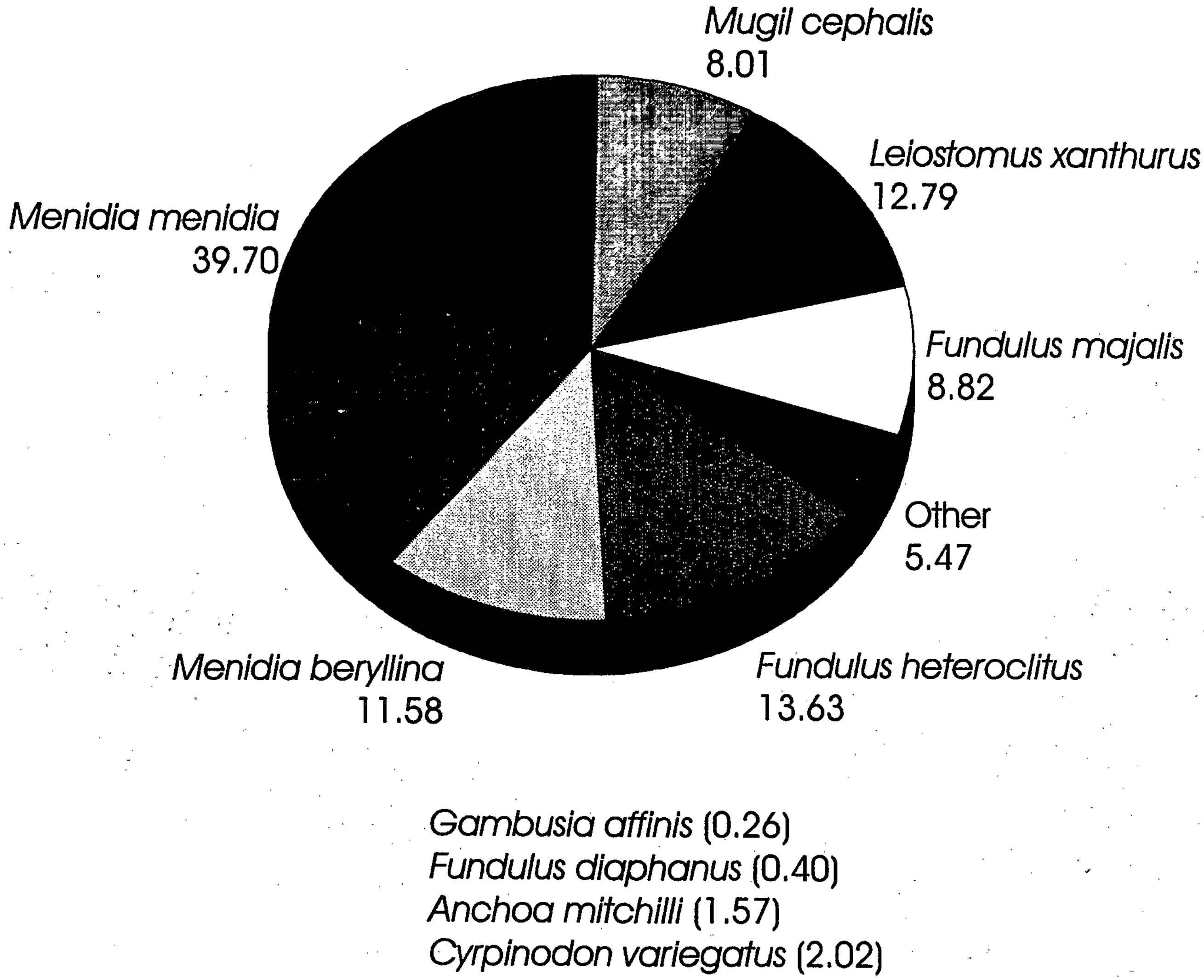

Figure 12. 1973 percentages of fish captured in White Creek, Indian River, DE.

Table 3. Rank and relative abundance of top ten shore zone fish collected by seine from Indian River and White Creek, Delaware--1957-1976.

	1957		1973		1974-75		1975-76		1976		1957-1976
	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Average Rank
Atlantic Silversides	3	18.2	1	39.7	2	14.8	2	26.0	3	6.5	1
Striped Killifish	8	2.1	5	8.8	7	1.3	4	4.4	8	0.7	7
Mummichog	4	13.5	2	13.6	3	12.2	1	27.6	4	6.5	2
Menhaden	1	32.5			1	58.6	5	3.3	1	70.9	3
Bay Anchovy	5	5.9	8	1.6	4	2.9	7	2.3	5	1.3	6
Sheepshead Minnow	9	1.1	7	2.0	10	0.6					9
Spot			3	12.8	6	2.6	3	25.6	2	10.3	5
Silver Perch	7	2.5									
Bluefish					9	0.7					
Golden Shiner							8	1.4			
Gizzard Shad							9	1.2			
White Perch									10	0.5	
Croaker					8	1.0					
White Mullet	10	1.0							9	0.5	10
Tidewater Silversides	2	19.5	4	11.6	5	2.9	6	3.2	7	0.8	4
Rainwater Fish	6	3.3									
Striped Mullet			6	8.0							
Banded Killifish			9	0.4			10	1.1	6	1.0	8
Top Minnow			10	0.3							
Total No. of Species	41		24		51		56		29		

DISCUSSION

One way of attempting to examine trends in fish populations over time in the Delaware's inland coastal bays is to compare the composition for the earliest records in the area with current compositions. For White Creek, the earliest record (1957) and three representative studies conducted in 1968, 1973, and 1993, there seems to be a significant shift in the fish faunal dominance as shown in Tables 2 and 3. These shifts are summarized below:

Rank	1957	1968	1973	1993
1	Menhaden	Atlantic Silversides	Atlantic Silversides	Striped Killifish
2	Tidewater Silversides	Striped Killifish	Mummichog	Mummichog
3	Atlantic Silversides	Mummichog	Spot	Sheepshead Minnow
4	Mummichog	Winter Flounder	Tidewater Silversides	White Mullet
5	Bay Anchovy	Bay Anchovy	Striped Killifish	Spot6
6	Rainwater Fish	Sheepshead Minnow	Striped Mullet	Atlantic Croaker
7	Silver Perch	Northern Puffer	Sheepshead Minnow	Striped Mullet
8	Striped Killifish	Rainwater Fish	Bay Anchovy	Atlantic Silversides
9	Sheepshead Minnow	Silver Perch	Banded Killifish	Winter Flounder
10	White Mullet	White Mullet	Top Minnow	Kingfish

During the past 36 years, it appears that dominance has shifted from juvenile menhaden, tidewater silversides, and bay anchovy to *Fundulus* sp. and sheepshead minnow. Basically, the general impression is that the Family Cyprinodontidae, which includes the killifish and sheepshead minnow, are becoming progressively more dominant with time, while menhaden, bay anchovy, and tidewater silversides are declining in dominance. Of these, the killifishes and silversides are year-round residents, while the anchovy and menhaden are warm-water migrants (Weston, 1993). Thornton (1975) reported that the killifish and sheepshead minnow have strong tolerances to low oxygen while menhaden and bay anchovy are quite sensitive to low oxygen. Based on the literature and his own research, Thornton (1975) constructed a classification of estuarine fish based on their sensitivity to low oxygen. For the dominant fishes encountered in this study, they are listed below in order of sensitivity:

	Scientific Name	Common Name
Most Sensitive	*Brevoortia tyrannus*	Atlantic Menhaden
↓	*Menidia menidia*	Atlantic Silversides
	Anchoa mitchilli	Bay Anchovy
	Mugil cephalus	Striped Mullet
	Bairdiella chrysoura	Silver Perch
	Leiostomus xanthurus	Spot
	Cyprinodon variegatus	Sheepshead Minnow
	Fundulus heteroclitus	Mummichog
Least Sensitive	*Fundulus majalis*	Striped Killifish

Although *Anchoa mitchilli*, the bay anchovy, was not included in the original list by Thornton (1975), he mentions that it is extremely sensitive to being held in captivity and dies within a few minutes in tanks or buckets, suggesting a very low tolerance to hypoxic stress; i.e., it would probably rank with the Atlantic menhaden and Atlantic silversides as being very sensitive. Thornton updated the ranking to include the bay anchovy as shown above and as reported in Daiber, et al. (1976).

Water Quality Considerations

The nutrient inputs to the inland bays affect the abundance and distribution of bay life. The microscopic floating plants (phytoplankton) are most prolific (as measured by chlorophyll concentrations) in the portions of the estuary closest to nutrient sources (e.g., in the upper and middle portions of Indian River Bay), while Rehoboth Bay generally represents an intermediate level of ambient nutrients and chlorophyll concentration, while the area nearest Indian River Inlet has the lowest concentrations of both. The same relationship is seen in the clarity (turbidity) of the water, with the upper portions of the tributaries having the most turbid water and the areas flushed near Indian River Inlet having the least turbid water. Turbidity also changes seasonally, with clarity of the water generally improving after Labor Day and lasting until about Memorial Day. The most turbid water in all three bays is seen during the summer season and probably results from a combination of biological effects (increased phytoplankton and microbial growth) and physical effects (boat traffic) (Ullman, et al., 1993).

Secchi depths in upper Indian River now average about 50 cm year-round, but may be as low as 10 cm during summer months when extremely high chlorophyll concentrations (in excess of $100 \mu g/L^{-1}$) occur in the mesohaline and tidal creek portions of the river (Ullman, et al., 1993). Based upon the EPA Chesapeake Bay classification system, the middle and upper segments of Indian River estuary are more enriched than any segment of the Chesapeake Bay (Weston, 1993) and very likely any portion of the Maryland coastal bays.

Submerged Aquatic Vegetation

A major worldwide decline of seagrass beds occurred in the 1930s and affected the Chesapeake Bay and the Delmarva Peninsula (Delaware, Maryland, and Virginia). While many areas revived from the decline, the inland bays of Delaware never recovered. Eelgrass, *Zostera marina*, once present in the inland bays in the 1920s has been seen sporadically in small quantities, but has not been verified since 1970. Transplanting of seagrasses has been unsuccessful in Delaware, probably due to high levels of suspended chlorophyll, increased turbidity, and high levels of nutrients (Orth and Moore, 1988).

The combination of excessive nutrient levels and high turbidity appears to eliminate the growth of submerged aquatic vegetation (SAV) such as eel grass (*Zostera marina*) in the inland bays. This probably has significant ecological effects, because SAV is desirable habitat for a variety of finfish and shellfish and is food for certain types of waterfowl, although the habitat function may be provided, to some extent, by attached benthic algae (seaweeds) (Timmons, 1995). The seaweeds probably also play a role in sequestering excess nutrients during the summer, but we have evidence that extremely high levels of nutrients and turbidity have a degrading effect on the seaweeds as well, especially in the upper portion of Indian River Bay (Timmons, 1995).

Orth and Heck (1980) found that the dominant fish species in Chesapeake Bay eelgrass meadows were *Leiostomus xanthurus* (1), *Sygnathus fuscus* (2), *Anchoa mitchilli* (3), *Bairdiella chrysoura* (4), and *Menidia menidia* (5). By contrast, *Fundulus heteroclitus* and *F. majalis* ranked 9th and 43rd in eelgrass meadows, respectively.

Habitat Loss through Salinity Changes

The aquatic habitats of the inland bays have been significantly modified during the last few hundreds years. The most significant impacts have occurred as a result of the stabilization and deepening of Indian River Inlet, which resulted in a dramatic change in the bays' complexion. Since the early 1930s, the bays have progressed from an almost totally freshwater, landlocked system to a marine-dominated estuary--all within 60 years. The most dramatic change has occurred since the early 1970s when the inlet depth eroded from 20 feet to depths in excess of 90 feet. The resulting increase in the volume of highly saline ocean that was allowed to pass with each tidal cycle and the accompanying increase in tidal range have had a profound impact on the habitats and living resources of the inland bays (Weston, 1993).

Of particular importance is the reduction (almost total loss) of the tidal freshwater portion of the inland bays. The establishment of dammed mill ponds and the dredging of the upper portions of tidal tributaries, thus allowing the extended upstream progression of the saline tidal wedge, coupled with the increased salinity of the bays, has virtually eliminated breeding and nursery habitat for anadromous fish once common to the inland bays. Striped bass, shad, and various herring, to name a few, were once common to the bays and have now virtually disappeared due to major losses of this high-value habitat. Many of those few upper tributary areas that could still function as spawning and nursery fisheries habitat have been channeled through coarse, woody habitat for the purpose of water drainage and small-boat navigation, yielding streams sterile of habitat structure necessary for protective cover (Weston, 1993).

Table 4 shows the increases in salinities that have occurred since the late 60s and early 70s at the uppermost stations in Indian River based on Edmunds and Jensen's 1971 data compared to the 1993 CBJA. A comparison of the dominant fish captured in 1971 in upper Indian River (Fig. 6) and at the base of the Millsboro dam (Fig. 8) with fish captured in 1993 at the same locations (Figs. 7 and 9) shows a distinct shift from a predominantly freshwater assemblage in 1971 to a more brackish fauna in 1993 dominated primarily by two *Fundulus* sp.

Table 4. Surface salinity comparison (Edmunds and Jensen, 1968-1971; CBJA 1993).								
Station	**7/68**	**7/69**	**8/70**	**6/71**	**8/71**	**7/93**	**8/93**	**9/93**
1	1	2	7.5	3	2	7.8	10.7	14.1
2	4	12.5	11	7.5	12	11.2	8.0	17.0
3	7.5	17	13.5	12	16	19	15.4	21.7
5	10	21	17.5	17.5	19	18.8	21.2	21.9
7	11	23.5	22.5	20	23.5	20.2	23.6	24.0
10	11	24	25	21.5	24	22.8	26.0	24.8
11	13.5	25	25.5	24	25	24.5	26.3	26.3
Data taken from line graphs in Jensen report for EPRI (Edmunds and Jensen, 1974).								

Channel Marker	Station	Channel Marker	Station
MD, 64	1	34	7
54	2	30-31	10
49	3	2	11
40	5		
Markers are mid-channel.			

Of special note is the appearance in 1993 of a strong year class of young-of-the-year striped bass (*Morone saxatilis*) not reported in these bays in significant numbers in any previous study (Pacheco and Grant, 1965; Derickson and Price, 1973; Edmunds and Jensen, 1974; Campbell, 1975). The only interpretation that is offered is that the great recent success of the striped bass population in the Chesapeake Bay is allowing an expansion of the spawning stock into Delaware's inland coastal bays. As evidence for a one-time recent occurrence of striped bass, Timmons (1995) surveyed the shore-zone fish of Indian River and Rehoboth Bay in 1992 duplicating the 1969-70 study of Derickson and Price (1973) and found no striped bass (*Morone saxatilis*).

MARYLAND'S COASTAL BAYS
SHORE ZONE FISH COMMUNITIES

Cecelia C. Linder, James F. Casey, Steve Doctor, Alan Wesche
Maryland Department of Natural Resources
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INTRODUCTION

The shallow waters of Maryland's coastal bays have historically supported large populations of juvenile finfish and shellfish; adults of many species of fish are also seasonally common. Atlantic croaker, bluefish, spot, summer flounder, weakfish, shark, blue crab and hard clam are important both recreational and commercial species which use habitats of the coastal bays. Over 115 species of finfish, 17 species of mollusks, 23 species of crustaceans and countless foraging/grazing organisms frequent these bays (Casey et al., 1991, 1992, 1993). Since 1972, Maryland's Department of Natural Resources has sampled the coastal bays, supplying data for environmental reviews and resource management. Current data on fishery stocks in Maryland's coastal bays are important for several reasons: (1) Many species which use this habitat (bluefish, butterfish, croaker, spot, American eel, summer flounder, scup, sea bass, weakfish, spotted sea trout, red and black drum, white perch, blue crab and horseshoe crab) are the subjects of interstate and/or state management plans, (2) development is increasing, and (3) important fisheries are dependent on production from this area.

Human population growth and watershed development are encroaching on the coastal bay system. Over the next 20 years, local human population levels are expected to increase by 28%, and most of the development will be along the shoreline. Survey data can be used in evaluating impacts of specific developments and tracking ecosystem health over the long term (Citizen's Agenda, 1990). The value of the local commercial and recreational fisheries is quite significant. In 1992, 15.8 million pounds of finfish and shellfish worth 7.7 million dollars were landed in Ocean City. This catch represented 28% of the weight and 21% of the value of Maryland landings. Most of the region's commercial and recreational fishery landings were composed of estuarine-dependent species (Citizen's Agenda 1990) such as summer flounder, weakfish, croaker, and sea bass. During 1985, the last survey year where coastal recreational catch data could be separated from total state recreational catch data, approximately 378,000 recreational fishing trips caught 1.1 million fish in Maryland's coastal waters (NOAA/NMFS, 1986). Trip related expenditures of these fishing trips was $19.1 million (U.S.F.&W.S.,1989).

Information from annual catch data and analysis have been of considerable value to a number of organizations and agencies. Among those requesting data are the ASMFC Spot and Atlantic Croaker Workshop, ASMFC Weakfish Technical Committee, ASMFC Summer Flounder Technical Committee, Mid-Atlantic Fisheries Management Council, MDNR Water Resources, Tidal Wetlands Division, U.S. Fish and Wildlife Service, Environmental Protection Agency, National Park Service, U.S. Corps of Engineers, Versar Inc., Virginia Institute of Marine Sciences, University of Maryland CEES, Delaware DNREC, offices of Maryland state delegates, U.S. Congressmen and Baltimore Sun and Washington Post newspapers. Educational seminars were also conducted with University and Elementary school students.

THE SETTING IN MARYLAND

Maryland's coastal bays (Fig. 13) are contained within a single Maryland county and consist of six interconnected water bodies- St. Martin River and Assawoman, Isle of Wight, Sinepuxent, Newport, and Chincoteague Bays- as well as a number of smaller tributaries. Combined they have a total water surface area of 140.6 square miles. The watershed however, is only about 205 square miles in size, primarily due to the proximity of the Pocomoke River to the west. The total length of the bays and watershed between the Virginia and Delaware lines is about 35 miles. The land is low, sandy, and generally poorly drained. Extensive Type 17 wetlands (*Spartina*) border much of the coastal bays. The coastal bays have been estimated to contain 92% of the state's inventory of this wetland type.

Geomorphology

The coastal bays and watershed are underlain by three distinct geologic formations:

1. Sinepuxent formation- dark, poorly sorted, silty, fine to medium sand with thin beds of peaty sand and black clay.

2. Ironshire formation- pale yellow to white sand and gravelly sand.

3. Beaverdam formation- pale coarse gravelly sand with thin local beds of dark gray clay containing peaty material.

Soils of the watershed are predominately of the Fallsington-Woodstown-Sassafras association. These are level to steep and poorly drained to well drained with a dominant sandy clay-loam subsoil. Smaller regions of other soil types exist here, characterized by poor drainage and a silty clay-loam subsoil. There are ten known aquifers that may impact the watershed with the Quaternary aquifer being the most important source of fresh water. It is recharged by precipitation over a broad area. Some of these aquifers contain salt water. Contamination of existing aquifers with salt water has taken place in limited areas due to dredging or excessive fresh water withdrawal. The water table is generally within 25 feet of the surface with basement rock formations found in excess of 7,500 feet deep.

Hydrography

Seven notable streams are tributaries to the coastal bays, with the St. Martin River, accounting for 62% of the total drainage area for the upper two bays, being the primary one. The coastal bays are connected to the Atlantic Ocean by an inlet at Ocean City and an inlet at the southern terminus of Chincoteague Bay in Virginia. The bays are shallow, generally less than six feet in depth, with the greatest depths in the marked navigation channels. Shoaling is common in many areas of the bays, reducing depths to only one to three feet. Mean salinities for the areas sampled by Maryland DNR vary from 25 ppt to 30 ppt during the summer. However, in Chincoteague Bay, the slow water exchange rate can cause evaporation to increase salinity to as much as 35 ppt. Circulation patterns and tidal ranges are dependent on wind conditions and proximity to the inlet. Currents near the inlet can reach five knots with tidal amplitudes of three to four feet. The currents rapidly drop off with distance from the inlet. Historically, the barrier island is susceptible to interdiction by severe storms. Since the 17th century, more than fifty hurricanes and heavy storms have hit Maryland's coast leaving more than eleven inlets in their wakes.

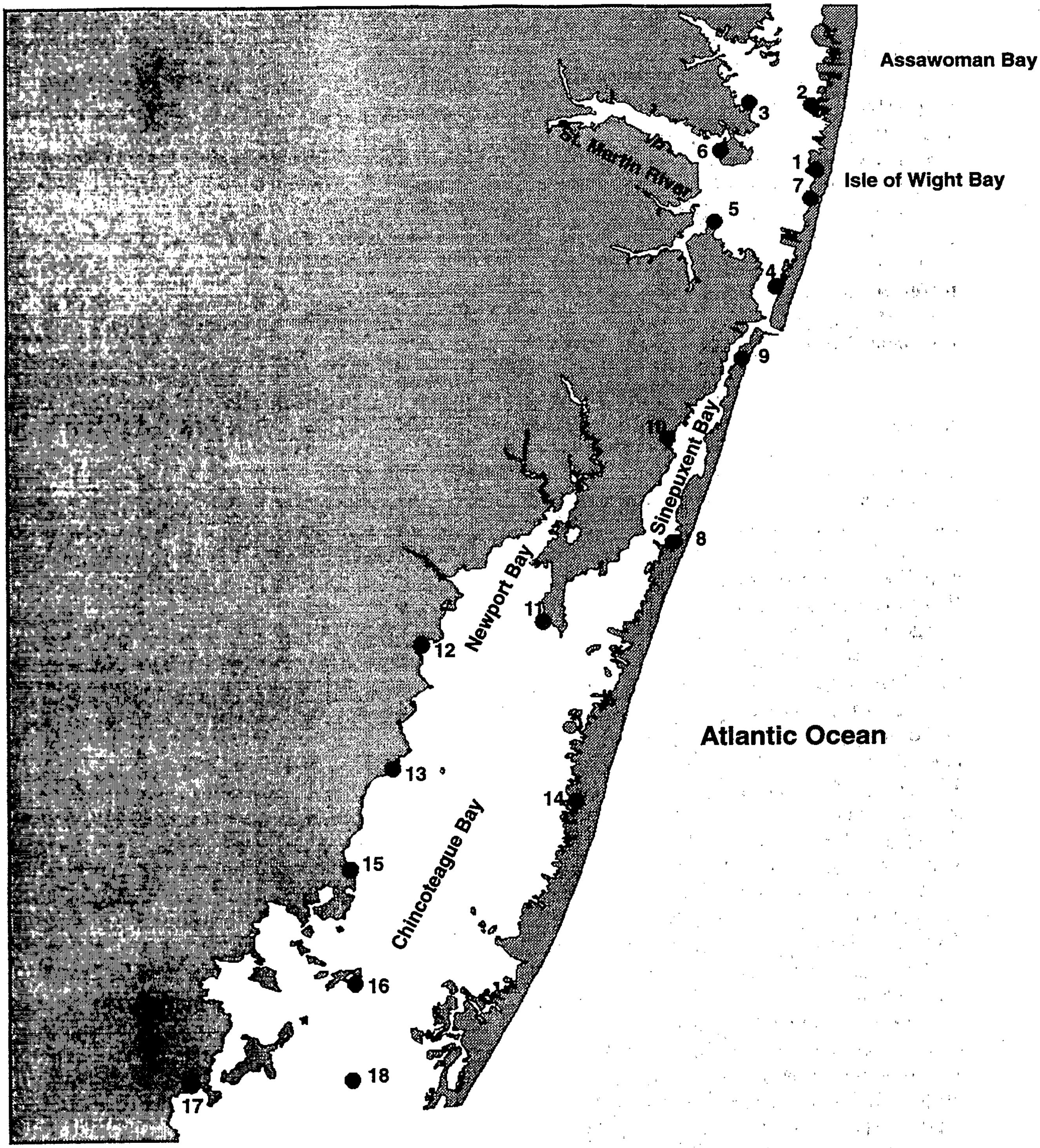

Figure 13. Historical finfish seine sites for Maryland's inland bays.

Sediments

Coastal bay sediments consist primarily of clay-silts along the western edge, grading through sand-silts in mid-bay to sand along the eastern edge. Numerous lenses of varying size of the clay-silts occur within the east side sands. In most upper coastal bay sediments, carbon, nitrogen and sulfur are generally within expected ranges for marine sediments. Metals are also generally within expected ranges although copper and zinc levels are slightly elevated.

Habitat

The area is biologically diverse. Many of the marshes are classified as Type 17 wetlands with additional species dominating the drier ecotones. Over 11,000 acres of low and high salt marsh have been estimated for the coastal bays. Submerged aquatic vegetation (SAV) is common and gradually increasing along the eastern sides of the lower two bays but somewhat uncommon and static in the upper two bays. The lack of SAV's in the upper bays can be due in part to over 25 years of dredge-and-fill activity and resultant changes along the bayside of Ocean City. In 1981, over 157 species of benthic invertebrates representing five phyla were sampled in the bay sediments (Casey and Wesche, 1982). Species richness and abundance varied both temporally and spatially. Diversity and density declined towards late summer and with proximity to the inlet. Generally, diversity and density were higher along the western edges of the bays with clay-silts being the preferred substrate. However, stressed habitat severely limited or eliminated these benthics. Over 115 species of finfish have been identified. Most of these are estuarine-dependent, particularly juvenile game fish such as flounder, sea trout, spot, croaker, bluefish, striped bass, eel and sea bass (Casey et al., 1991, 1992, 1993). The coastal bays are recognized as a valuable breeding and nursery habitat for game species as well as the forager/grazers (Figs. 14 and 15).

The bays are an important area for more than 200 species of birds. More than 11 species actively feed on emergent shoals while many more use the area for breeding, feeding, staging and wintering. Several are listed as threatened or endangered (Citizen's Agenda, 1990). Diamondback terrapin, which have never fully recovered from excessive harvest in the early 1900's, use small, protected sandy beaches within the wetlands to deposit eggs, spending the balance of the year foraging around the more isolated wetlands. Protected turtles such as the Atlantic Loggerhead and Leatherback have been observed in the upper two bays. A variety of mammals including raccoon, muskrat, otter and harbor seals use the bays for feeding and/or breeding.

Land Use in the Watershed

The western side of the bays are primarily rural but with rapidly accelerating housing and strip development on the upper two bays. The eastern side represents extremes, with 25 miles of Assateague Island maintained in its natural state by the National and Maryland statepark systems and to the north, ten miles of Fenwick Island as Ocean City, a heavily developed resort, holding as many as 240,000 visitors on a summer weekend. In 1990, it was estimated that 43 developments of various kinds were under construction or completed (Citizen's Agenda, 1990). Currently, at least eight more are in the planning stages or under construction. Much of this development and construction is taking place on land recognized since 1977 as a flood hazard area. The rural areas of the watershed are devoted to lumber production, agriculture, and the chicken industry. Two wildlife management areas are within the watershed as are six sewage treatment plants of varying capacity; five of which empty into the coastal bays.

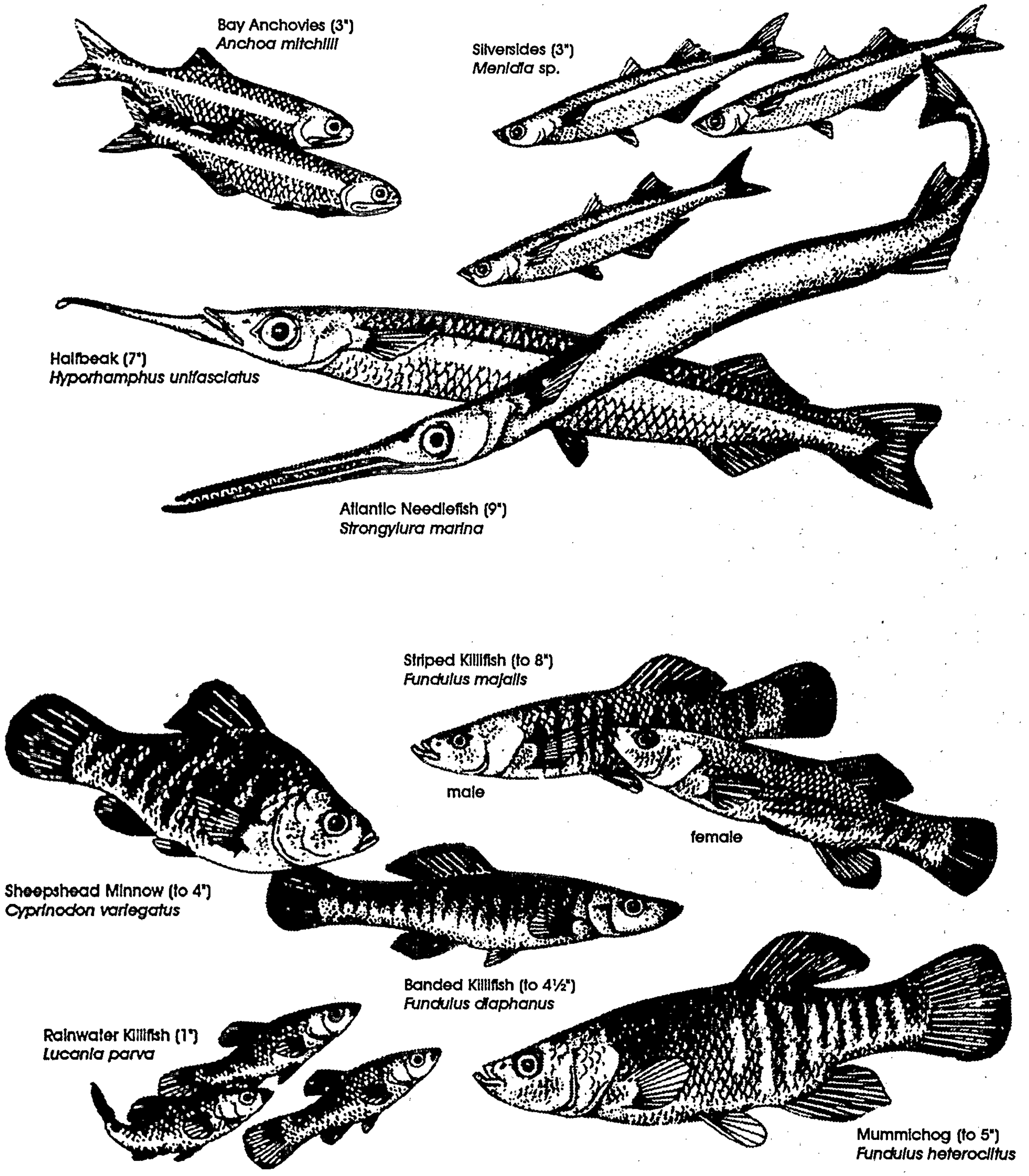

Figure 14. Common shallow water species present in the Delaware and Maryland inland bays (Lippson and Lippson, 1984).

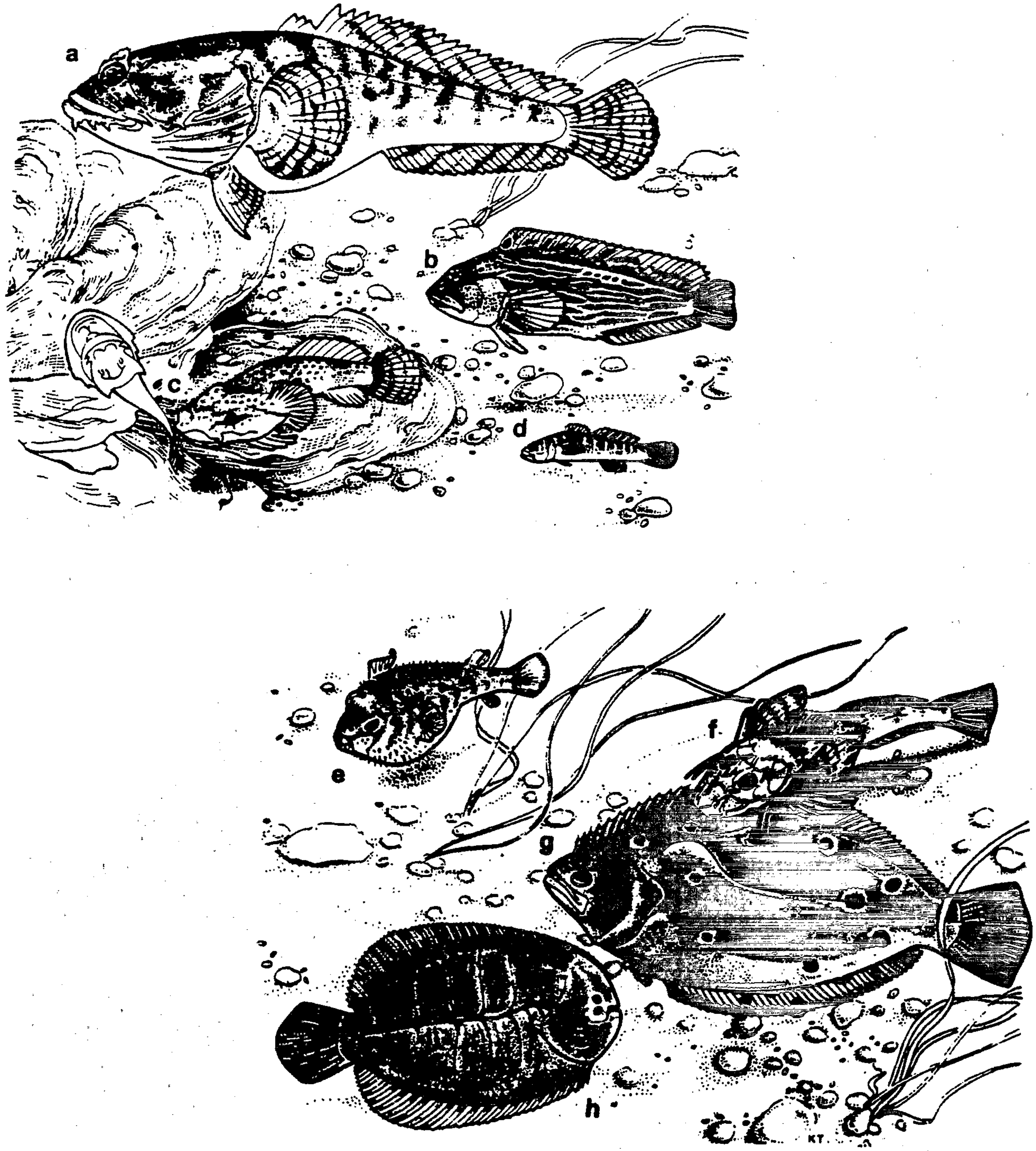

Figure 15. Common benthic species in Maryland's inland bays: a) oyster toadfish, *Opsanus tau*; b) skilletfish, *Gobiesox strumosus*; c) striped blenny, *Chasmodes bosquianus*; d) naked goby, *Gobiasoma bosci*; e) northern puffer, *Sphoeroides maculatus*; f) northern searobin, *Prinotus carolinus*; g) summer flounder, *Paralichthys dentatus*; h) hogchoker, *Tinectes maculatu* (White, 1989).

Perceived Stressors on the System

Rapid growth of housing and strip developments and the resultant associated problems of sewage, stormwater runoff, boat traffic and dockage demands, and service and solid waste demands are the primary stresses on much of the coastal waters. Bulkheading eliminates wetlands and shallow water habitats and creates unstable bottom conditions. Dredging and dead-end canal developments create unusable or detrimental habitat. Discharge of untreated and treated sewage from five sewage treatment systems, landfill leachate, poultry plant and agricultural runoff, and aging septic systems add to the problem. Currently, Turville/Herring Creeks and the St. Martin River have been closed to shellfishing from coliform contamination since 1975 and Johnson Bay since 1966. Generally, it is acknowledged that seasonal patterns for dissolved nutrients, chlorophyll-a and dissolved oxygen are similar to other healthy high saline coastal bays. However, current water quality data is distinctly inadequate at detecting short and long term trends in toxic contaminants and water degradation.

Commercial and recreational fishing contribute considerably to the local economy, bringing in an estimated total of 427 million dollars annually to their respective industries. Currently however, over 18 species of finfish and shellfish are undergoing state and/or federally mandated management measures because their populations are near, at, or below sustainable harvest levels. Contributing to this problem have been the alteration, degradation, and/or elimination of quality habitat.

METHODOLOGY

Field Collection

Fishes were sampled with a 4.9 m (16 ft.) semi-balloon otter trawl in areas over 1.0 m deep and a 30.5 m X 1.8 m X 6.4 cm (100 ft X 6 ft X .25 in) bag seine in areas less than 1.0 m in depth. Single six-minute trawls were made at 20 fixed sites each month between April and October, 1989-1994. Single quarter-circle seine hauls were made at 19 fixed sites around the perimeter of the coastal bays in tributaries in June and September, 1989-1994. Between 1972 and 1988, both seine and trawl were made at the same sites in various degrees of frequency in this time period (Table 5). Finfish data collected at each site included species, number, total length (TL, mm), salinity, temperature, wind and weather conditions and tide state.

Table 5. Sampling frequency for the Maryland inland bay finfish survey by year (top row) and month (subsequent rows) for each site (left-most column).

SITE	72	73	74	75	76	77	78	79	80	81	82	83	86	87	88	89	90	91	92	93	94
2		6			7		7	6		7	7			7	7; 9	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
3	8	6; 8	7; 8		7		7				7			7	7; 9	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
14		8		6; 8	7	6; 8		7			7			8	7; 9	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
13		7	7	5; 8	6; 8	6; 8	6; 8	6; 7	8	7	7			7; 8	7; 9	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
18		8	8	8	7	6	8	6	6; 10		8			7; 8	7; 9	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
15		7	7	8	7	6; 8	6; 8	6; 8	8		8			8	7; 9	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
16			8	6			7	6; 8			8			8	7; 9	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
17				6		6	/	6; 8			8			7; 9	7; 9	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
7	6; 8	7; 8	7	7	7	7	7	7	9	7; 10	7	8	10	7	7; 9	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
1								7	9			7; 8	10	7	7; 9	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
4	6; 8	6;7;8	7; 8	7	7	7	7	7		7; 9	7	8		7	7	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
5		6			7	7	7		9	7	7	8		7	7	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
6	6; 8	6; 8	7; 8	7	6	6	7	7	9	7	7	7	10	7	7; 9	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
11	7	6	7	6	6	6; 8	6	7	8	7	7			8	7; 9	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
12	9	7		5; 8	6	6; 8	6; 8	7	8	7	7			8	7; 9	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
9	6	6	7		7	7	8	7	9		7		10	8	7; 9	8; 9	7; 9	7; 9	7; 9	9	6; 9
8	6; 8	7; 9		7		7	8	7	9	7	7			8	7; 9	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9
10	8	6	6	7	7		8	7		7	7			8	7; 9	8; 9	7; 9	7; 9	7; 9	6; 9	6; 9

Total effort and number of species collected annually were tested for linear or curvilinear (quadratic) relationships with regression analysis. Residuals of regression of number of species and effort were tested against time for trends. Effect of sampling effort on number of species collected was allowed for by using the residuals of the linear regression of sampling effort against number of species. Studentized residuals and Cook's D were examined to diagnose outliers or highly influential observations. Plots of residuals against predicted values and residuals against year were examined for the need for additional terms or sequential trends, respectively.

In order to make comparisons with the fish community structure of Delaware, the data from the Maryland trawl effort was dropped from analysis. Also, seine site 19, which is located in Ayers Creek, a tributary of Newport Bay, was dropped from analysis due to the great difference in salinity at this station (0 ppt) compared to the rest of the sampling sites (25-35 ppt). From the resultant 18 seine sites (Figure 13), percent abundances for each species were calculated for each year over the entire system and ranks were assigned. Mean rank and mean percent abundance were also calculated for each species for five-year increments aggregated over the Assawoman/Isle of Wight/St. Martin River complex (seine sites 1-7) and Chincoteague Bay (seine sites 13-18) in order to compare the fish community structure within these two subsystems.

RESULTS

From within the coastal bays, a total of 101,291 individuals representing 107 species of fish and invertebrates was collected in trawl and seine samples between April and October, 1993 (Attachment). Some of the important shallow water and benthic species are illustrated in Figures 14 and 15, respectively. Sampling effort was the same in both 1992 and 1993; however, there was a significant increase of 93% in numbers caught and a 21% increase in the number of species from 1992 to 1993. Abundance of the 14 major species of foragers and grazers (Table 6) showed a 63% increase over 1991 levels and comprised 90% of the total 1993 finfish catch. Virtually all major game fish were below 1991 levels.

The linear regression of total number of species collected against sampling effort was significant ($r^2 = 0.60$, $p =< 0.001$). The time trend of the residuals of the previous regression was significant ($r^2 = 0.32$, $p =< 0.006$), indicating that the number of species has been increasing slightly in the coastal bays during 1972-1993.

<u>Northern bays versus Chincoteague Bay</u>

The fish community structure for the northern bays (represented as mean rank and mean percent abundance) for Assawoman/Isle of Wight/St. Martin River complex (seine sites 1-7) and for Chincoteague Bay (seine sites 13-18) are shown in Table 7. For the years 1972 to 1976, the five species with the highest mean ranks (with mean percent abundance over the same time frame to give an impression of the strength of their presence) for the northern bays were (1) *Leiostomus xanthurus* (25%), (2) *Menidia menidia* (35%), (3) *Brevoortia tyrannus* (26%), (4) *Fundulus heteroclitus* (1.7%), and (5) *Fundulus majalis* (3.6%). By the 1989 to 1993 time frame, the picture changed such that the ranking was (1) *Menidia menidia* (32%), (2) *Anchoa mitchilli* (11%), (3) *Bairdiella chrysoura* (8%), (4) *Mugil curema* (11%), and (5) *Leiostomus xanthurus* (11%). Over the same two time frames, the Chincoteague Bay went from a species ranking of (1) *Brevoortia tyrannus* (33%), (2) *Menidia menidia* (33%), (3) *Anchoa mitchilli* (15%), (4) *Leiostomus xanthurus* (9%), and (5) *Strongylura marina* (0.6%) to (1) *Menidia menidia* (25%), (2) *Anchoa mitchilli* (20%), (3) *Brevoortia tyrannus* (33%), (4) *Bairdiella chrysoura* (6.5%), (5) *Leiostomus xanthurus* (5.1%). Over the entire twenty years, the four most dominant species were *Menidia menidia*, *Anchoa mitchilli*, *Leiostomus xanthurus*, and *Brevoortia tyrannus* with the fifth most dominant species being *F. heteroclitus* in

Chincoteague Bay and *F. majalis* in the northern bays. The mean number of species and the mean total catch over the five year increments were always significantly larger for the northern bays than the Chincoteague Bay although the effort is comparable.

Table 6. Species of foragers and grazers comprising 90% of the total 1993 finfish catch.

SPECIES	SEINE CATCH	TRAWL CATCH	TOTAL
BAY ANCHOVY	4,331	20,249	24580
ATLANTIC SILVERSIDE	10,947	27	10974
SPOT	1,155	1,118	2273
ATLANTIC MENHADEN	894	23	917
ATLANTIC HERRING	1	1,893	1894
WHITE MULLET	2,132	1	2133
SILVER PERCH	1,056	184	1240
STRIPED KILLIFISH	380	0	380
MUMMICHOG	693	8	701
NORTHERN PIPEFISH	88	141	229
SMALLMOUTH FLOUNDER	10	20	30
RAINWATER KILLIFISH	378	55	433
NAKED GOBY	109	60	169
STRIPED ANCHOVY	69	15	84
SUBTOTAL	22,343	23,794	46137

Table 7. Mean rank and abundance for the top ten species of each year for the Assawoman/Isle of Wight/St. Martin River complex (seine sites 1-7) and Chincoteague Bay (seine sites 13-18).

Species	1972-1976		1976-1981		1982-1988		1989-1993		1972-1993	
	MEAN RANK (%OF TOTAL)		MEAN RANK (%OF TOTAL)		MEAN RANK (%OF TOTAL)		MEAN RANK (%OF TOTAL)		MEAN RANK (% OF TOTAL)	
	A/IW/S	CHINC	A/IW/S	CHINC	A/IW/S	CHINC	A/IW/S	CHINC	A/IW/S	CHINC
Atlantic silverside	2(35)	2 (33)	1 (41)	4 (10)	1.5 (33)	2 (40)	1 (32)	1 (25)	2 (32)	2(24)
Atlantic menhaden	3 (26)	1 (33)	5 (28)	1 (43)	5 (13)	4 (2.8)	6 (16)	3 (33)	4 (23)	3 (29)
Spot	1(25)	4 (9.0)	2 (16)	3 (12)	3 (30)	1 (27)	5 (11)	5 (5.1)	1 (20)	4 (13)
Bay anchovy	6 (1.9)	3 (15)	3 (7.5)	2 (31)	1.5 (9)	3 (11)	2 (11)	2 (20)	3 (5.9)	1 (22)
Striped killifish	5 (3.6)		8 (0.2)		6 (1.7)	7 (4.3)	9 (1.1)	7 (1.0)	5 (1.6)	8 (1.1)
Mummichog	4 (1.7)	7 (1.8)		7 (1.5)	7 (2.5)	6 (0.7)	7 (1.4)		6 (2.2)	5 (1.3)
Striped mullet	7 (1.5)	9 (0.4)	4 (1.8)		4 (3.7)	9 (0.2)			7 (2.8)	9 (0.3)
Atlantic needlefish		5 (0.6)	9 (1.3)	5 (0.2)	8 (0.7)	8 (0.3)		6 (0.8)	8 (1.1)	
Summer flounder	10 (0.4)	10 (0.1)	7 (0.4)	6 (0.3)				10 (0.3)	9 (0.5)	6 (0.3)
Bluefish	9 (0.6)			9 (0.1)	10 (0.3)				10 (0.3)	
Oyster toadfish						10 (0.2)				10 (0.2)
Northern pipefish								8 (0.6)		
American eel			10 (0.1)	10 (0.1)						
Silver perch		6 (1.9)				5 (2.8)	3 (8)	4 (6.5)		7 (2.8)
Inshore lizardfish							10 (1)	9 (0.6)		
White mullet							4 (11)			
Atlantic croaker	8 (1.6)									
Striped anchovy							8 (1.0)			
Weakfish					9 (0.9)					
Sheepshead minnow		8 (0.1)								
Southern stingray				8 (0.1)						

Species	1972-1976 MEAN RANK (%OF TOTAL)		1976-1981 MEAN RANK (%OF TOTAL)		1982-1988 MEAN RANK (%OF TOTAL)		1989-1993 MEAN RANK (%OF TOTAL)		1972-1993 MEAN RANK (% OF TOTAL)	
	A/TW/S	CHINC	A/TW/S	CHINC	A/TW/S	CHINC	A/TW/S	CHINC	A/TW/S	CHINC
Winter flounder			6 (1.4)							
Mean # of Species	22	13	18	16	34	23	44	32	30	21
Mean Total Catch	8635	2941	18173	3794	11027	7002	6370	5376	11051	4778

<u>Entire Maryland Coastal Bays</u>

In 1972, the predominant species collected were *Brevoortia tyrannus* (39.0%), *Menidia menidia* (28.2%), *Leiostomus xanthurus* (25.3%), *Fundulus heteroclitus* (4.6%), and *Paralichthys dentatus* (1.4%) for a total of 98.5 percent of the fish community (Fig. 16). By 1977, the dominant species were *Brevoortia tyrannus* (35.7%), *Menidia menidia* (30.2%), *Leiostomus xanthurus* (18.1%), *Anchoa mitchilli* (12.2%), *Mugil cephalus* (1.4%) for a total of 97.6 percent of the fish community (Fig. 17). In 1982, the dominants were the same except that *F. majalis* was the fifth most dominant species replacing *Mugil cephalus* at 1.2 percent of the total fish community (Fig. 18). By 1987, the dominant species were *Menidia menidia* (87.5%), *Anchoa mitchilli* (3.6%), *Mugil cephalus* (2.4%), *Brevoortia tyrannus* (2.3%), and *Bairdiella chrysoura* (1.0%) for a total of 96.8 percent of the fish community (Fig. 19). In 1992, the dominant species were *Brevoortia tyrannus* (37.4%), *Menidia menidia* (34.2%), *Bairdiella chrysoura* (13.5%), *Anchoa mitchilli* (2.9%), and *Mugil curema* (2.4%) for a total of 90.4 percent of the fish community (Fig. 20). In 1993, the dominant species were *Menidia menidia* (48.5%), *Anchoa mitchilli* (19.1%), *Mugil curema* (9.5%), *Leiostomus xanthurus* (5.0%), and *Bairdiella chrysoura* (4.3%) for a total of 86.4 percent of the shore-zone fish population (Fig. 21). Since 1989, the average rank of the top five dominant species is *Menidia menidia* (1), *Anchoa mitchilli* (2), *Brevoortia tyrannus* (3), *Leiostomus xanthurus* (4), and *Fundulus majalis* (5). The ranking of the top five dominants has essentially included the same five species for the past 20 years.

Using five year means of ranks of species determined by percent abundance, the same six species are ranked in the top seven for the four time periods calculated. In descending order of their twenty year mean rank, these six species are Atlantic silverside (*Menidia menidia*), Atlantic menhaden (*Brevoortia tyrannus*), spot (*Leiostomus xanthurus*), bay anchovy (*Anchoa mitchilli*), striped killifish (*Fundulus majalis*), and mummichog (*Fundulus heteroclitus*) (Tables 8-11). Striped mullet (*Mugil cephalus*), whose average rank from 1972 to 1988 was between 6 and 7, dropped in average rank to 12 in the 1989 to 1993 time period. For the same time periods, atlantic menhaden dropped from an average rank of 1 to 3, summer flounder (*Paralichthys dentatus*) dropped from 7.5 to 11, and northern pipefish (*Sygnathus fuscus*) rose from 12 to 9 (Table 8-11).

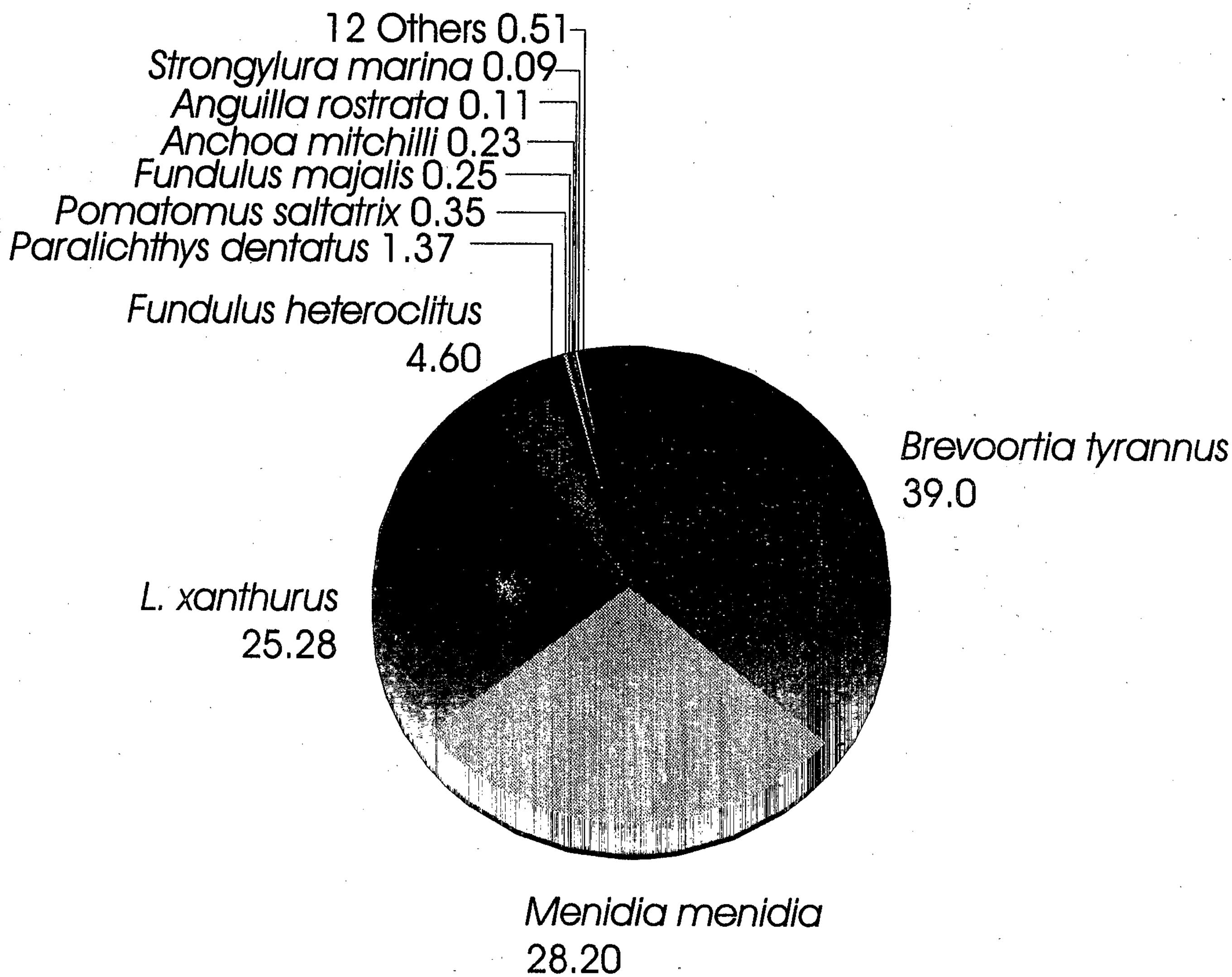

Figure 16. Percent abundance of total catch for the top ten species caught in the Maryland seine effort for 1972.

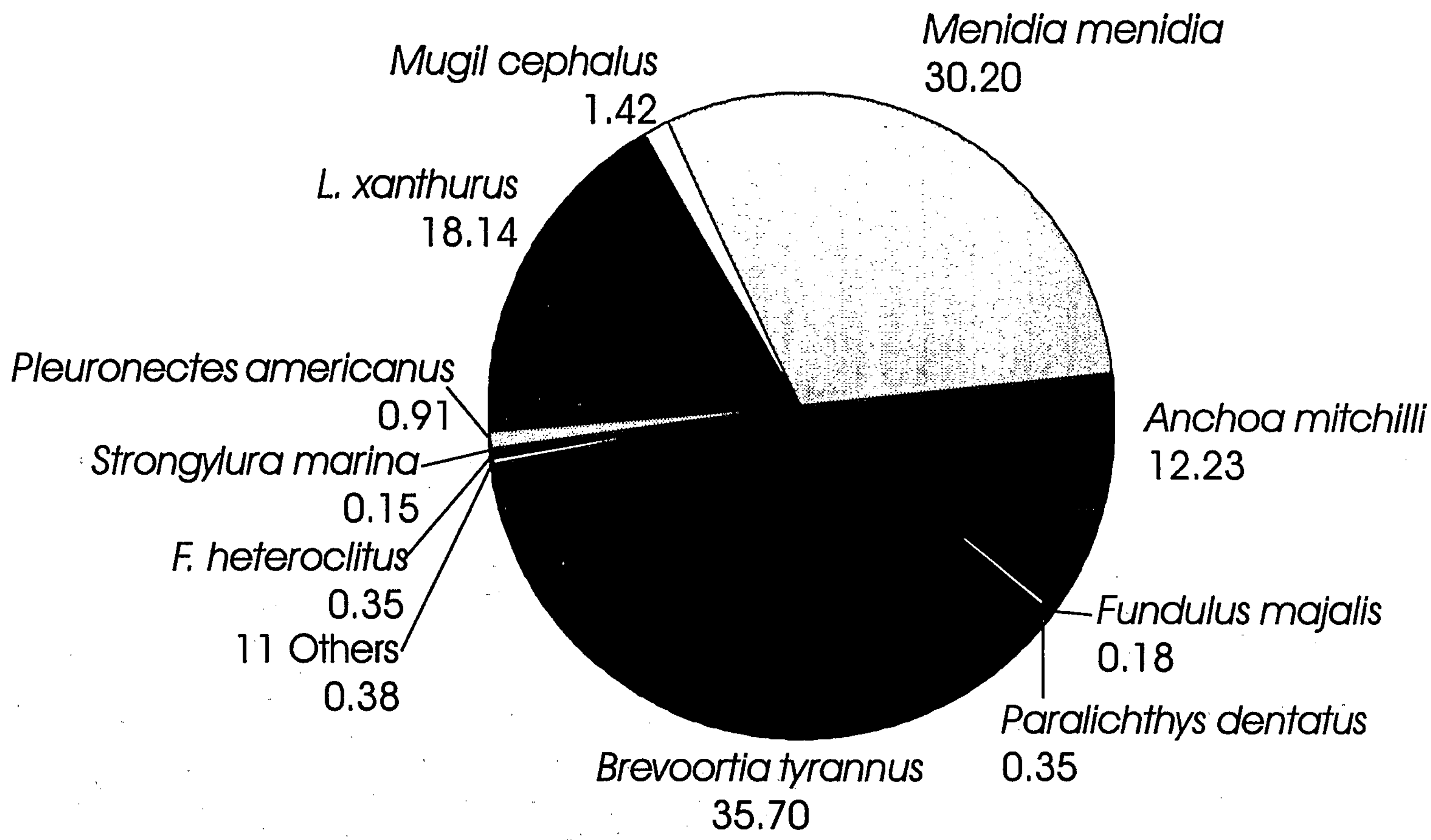

Figure 17. Percent abundance of total catch for the top ten species caught in the Maryland seine effort for 1977.

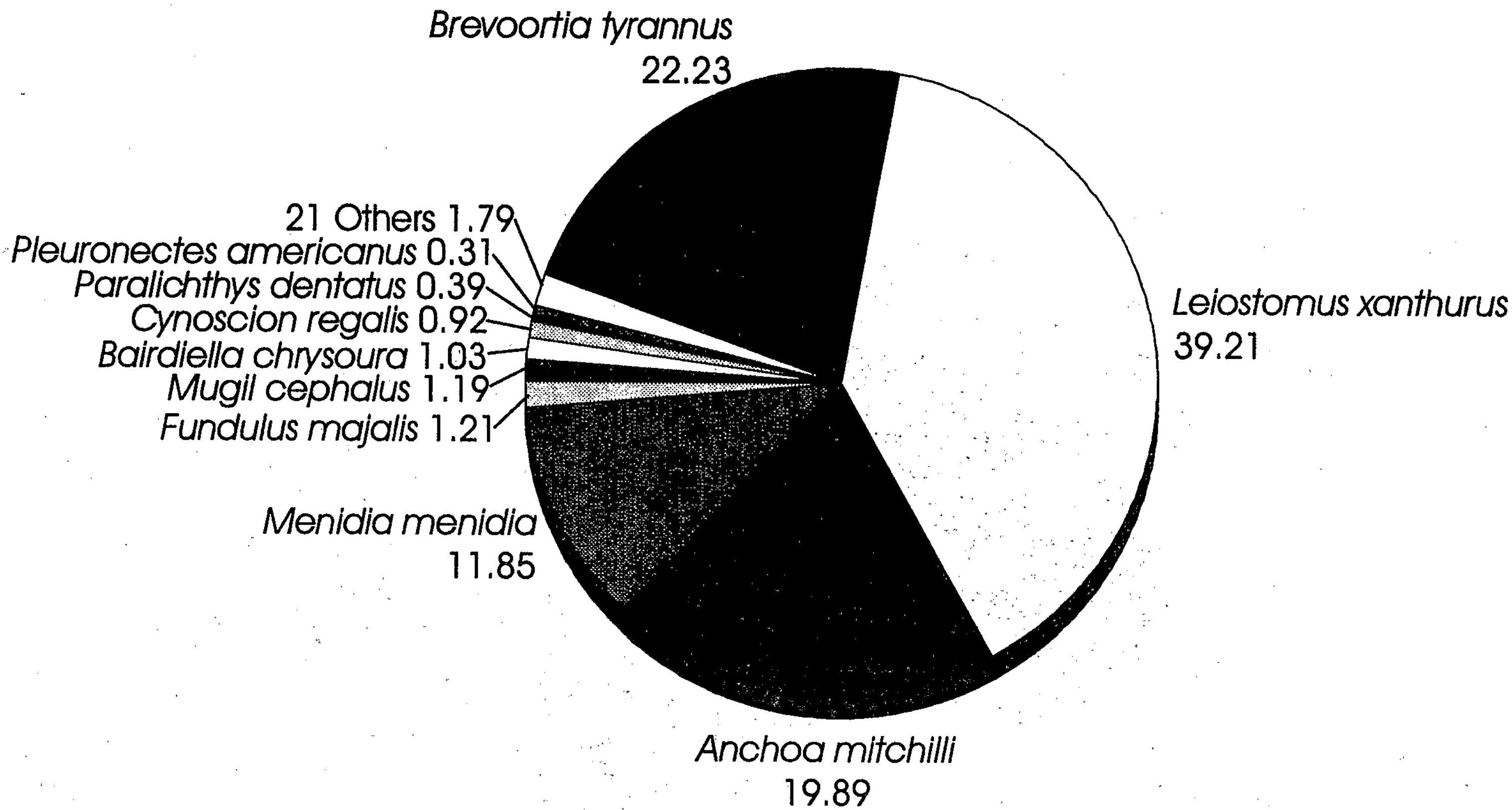

Figure 18. Percent abundance of total catch for the top ten species caught in the Maryland seine effort for 1982.

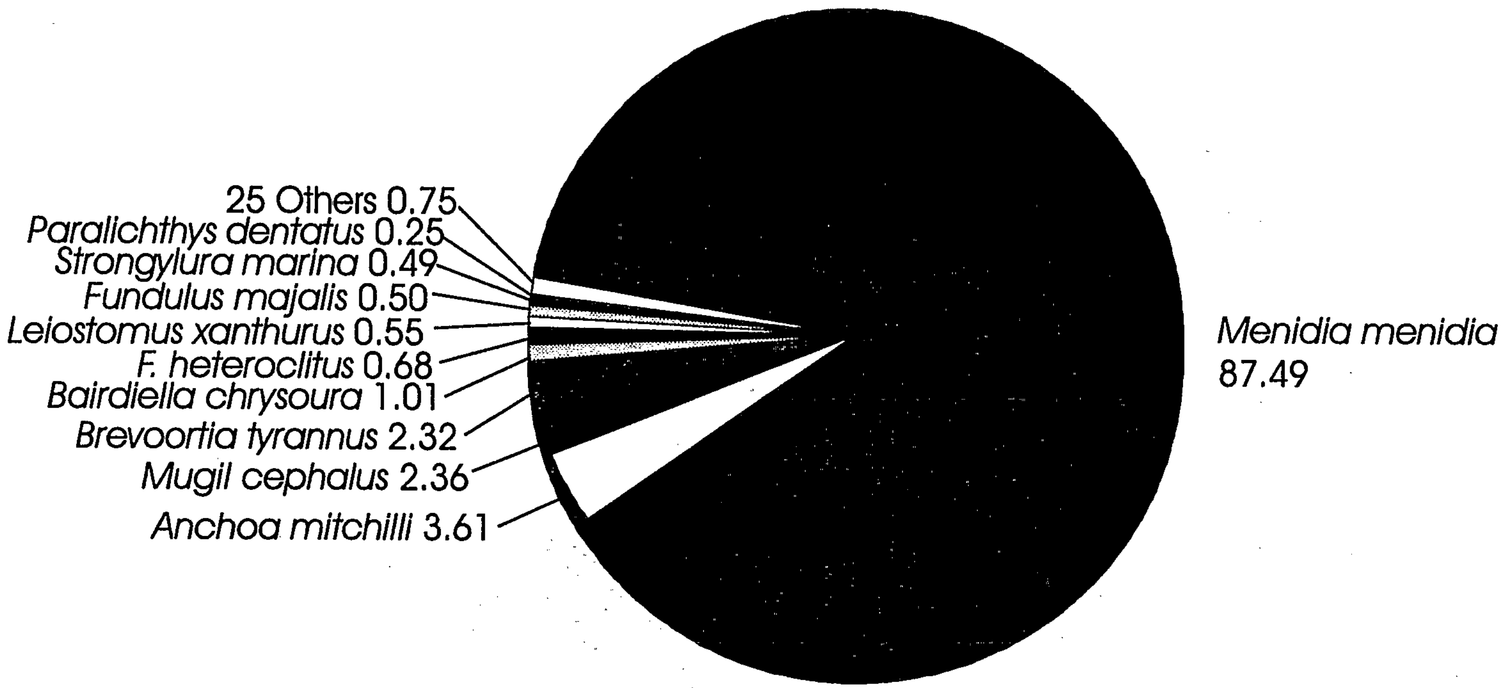

Figure 19. Percent abundance of total catch for the top ten species caught in the Maryland seine effort for 1987.

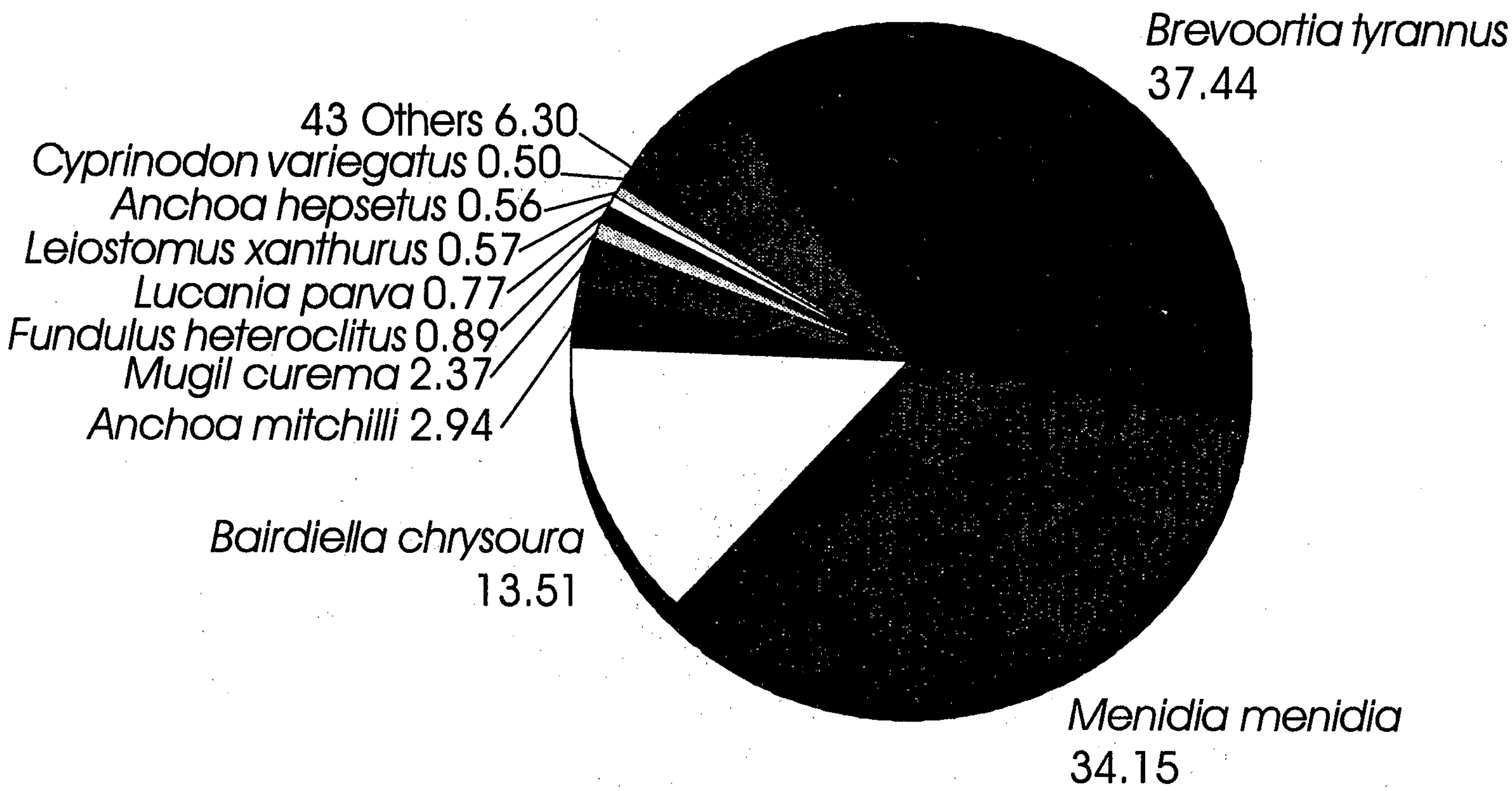

Figure 20. Percent abundance of total catch for the top ten species caught in the Maryland seine effort for 1992.

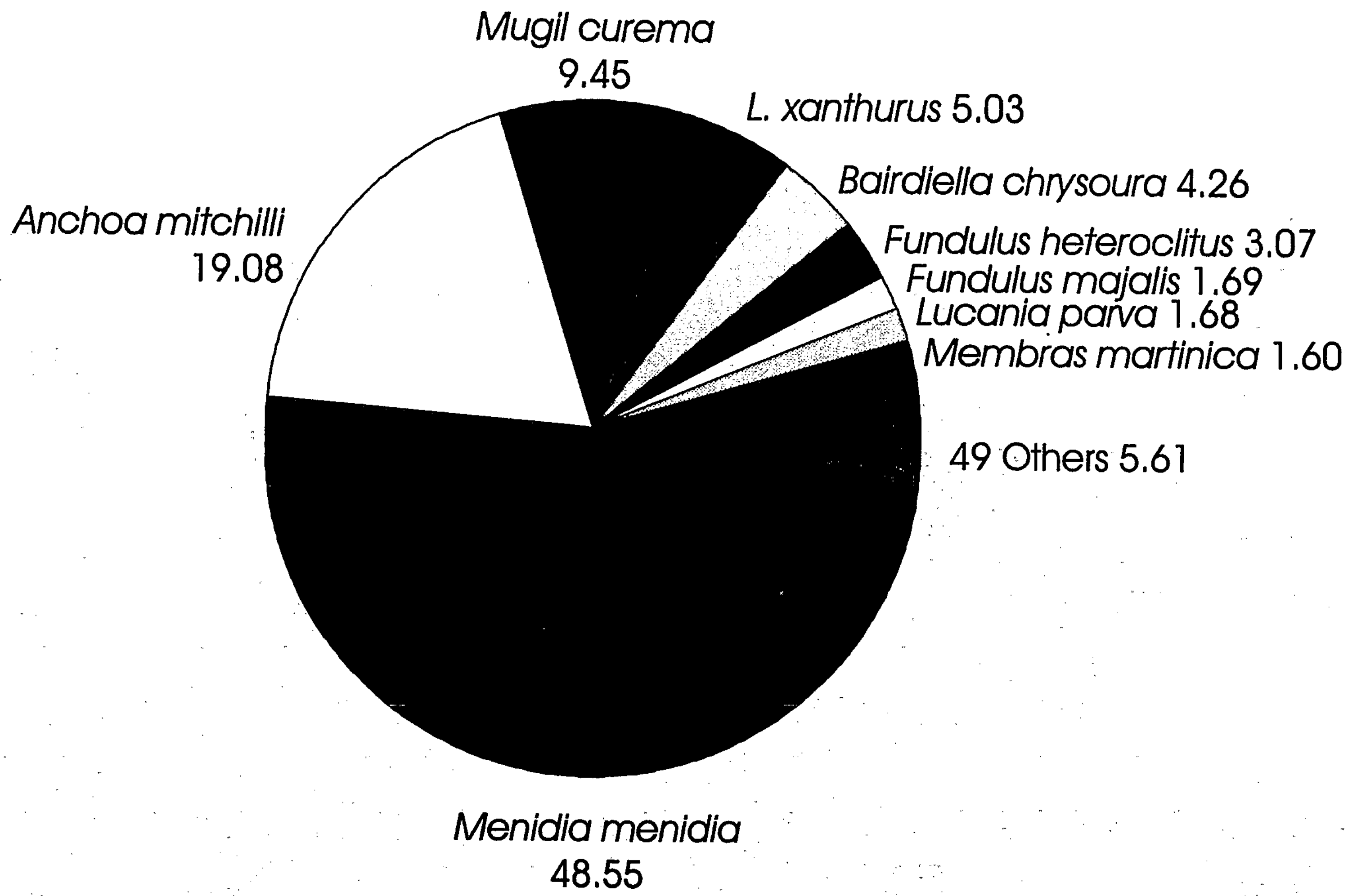

Figure 21. Percent abundance of total catch for the top ten species caught in the Maryland seine effort for 1993.

Table 8. Rank and relative abundance of the top thirteen shore zone fish collected by seine from the Maryland coastal bays 1972 - 1976.

Species	1972		1973		1974		1975		1976		1972-1976
	RANK	%	RANK	%	RANK	%	RANK	%	RANK	%	AVG. RANK
Atlantic silverside	2	28.2	1	46.4	3	22.2	3	16.5	3	10.6	2.4 = 2
Atlantic menhaden	1	39.0	4	5.5	1	28.8	1	43.8	1	46.2	1.6 = 1
Spot	3	25.3	2	18.7	2	27.5	4	10.7	2	27.2	2.6 = 3
Bay anchovy	8	0.22	5	4.8	4	6.8	2	22.9	5	4.8	4.8 = 4
Striped killifish	7	0.24	6	3.6	5	5.3	10	0.43	4	5.7	6.4 = 6
Mummichog	4	4.6	3	14.4	7	3.1	5	1.4	6	2.1	5 = 5
Striped mullet	16	0.04	10	0.22	11	0.29	6	1.3	7	0.99	10 = 7.5
Atlantic needlefish	10.5	0.09	13	0.06	20	0.03	7	0.62	10	0.26	12.1 = 10
Summer flounder	5	1.4	11	0.19	8	0.61	11	0.34	15	0.06	10 = 7.5
Bluefish	6	0.35	19.5	0.03	10	0.30	8	0.60	12	0.17	11.1 = 9
Oyster toadfish	17.5	0.04	16.5	0.04	24.5	0.02	18	0.04	23.5	0.01	20 = 13
Northern pipefish	13	0.07	16.5	0.04	24.5	0.02	14	0.09	23.5	0.01	18.3 = 12
American eel	9	0.11	19.5	0.03	14	0.11	15	0.07	15	0.06	14.5 = 11
Number of Species	22		33		28		31		26		28
Total catch	11359		30081		11395		10429		15532		15759

Table 9. Rank and relative abundance of the top thirteen shore zone fish collected by seine from the Maryland coastal bays 1977 - 1981.

Species	1977		1978		1979		1980		1981		1977-1981
	RAN	%	RAN	%	RANK	%	RANK	%	RAN	%	AVG. RANK
Atlantic silverside	2	30.2	2	3.94	1	36.8	2	38.1	3	24.7	2 = 2
Atlantic menhaden	1	35.7	1	91.4	4	10.3	1	38.9	1	30.3	1.6 = 1
Spot	3	18.1	4	1.0	3	12.8	3	8.7	2	30.0	3 = 3
Bay anchovy	4	12.2	3	3.2	2	29.1	5	3.4	4	9.6	3.6 = 4
Striped killifish	9	0.18	5	0.15	7	0.26	4	3.7	6	0.85	6.2 = 5
Mummichog	7.5	0.35	11	0.02	5	9.4	9	0.33	8	0.59	8.1 = 7
Striped mullet	5	1.42	6	0.05	9	0.15	7	1.8	7	0.66	6.8 = 6
Atlantic needlefish	10	0.15	12	0.02	11.5	0.10	6	2.7	15	0.05	10.9 = 9
Summer flounder	7.5	0.35	14	0.01	6	0.32	10	0.26	9	0.56	9.3 = 8
Bluefish	12	0.08	23	0.00	14.5	0.06	26.5	0.02	15	0.05	18.2 = 13
Oyster toadfish	22	NP	10	0.02	16	0.05	13.5	0.11	12	0.06	14.7 = 11
Northern pipefish	13	0.06	20	0.00	13	0.07	11.5	0.12	18	0.04	15.1 = 12
American eel	19	0.01	9	0.03	11.5	0.10	13.5	0.11	15	0.05	13.6 = 10
Number of Species	21		24		26		31		25		25
Total catch	9257		101651		18571		5453		11434		29273

Table 10. Rank and relative abundance of the top thirteen shore zone fish collected by seine from the Maryland coastal bays 1982 - 1988.

Species	1982		1987		1988		1982-1988
	RANK	%	RANK	%	RANK	%	AVG. RANK
Atlantic silverside	4	11.8	1	87.5	4	12.0	3 = 3.5
Atlantic menhaden	2	22.2	4	2.3	2	16.5	2.7 = 1.5
Spot	1	39.2	7	0.55	1	38.8	3 = 3.5
Bay anchovy	3	19.9	2	3.6	3	12.8	2.7 = 1.5
Striped killifish	5	1.2	8	0.50	6	3.7	6.3 = 5
Mummichog	11	0.26	6	0.68	5	4.1	7.3 = 7
Striped mullet	6	1.2	3	2.4	11	0.40	6.7 = 6
Atlantic needlefish	13.5	0.20	9	0.49	12	0.36	11.5 = 8
Summer flounder	9	0.39	10	0.25	32.5	0.03	17.2 = 10
Bluefish	13.5	0.20	11	0.17	18	0.14	14.2 = 9
Oyster toadfish	19	0.09	15.5	0.05	20	0.10	18.2 = 11
Northern pipefish	18	0.10	12	0.10	25.5	0.07	18.5 = 12
American eel	22.5	0.04	21	0.02	36	0.02	26.5 = 13
Number of Species	31		35		53		40
Total catch	9700		18888		39108		22565

Table 11. Rank and relative abundance of the top thirteen shore zone fish collected by seine from the Maryland coastal bays 1989 - 1993.

Species	1989		1990		1991		1992		1993		1989-1993
	RAN	%	RAN	%	RANK	%	RAN	%	RAN	%	AVG. RANK
Atlantic silverside	1	30.4	2	16.7	1	27.6	2	34.1	1	48.5	1.4 = 1
Atlantic menhaden	5	4.77	1	53.0	2	21.3	1	37.4	10	0.74	3.8 = 3
Spot	3	16.0	4	6.3	5	7.2	8	0.57	4	5.0	4.8 = 4
Bay anchovy	2	29.8	3	14.7	3	12.5	4	2.9	2	19.1	2.8 = 2
Striped killifish	8	1.0	6	1.0	7	1.9	22	0.31	7	1.7	10 = 5
Mummichog	10	0.69	21	0.10	13	0.96	6	0.89	6	3.1	11.2 = 6
Striped mullet	34.5	0.06	9	0.45	14	0.69	42	0.02	22	NP	24.3 = 12
Atlantic needlefish	16	0.40	13	0.31	9	1.7	13	0.43	17.5	0.31	13.7 = 7
Summer flounder	17	0.35	8	0.50	20	0.22	15	0.39	22	0.13	23.2 = 11
Bluefish	12	0.59	16	0.16	15	0.53	32	0.07	24	0.12	19.8 = 10
Oyster toadfish	14.5	0.41	12	0.33	17.5	0.24	24.5	0.17	13	0.43	16.3 = 8
Northern pipefish	19	0.27	17	0.16	17.5	0.24	27	0.11	15	0.39	19.1 = 9
American eel	30.5	0.07	37	0.01	45	0.02	45	0.02	11	0.53	33.7 = 13
Number of Species	51		44		57		53		58		53
Total catch	7007		18559		10095		20715		22549		15785

DISCUSSION

In general, the fish community structure of the Maryland inland bays is quite stable over the years. The Maryland inland bays might be seen as an example of what type of structure there might have been in Delaware's system before more intensive development and nutrient enrichment took place. In fact there is evidence of a slight increase in species richness in the Maryland inland bays over the past 20 years as proven by three different investigators using three different techniques (Casey et al., 1992, 1994; Linder, pers. comm.). Moderate disturbances in some systems have actually promoted species diversity; and hypothetically, the increase in species richness for the Maryland bays might be attributable to changing physical conditions such as increases in land development, bottom currents, and nutrient enrichment. As with the Delaware data, the shifts in the community composition of the entire Maryland system are summarized below:

Rank	1972	1977	1987	1993
1	Menhaden	Menhaden	Atlantic Silversides	Atlantic Silversides
2	Atlantic Silversides	Atlantic Silversides	Bay anchovy	Bay Anchovy
3	Spot	Spot	Striped mullet	White mullet
4	Mummichog	Bay anchovy	Menhaden	Spot
5	Summer flounder	Striped mullet	Silver perch	Silver perch
6	Bluefish	Winter flounder	Mummichog	Mummichog
7	Striped killifish	Mummichog	Spot	Striped killifish
8	Bay anchovy	Summer flounder	Striped killifish	Rainwater killifish
9	American eel	Atlantic needlefish	Atlantic needlefish	Rough silverside
10	Atlantic needlefish	Striped Killifish	Summer flounder	Menhaden

During the past 20 years, the dominance has shifted from Atlantic menhaden, Atlantic silversides, and spot to Atlantic silversides, bay anchovy, and *Mugil* spp. Unlike the Delaware coastal bays system, Maryland has not seen the degree of increase in cyprinodontids to a position within the top four ranks. However, in 1993 three cyprinodontids are representing ranks 6 to 8, which might indicate an early warning sign for the future. The 1994 data (not shown in this report) also represent a higher abundance of combined *Fundulus* spp. than the average amount for this sytem. However, attempting to make a conclusion might be premature without more sampling. Important game species, such as summer flounder, bluefish, Atlantic croaker, and American eel, have dropped from ranking in the top ten to record low levels in the past 23 years of data collection. It appears at this time that more planktivorous species such as *Mugil* spp. and bottom feeders such as silver perch have replaced them in the rankings. In attempting to glean an idea of what is happening within the system, it is important to take into account the scope of the effort and the natural variability in fish populations, as well as the positive effects that nutrients might be playing on the living resources. One might expect the Chincoteague Bay, in its pristine state with an abundance of wetlands, to have a more diverse and abundant assemblage of fish. This hypothesis does not hold true. In fact, it is the northern bays and Newport Bay, both of which are affected by a greater nutrient load, that have the more diverse sites with large complements of fish species (Table 8-11). In general, the Maryland system does not appear to be under the degree the stress as the Delaware system, which might indicate why the *Fundulus* spp are not as dominant in the Maryland system.

One of the more detrimental forces acting upon the fish community in Maryland is the degree of over-utilization of fisheries resources. The population of summer flounder crashed in the early 1990s and is showing some signs of a come-back since restrictions have been placed on the amount and size of their catch. Bluefish have crashed all over the Atlantic Coast fishery and the impacts of that can be seen in the Maryland coastal bays data. Weakfish have declined over the years as well, as have American eel which itself is in jeopardy from encroaching development in the northern bays in areas of elver concentration up the smaller creeks.

Habitat loss is a concern in the upper bays of Maryland with the degree of development planned for this area. It appears that the fish communities of this system tend to aggregate at spots that provide a good three dimensional structure and have marsh areas within a close distance (<50 feet). With development comes a loss in the surface area of healthy shallow water habitat with dredge operations and canalization. Moderate levels of nutrients might have a positive impact on the faunal assemblage, but loss of habitat and refuge has no positive effect.

CONCLUSIONS

Therefore, one can conclude that generally speaking the Maryland coastal bays are dominated primarily by Atlantic silverside, bay anchovy, Atlantic menhaden, and spot, and not by *Fundulus majalis* and *Fundulus heteroclitus* which is the case in the Delaware coastal bays today. Indeed, if one compares the earliest available Delaware record for shore-zone fishes in Delaware Bay (1959) with the Maryland coastal bays fish fauna, they are strikingly similar. deSylva et al. (1962) reported that the dominant shore-zone fish species for the Delaware Bay were *Menidia menidia* (53.0%), *Bairdiella chrysoura* (17.9%), *Anchoa mitchilli* (15.1%), *Brevoortia tyrannus* (2.3%), and *Fundulus majalis* (2.2%) for a total of 90.5 percent of the shore-zone fish community (Fig. 22). Likewise, in 1957, the dominant species in White Creek, a tributary of Indian River Bay were *Brevoortia tyrannus* (32.5%), *Menidia beryllina* (19.5%), *Menidia menidia* (18.2%), *Fundulus heteroclitus* (13.5%), and *Anchoa mitchilli* (5.9%) for a total of 89.6% of

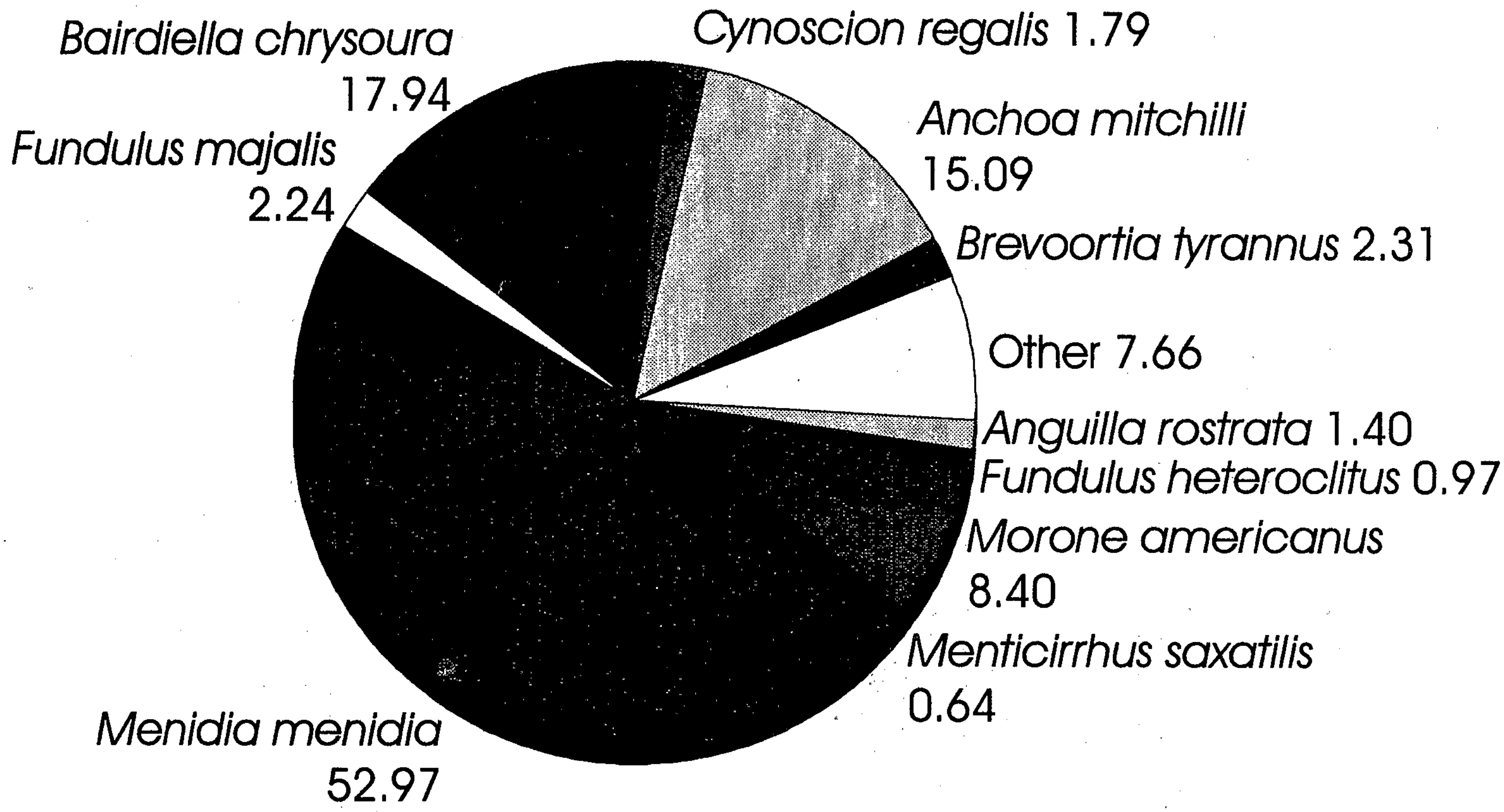

Figure 22. Percent abundance of total catch for the top ten species caught in the share zone of the Delaware Bay.

the shore-zone fish community (Table 3; Pacheco and Grant, 1965). Therefore, if one goes back in history some 35 years, at least in Delaware's bays, the shore-zone fish community strongly resembles that of the less impacted Maryland coastal bays of today.

The fish community dominance in Delaware's coastal bays has shifted toward those species that are more tolerant to low oxygen stress [Thornton (1975) in Daiber, et al. (1976)] and which are also more tolerant to salinity and temperature extremes. There is also a strong possibility that *Fundulus* sp. and *Cyprinodon* sp. are more adaptable to eutrophication mediated shifts in the food chain with its attendant increase in turbidity; i.e., under eutrophied conditions there would be a selective advantage for species that are omnivorous (Bigelow and Schroeder, 1953) and which do not feed primarily by sight. Grecay (1990) showed that weakfish juveniles (which are sight-feeding predators) were more successful at obtaining prey when light was not severely limited by turbidity. Vaas and Jordan (1991) also noticed a steady increase in *Fundulus* spp. in the Chesapeake Bay over the last 32 years, which they attributed to the effects of eutrophication. There might be some slight indication of an increase in *Fundulus* spp. in the Maryland system as well, but it might be too early to judge if this is truly representing an impact of eutrophication. It is important to recall the great difference in watershed area and resulting nutrient impact on the two systems. The Delaware inland bays have a watershed to water ratio of 10 to 1, while the ratio for the Maryland bays are close to 1 to 1; which might go a long way in explaining the differences in species dominance.

Therefore, we are reporting here for the first time that dominance of shore-zone fish communities by species from the Family Cyprinodontidae is an apparent indicator of eutrophication in certain estuarine systems.

REFERENCES

Andres, A. S. 1992. Estimate of Nitrate Flux to Rehoboth and Indian River Bays, Delaware, through Direct Discharge of Ground Water. Delaware Geological Survey Open File Report #35. 36 p.

Andres, A. S. 1994. Nitrate loss via ground-water flow coastal Sussex County, Delaware. In: Conference Proceedings of "Impact of Animal Waste on the Land-Water Interface." In press.

Bigelow, H. B., and W. C. Schroeder. 1953. Fishes of the Gulf of Maine. Fish Bull. of Fish and Wildlife Ser., Vol. 53, 577 pp.

Campbell, T. G. 1975. The Fishes and Hydrographic Parameters of White Creek, Delaware: A Description and Comparison of 1973-1974 to 1957-1958. M.S. Thesis, University of Delaware.

Casey, J. F., and A. E. Wesche. 1982. Marine Benthic Survey of Maryland's Coastal Bays. Maryland Department of Natural Resources, Tidewater Administration. Annapolis, Maryland. **Unpublished.**

Casey, J. F., S. Doctor, and A. E. Wesche. 1994. Investigation of Maryland's Atlantic Ocean and coastal bay finfish stocks. Federal Aid Project No. F-50-R-3. Maryland Department of Natural Resources, Tidewater Administration. Annapolis, Maryland.

Casey, J. F., S. Doctor, and A. E. Wesche. 1993. Investigation of Maryland's Atlantic Ocean and coastal bay finfish stocks. Federal Aid Project No. F-50-R-2. Maryland Department of Natural Resources, Tidewater Administration. Annapolis, Maryland.

Casey, J. F., R. C. Raynie, and A. E. Wesche. 1992. Investigation of Maryland's Atlantic Ocean and coastal bay finfish stocks. Federal Aid Project No. F-50-R-1. Maryland Department of Natural Resources, Tidewater Administration. Annapolis, Maryland.

Cao, L. N., and J. A. Musick. 1977. Life history, feeding habits, and functional morphology of juvenile sciaenid fishes in York River Estuary. Virginia Fish Bull. 75(4): 657-702.

Cerco, C. F., B. Bunch, M. A. Cialone, and H. Wang. 1994. Hydrodynamics and eutrophication model study of Indian River and Rehoboth Bay, Delaware. U.S. Army Corps of Engineers, Technical Report EL-94-5. 246 p.

Citizens Agenda. 1990. Focus on Maryland's Forgotten Bays. The Beldon Fund. U.S. EPA, Region III, Institute for Cooperation in Environmental Management.

Daiber, F. C., et al. 1976. An Atlas of Delaware's Wetlands and Estuarine Resources. Technical Report 2. Office of Coastal Zone Management, Dover, Delaware.

Delaware DNREC. 1986. Monitoring Fish Population in Delaware's Estuaries. Del. Div. of Fish and Wildlife, Dover, DE.

Delaware DNREC. 1987. Monitoring Fish Population in Delaware's Estuaries. Del. Div. of Fish and Wildlife, Dover, DE.

Delaware DNREC. 1988. Monitoring Fish Population in Delaware's Estuaries. Del. Div. of Fish and Wildlife, Dover, DE.

Delaware DNREC. 1989. Monitoring Fish Population in Delaware's Estuaries. Del. Div. of Fish and Wildlife, Dover, DE.

Delaware DNREC. 1990. Monitoring Fish Population in Delaware's Estuaries. Del. Div. of Fish and Wildlife, Dover, DE.

Delaware DNREC. 1991. Monitoring Fish Population in Delaware's Estuaries. Del. Div. of Fish and Wildlife, Dover, DE.

Delmarva Power and Light. 1976. Ecological Studies in the Vicinity of the Indian River Power Plant: A 316 Demonstration. Ecological Analysts, Inc.

Derickson, W. K., and K. S. Price. 1973. The Fishes of the shore zone of Rehoboth. Trans. Amer. Fish. Soc. 102(3): 552-562.

deSylva, D. P., F. A. Kalber, Jr., and C. N. Schuster. 1962. Fishes and Ecological Conditions in the Shore Zone of the Delaware River Estuary, with Notes on Other Species Collected in Deeper Water. University of Delaware, Marine Laboratory, Information Series, Publ. No. 5. 164 pp.

Ecological Analysts. 1976. Final Report on Ecological Studies in the Vicinity of the Indian River Power Plant Covering the Period Jun 74-Jun 76. Prepared for the Delmarva Power & Light Co., Towson, Maryland.

Edmunds, J. R., IV, and L. D. Jensen. 1974. Fish populations. In: Environmental Responses to Thermal Discharges from the Indian River, Delaware, pp. 127-163; L. D. Jensen, editor. Cooling Water Studies (RP-49) conducted by Johns Hopkins University for the Electric Power Research Institute. Report No. 12. Palo Alto, California.

Fowler, H. W. 1911. The fishes of Delaware. Proc. Acad. Nat. Sci. Phila. 63: 3-16.

Grecay, P. A. 1990. Factors Affecting Spatial Patterns of Feeding Success and Condition of Juvenile Weakfish (*Cynoscion regalis*) in Delaware Bay: Field and Laboratory Assessment. Ph.D. Dissertation, University of Delaware, Newark, Delaware.

Grant, G. C. 1962. Predation of the bluefish on young Atlantic menhaden in Indian River, Delaware. Ches. Sci. 3: 45-47.

Horn, J. G. 1957. The History of the Commercial Fishing Industry in Delaware. B.S. Thesis. Newark, DE: University of Delaware. 66 pp.

Jeffries, H. P., and W. C. Johnson. 1974. Seasonal variations of bottom fishes in the Narragansett Bay area: seven year variations in the abundance of winter flounder. J. Fish. Res. Bd. Can. 31: 1057-1066.

Kaplovsky, A. J., and D. B. Aulenbach. 1956. A Comprehensive Study of Pollution and its Effects on Waters within the Indian River Drainage Basin. Report to Delaware Water Pollution Commission. 207 pp.

Lee, G. F., and R. A. Jones. 1991. Effects of eutrophication on fisheries. Reviews in Aquatic Sciences 5(3-4): 287-305.

Lippson, A. J. and R. L. Lippson. 1984. Life in the Chesapeake Bay. Baltimore, MD: The Johns Hopkins University Press. 230 pp.

NOAA/NMFS. 1986. Marine Recreational Fishery Statistics Survey, Atlantic and Gulf Coasts, 1987-1989. Current fisheries statistics number 8904. NOAA/NMFS. 1993. Preliminary commercial fishery landings, by state. NOAA 1993. Status of Fishery Resources off the Northeastern United States for 1993. October 1993. NOAA Technical Memorandum NMFS-F/NEC-101.

Orth, R. J., and K. L. Heck. 1980. Structural components of eelgrass meadows (*Zostera marina*) in lower Chesapeake Bay--fishes. Estuaries 3(4): 278-288.

Pacheco, A. L., and G. C. Grant. 1965. Studies of the Early Life History of Atlantic Menhaden in Estuarine Nurseries. Part I. Seasonal Occurrence of Juvenile Menhaden and Other Small Fishes in a Tributary Creek of Indian River, Delaware. 1957-1958. U.S. Fish and Wildlife Service. Spec. Sci. Rep. Fish. No. 504. 32 pp.

Price, K. S., D. A. Flemer, J. L. Taft, G. B. Mackiernan, W. Nelsen, R. B. Biggs, N. H. Burger, and D. A. Blaylock. 1985. Nutrient enrichment of Chesapeake Bay and its impact on striped bass: a speculative hypothesis. Trans. Amer. Fish. Soc. 114: 97-106.

Radle, E. W. 1971. A Partial Life History of the Winter Flounder (*Pseudopleuronectes americanus*) Exposed to Thermal Addition in an Estuary, Indian River Bay, Delaware. M.S. Thesis. University of Delaware, Newark, DE.

Schwartz, F. J. 1961. Fishes of Chincoteague and Sinepuxent bays. J. Am. Midl. Nat. 65(2): 385-407.

Scotton, L. W. 1970. Occurrence and Distribution of Larval Fishes in the Rehoboth and Indian River Bays of Delaware. M.S. Thesis. Univ. of Delaware, Newark, DE. 66 pp.

Shirey, C. A. 1988. Stream and Inland Bays Fish Survey, Delaware: February 1, 1987-January 31, 1988. Annual Report. Federal Aid in Fisheries Restoration Act. Delaware DNREC, Division of Fish and Wildlife, Dover, DE.

Thornton, L. L. 1975. Laboratory Experiments on the Oxygen Consumption and Resistance to Low Oxygen Levels of Certain Estuarine Fishes. Master's Thesis, University of Delaware, Newark, Delaware.

Timmons, Maryellen. 1995. Relationships between Macroalgae and Juvenile Fishes in the Inland Bays of Delaware. Ph.D. Dissertation, University of Delaware, Newark, Delaware.

U.S. EPA. 1983. Chesapeake Bay: A Profile of Environmental Change. Washington, DC: Superintendent of Documents, U.S. Government Printing Office.

U.S. Fish and Wildlife Service. 1989. 1989 National Survey of Fishing, Hunting and Wildlife-associated Recreation. Maryland Summary. March, 1989. 81 pp.

Ullman, W. J., R. J. Geider, S. A. Welch, L. M. Graziano, and B. Overman. 1993. Nutrient Fluxes and Utilization in Rehoboth and Indian River Bays. College of Marine Studies, University of Delaware. Report to DNREC and Delaware's Inland Bays Program.

Vaas, P. A. and S. J. Jordan. 1991. Long term trends in abundance indices for 19 species of fish of Chesapeake Bay fishes: reflections of trends in the Bay ecosystem. In: J.A. Mihursky and A. Chaney (eds.). New Perspectives on the Chesapeake System: a Research and Management Partnership. Chesapeake Research Consortium., Inc. CRC Publ. No. 137. Solomons, Maryland.

Wang, J. C., and R. J. Kernehan. 1979. Fishes of the Delaware Estuary: A Guide to the Early Life Histories. Towson, MD: E. A. Communications. 410 pp.

Weston, Roy F., Inc. 1993. Characterization of the Inland Bays Estuary. Report to the Delaware Inland Bays National Estuary Program, DNREC, Dover, Delaware.

White, C. P. 1989. Chesapeake Bay: Nature of the Estuary, A Field Guide. Centreville, MD: Tidewater Publishers. 212 pp.

ATTACHMENT

Table 1. List of species collected in Maryland's coastal bays between April and October, 1993. Fish, crustaceans, and other species are listed separately. Total trawl sites = 140, total seine sites = 38.

Species	Total Number Collected			Mean CPUE	
	Trawl n=140	Seine n=38	Total	Trawl	Seine
A. Fish					
Bay Anchovy (*Anchoa mitchilli*)	20,249	4,331	24,580	144.6	114.0
Atlantic silverside (*Menidia menidia*)	27	10,947	10,974	0.2	288.1
Spot (*Leiostomus xanthurus*)	1,118	1,155	2,273	8.0	30.4
Atlantic menhaden (*Brevoortia tyrannus*)	23	894	917	0.2	23.5
White mullet (*Mugil curema*)	1	2132	2133	0.01	56.11
Golden shiner (*Notemigonus crysoleucas*)	0	959	959	0.0	25.2
Atlantic croaker (*Micropogon undulatus*)	894	3	897	6.4	0.1
Silver perch (*Bairdiella chrysoura*)	184	1,056	1,240	1.3	27.8
Weakfish (*Cynoscion regalis*)	217	1	218	1.6	0.03
Summer flounder (*Paralichthys dentatus*)	222	30	252	1.6	0.8
Inshore lizardfish (*Synodus foetens*)	148	90	238	1.1	2.4
Hogchoker (*Trinectes maculatus*)	81	6	87	0.6	0.2
Striped killifish (*Fundulus majalis*)	0	380	380	0.0	10.0
Northern puffer (*Sphoeroides maculatus*)	78	72	150	0.6	1.9

Species	Total Number Collected			Mean CPUE	
	Trawl n=140	Seine n=38	Total	Trawl	Seine
Striped anchovy (*Anchoa hepsetus*)	15	69	84	0.1	1.8
Atlantic needlefish (*Strongylura marina*)	0	69	69	0.0	1.8
Black sea bass (*Centropristis striata*)	10	1	11	0.1	0.03
Northern pipefish (*Syngnathus fuscus*)	141	88	229	1.0	2.32
Bluefish (*Pomatomus saltatrix*)	3	28	31	0.02	0.7
Blackcheek tonguefish (*Symphurus plagiusa*)	4	6	10	0.03	0.2
Oyster toadfish (*Opsanus tau*)	7	97	104	0.1	2.6
Spotted hake (*Urophycis regius*)	20	0	20	0.1	0.0
Northern searobin (*Prionotus carolinus*)	16	2	18	0.1	0.1
Butterfish (*Peprilus triacanthus*)	13	0	13	0.1	0.0
Rough silverside (*Membras martinica*)	0	361	361	0.0	9.5
Northern kingfish (*Menticirrhus saxatilis*)	7	17	24	0.1	0.5
Smallmouth flounder (*Etropus microstomus*)	20	10	30	0.1	0.3
Spotfin mojarra (*Eucinostomus argenteus*)	0	17	17	0.0	0.4
Gag (*Mycteroperca microlepis*)	0	1	1	0.0	0.03

Species	Total Number Collected			Mean CPUE	
	Trawl n=140	Seine n=38	Total	Trawl	Seine
Rainwater killifish (*Luciana parva*)	55	378	433	0.4	10.0
Fourspine stickleback (*Apeltes quadracus*)	74	39	113	0.5	1.0
American eel (*Anguilla rostrata*)	31	119	150	0.2	3.1
Spotted seatrout (*Cynoscion nebulosus*)	6	10	16	0.04	0.3
Winter flounder (*Pseudopleuronectes americanus*)	15	26	41	0.1	0.7
Windowpane flounder (*Scophthalmus aquosus*)	6	1	7	0.04	0.03
Blueback herring (*Alosa aestivalis*)	1	0	1	0.01	0.0
Atlantic herring (*Clupea harengus*)	1,893	1	1,894	13.5	0.03
Lookdown (*Selene vomer*)	2	0	2	0.01	0.0
Brown bullhead (*Ameiurus nebulosus*)	0	2	2	0.0	0.1
Striped cusk eel (*Ophidion marginatum*)	16	1	17	0.1	0.1
Crevalle jack (*Caranx hippos*)	10	29	39	0.1	0.8
Feather blenny (*Hypsoblennius hentzi*)	11	15	26	0.1	0.4
Tautog (*Tautoga onitis*)	3	3	6	0.02	0.1
Naked goby (*Gobiosoma bosci*)	60	109	169	0.4	2.9

Species	Total Number Collected			Mean CPUE	
	Trawl n=140	Seine n=38	Total	Trawl	Seine
Lined seahorse (*Hyppocampus erectus)*	0	1	1	0.0	0.03
Red snapper (*Lutjanus campechanus*)	4	9	13	0.03	0.2
Sheepshead minnow (*Cyprinodon variegatus*)	1	34	35	0.01	0.9
Scup (*Stenotomus chrysops)*	13	3	13	0.1	0.1
Striped burrfish (*Chilomycterus schoepfi*)	5	6	11	0.04	0.2
Banded killifish (*Fundulus diaphanus*)	0	131	131	0.0	3.4
Black Crappie (*Pomoxis nigromaculatus*)	0	2	2	0.0	0.1
Halfbeak (*Hyporhamphus unifasciatus*)	0	1	1	0.0	0.03
Pumpkinseed (*Lepomis gibbosus*)	0	53	53	0.0	1.4
Bluegill (*Lepomis macrochirus*)	0	8	8	0.0	0.2
Gizzard shad (*Dorosoma cepedianum*)	2	12	14	0.01	0.3
Striped searobin (*Prionotus evolans*)	9	8	17	0.1	0.2
Conger eel (*Conger oceanicus*)	1	0	1	0.01	0.0
Spotfin butterflyfish (*Chaetodon ocellatus*)	1	0	1	0.01	0.0
Red drum (*Sciaenops ocellata*)	2	0	2	0.01	0.0
Skilletfish (*Gobiesox strumosus*)	1	3	4	0.01	0.1

Species	Total Number Collected			Mean CPUE	
	Trawl n=140	Seine n=38	Total	Trawl	Seine
Tidewater silverside (*Menidia beryllina)*	0	15	15	0.0	0.4
Mosquitofish (*Gambusia holbrooki*)	0	2	2	0.0	0.1
Common trunkfish (*Lactophrys trigonus*)	0	1	1	0.0	0.03
Crabeater (*Rachycentron canadus*)	0	4	4	0.0	0.1
Bluespotted sunfish (*Enneacanthus gloriosus*)	0	2	2	0.0	0.1
Bluenose ray (*Myliobatis freminvillei*)	0	4	4	0.0	0.1
Pigfish (*Orthopristis chrysoptera*)	0	1	1	0.0	0.03
Alewife (*Alosa pseudoharengus*)	0	15	15	0.0	0.4
White perch (*Morone americana*)	0	44	44	0.0	1.2
Smooth butterfly ray (*Gymnura micrura*)	1	0	1	0.01	0.0
Green goby (*Microgobius thallassinus*)	24	10	34	0.2	0.3
Atlantic spadefish (*Chaetodipterus faber*)	2	0	2	0.01	0.0
Spanish mackeral (*Scomberomorus cavalla*)	1	0	1	0.01	0.0
Rough scad (*Trachurus trachurus*)	1	1	2	0.01	0.03
Dwarf Goatfish (*Upenus parvus*)		1	1	0.0	0.02

Species	Total Number Collected			Mean CPUE	
	Trawl n=140	Seine n=38	Total	Trawl	Seine
Blue crab (*Callinectes sapidus*)	7,640	5,064	12,704	54.6	133.3
Sand shrimp (*Crangon septemspinosa*)	9,801	123	9,924	70.0	3.2
Grass shrimp (*Palaemonetes sp.*)	3,136	17,776	20,912	22.4	467.8
Brown shrimp (*Penaeus aztecus*)	104	22	126	0.7	0.6
Lady crab (*Ovalipes ocellatus*)	106	146	252	0.8	3.8
Mud crab (*Neopanope texana sayi*)	35	1	36	0.2	0.03
Hermit crab (*Pagurus longicarpus*)	55	30	85	0.4	0.8
Mantis shrimp (*Squilla empusa*)	36	0	36	0.3	0.0
Spider crab (*Libinia emarginata*)	36	0	36	0.3	0.0
Mud crab (*Panopeus sp.*)	10	0	10	0.1	0.0
Hermit crab (*Pagurus pollicaris*)	6	1	7	0.04	0.03
Rock crab (*Cancer irroratus*)	58	0	58	0.4	0.0
Mud shrimp (*Callianassa atlantica*)	7	1	8	0.05	0.03

Species	Total Number Collected			Mean CPUE	
	Trawl n=140	Seine n=38	Total	Trawl	Seine
Long-finned squid (*Loligo pealei*)	39	0	39	0.3	0.0
Forbes asterias star (*Asterias forbesi*)	21	0	21	0.2	0.0
Oyster drill (*Urosalpinx cinereus*)	2	0	2	0.01	0.0
Horseshoe crab (*Limulus polyphemus*)	16	1	17	0.1	0.03
Diamondback terrapin (*Malaclemys centrata concentrica*)	55	12	67	0.4	0.3
Mud snail (*Nassarius vibex*)	43	1	44	0.3	0.03
snail (*Nassariidae*)	8	1,014	1,022	0.1	26.7
Hard shell clam (*Mercenaria mercenaria*)	98	2	100	0.7	0.1
Lobed moon snail (*Polinices duplicatus*)	1	0	1	0.01	0.0
Mulinia lateralis	8	0	8	0.1	0.0
Haminoea solitaria	5,310	0	5,310	37.9	0.0
Tellina agilis	4	0	4	0.03	0.0
Ensis sp.	3	0	3	0.02	0.0
Solen sp.	5	2	7	0.04	0.1
Eupleura caudata	7	1	8	0.1	0.03

CATEGORY	TOTAL NUMBERS	TOTAL SPECIES
A. Fish	50,444	79
B. Crustaceans	44,194	13
C. Other	6,653	15
	101,291	107

APPENDIX B

Area-weighted Mean Concentrations
for all Measured Sediment Contaminant

Appendix Table B-1. Mean concentrations (90% confidence intervals) of sediment contaminants in the Delaware/Maryland Coastal Bays and Artificial Lagoons

	Coastal Bays	Artificial Lagoons
Metals (ppm)		
Aluminum	44,103 ± 7,421	49,605 ± 15,371
Antimony	0.23 ± 0.09	0.29 ± 0.07
Arsenic	7.03 ± 1.91	10.64 ± 2.09
Cadmium	0.14 ± 0.05	0.20 ± 0.05
Chromium	41.98 ± 10.58	56.11 ± 20.71
Copper	9.52 ± 2.81	40.64 ± 10.38
Iron	20,588 ± 4,519	24,146 ± 7,826
Lead	24.14 ± 5.83	34.35 ± 6.60
Manganese	283 ± 40	217 ± 54.68
Mercury	0.04 ± 0.01	0
Nickel	13.93 ± 4.65	21.11 ± 9.26
Selenium	0.33 ± 0.17	0.42 ± 0.10
Silver	0.05 ± 0.02	0.12 ± 0.03
Tin	1.82 ± 0.41	2.44 ± 1.30
Zinc	64.53 ± 16.35	107.9 ± 28.94
SEM-Cadmium	0.18 ± 0.13	0.13 ± 0.31
SEM-Copper	1.39 ± 1.12	3.27 ± 2.29
SEM-Nickel	1.71 ± 1.03	3.16 ± 1.15
SEM-Lead	7.69 ± 4.66	7.79 ± 1.45
SEM-Zinc	26.50 ± 13.58	27.68 ± 5.41
Pesticides (ppb)		
DDT and its metabolites		
Total DDD	0.64 ± 0.42	1.71 ± 2.17
Total DDE	1.31 ± 0.72	1.06 ± 0.28
Total DDT parent	0.20 ± 0.15	0.37 ± 0.92
Total DDT	2.15 ± 1.09	3.14 ± 2.91
o,p'-DDD	0.09 ± 0.09	0.82 ± 0.99
p,p'-DDD	0.55 ± 0.35	0.89 ± 1.20
o,p'-DDE	0.19 ± 0.14	1.06 ± 0.28
p,p'-DDE	1.12 ± 0.60	0
o,p'-DDT	0.02 ± 0.02	0.18 ± 0.44
p,p'-DDT	0.18 ± 0.15	0.19 ± 0.49
Total OPDDT	0.31 ± 0.20	2.06 ± 1.27
Total PPDDT	1.85 ± 0.93	1.08 ± 1.68

Appendix Table B-1. Continued		
	Coastal Bays	**Artificial Lagoons**
Chlorinated Pesticides other than DDT		
Aldrin	0.15 ± 0.17	0.03 ± 0.08
Alpha-Chlordane	0.15 ± 0.18	1.21 ± 0.39
Dieldrin	0.13 ± 0.07	1.66 ± 1.83
Endosulfan I	0.40 ± 0.37	0.57 ± 0.13
Endosulfan II	0.17 ± 0.14	0.06 ± 0.16
Endosulfan Sulfate	0.54 ± 0.09	5.17 ± 1.12
Endrin	0.04 ± 0.02	0.65 ± 0.16
Endrin Aldehyde	0.01 ± 0.02	0.01 ± 0.03
Endrin Ketone	0.14 ± 0.17	0.55 + 0.16
Heptachlor	0.13 ± 0.12	0.03 ± 0.07
Heptachlor Epoxide	0.04 ± 0.05	0
Hexachlorobenzene	0.05 ± 0.04	0.63 ± 0.41
Lindane	0.20 ± 0.15	0.94 ± 0.20
Mirex	0.12 + 0.17	0.01 ± 0.03
Total Chlordane	0.41 ± 0.39	1.85 ± 0.74
Trans-Nonachlor	0.12 ± 0.11	0.61 ± 0.33
PCB Cogeners (ppb)		
No. 8	0.21 ± 0.18	0.03 ± 0.10
No. 18	0.23 ± 0.18	0.54 ± 0.38
No. 28	0.37 ± 0.20	7.32 ± 5.15
No. 44	0.07 ± 0.05	2.06 ± 2.96
No. 52	0.13 ± 0.09	4.23 ± 1.48
No. 66	0.23 ± 0.13	0.28 ± 0.69
No. 101	0.23 ± 0.14	0.18 ± 0.46
No. 105	0.10 ± 0.05	1.12 ± 0.84
No. 118	0.24 ± 0.12	0.19 ± 0.46
No. 128	0.01 ± 0.01	0.27 ± 0.72
No. 138	0.21 ± 0.13	0.46 ± 0.28
No. 153	0.32 ± 0.13	0.68 ± 0.89
No. 170	0.12 ± 0.12	0.55 ± 0.25
No. 180	0.07 ± 0.06	0.14 ± 0.36
No. 187	0.13 ± 0.07	0.95 ± 0.59
No. 195	0.07 ± 0.07	0.81 ± 0.99
No. 206	0.05 ± 0.04	0.01 ± 0.16
No. 209	0.10 ± 0.07	0
Total PCBs	2.89 ± 1.04	19.81 ± 5.51

Appendix Table B-1. Continued		
	Coastal Bays	**Artificial Lagoons**
Polycyclic Aromatic Hydrocarbons (ppb)		
Acenapthene	1.38 ± 1.06	2.13 ± 5.35
Acenapthylene	0.27 ± 0.23	0.72 ± 2.07
Anthracene	3.87 ± 2.34	59.92 ± 63.81
Benzo[a]anthracene	8.82 ± 4.38	210 ± 292
Benzo[a]pyrene	6.60 ± 4.23	79.46 ± 31.60
Benzo[e]pyrene	8.27 ± 4.26	94.32 ± 752.49
Benzo[b,k]fluoranthene	25.31 ± 12.30	268.8 ± 90.39
Benzo[g,h,i]perylene	10.14 ± 5.17	60.00 ± 21.15
Biphenyl	2.11 ± 1.51	0.19 ± 0.54
Chrysene	11.12 ± 5.06	385.04 ± 213.14
Dibenz[a,h,]anthracene	0.65 ± 0.69	17.96 ± 10.18
2,6-Dimethylnaphthalene	6.33 ± 3.10	16.11 ± 3.09
Flouranthene	31.00 ± 12.69	315.50 ± 265.59
Fluorene	4.20 ± 2.61	19.28 ± 13.77
Inden[1,2,3-cd]pyrene	9.73 ± 5.77	74.19 ± 26.86
1-methylnaphthalene	4.23 ± 2.46	2.02 ± 5.18
2-methylnaphthalene	11.51 ± 5.27	19.05 ± 4.19
1-methylphenanthrene	0.57 ± 0.74	6.72 ± 18.87
Naphthalene	13.49 ± 5.66	18.36 ± 5.46
Perylene	26.01 ± 13.87	73.83 ± 33.82
Phenanthrene	24.80 ± 11.82	85.57 ± 33.84
Pyrene	20.48 ± 8.50	250.87 ± 157.48
Total 2-Ring PAHs	40.74 ± 17.13	59.65 ± 17.47
Total 3-Ring PAHs	33.45 ± 15.52	171.50 ± 129.03
Total 4-Ring PAHs	60.30 ± 24.98	776.20 ± 713.85
Total 5-Ring PAHs	87.70 ± 43.90	993.59 ± 352.82
Total 6-Ring PAHs	10.14 ± 5.17	59.97 ± 21.16
1,6,7-trimethylnaphthalene	1.42 ± 0.94	1.07 ± 2.80
Total High Mol. Wt. PAHs	158 ± 71	1,829 ± 964
Total Low Mol. Wt. PAHs	74 ± 30	231 ± 143
Total PAHs	232 ± 92	2,061 ± 1,103
Other Measurements		
Acid Volatile Sulfide (ppm)	231 ± 137	1,271 ± 753
Dibutyltin (ppb)	5.56 ± 5.15	0
Monobutyltin (ppb)	4.38 ± 4.09	0
Tributyltin (ppb)	15.48 ± 14.23	0
Total Butyl Tins (ppb)	25.42 ± 18.25	0
Total Organic Carbon (ppm)	14,415 ± 3,844	21,083 ± 3,726

APPENDIX C

Area-weighted Mean Abundances of Benthic Macroinvertebrate Species

Group	Name	Entire Study Area	Rehoboth Bay	Indian River	Assa-woman Bay	Chinco-teague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
Anthozoa	Anthozoa	144.36	277.72	124.48	10.85	281.52	180.22	11.44	47.85	1.27
	Ceriantheopsis americanus	2.61		1.35		6.78			1.45	
Turbellaria	Turbellaria	11.32	3.78	26.07	13.68	6.78	26.57	0.42	2.17	
Nemertinea	Nemertinea	123.11	79.35	32.98	135.63	257.77	20.78	28.82	34.80	1.11
Sipuncula	Sipuncula	0.70				3.39				
Bivalvia	Aligena elevata	1.08	0.94		0.61	3.39		0.85	0.72	
	Anadara transversa	9.68	2.83		0.61	44.09		0.85		
	Anomiidae	10.47				50.88				
	Barnea truncata	2.09				10.18				
	Bivalvia: Other - Suspension Feeders	33.10	35.90	42.02	7.77	71.23	52.18	3.39	2.90	0.11
	Chione spp.	0.57		2.71						
	Ensis directus	7.78	12.28	13.53	3.28			0.85		
	Gemma gemma	1184.23	3703.86	878.18	237.38	1404.19	1299.71	197.48	5.07	12.78
	Lyonsia spp.	1.40				6.78				
	Macoma balthica	0.70				3.39				
	Macoma tenta	38.23	4.72		7.47	169.59		2.97	7.25	
	Mercenaria mercenaria	54.04	72.74	26.36	1.51	71.23	0.97	2.12		0.03
	Mulinia lateralis	445.93	43.45	30.13	478.99	1414.37	12.56	284.78	133.40	0.16
	Mya arenaria	0.70				3.39				
	Mysella planulata	1.40				6.78				
	Mytilidae	0.54		0.65	0.30		0.97	0.42		
	Mytilus edulis	2.98	17.00	0.33			0.48			
	Nucula annulata	12.19	3.78	12.83	12.22	30.53	0.97	2.12	0.72	0.03

Group	Name	Entire Study Area	Rehoboth Bay	Indian River	Assa-woman Bay	Chinco-teague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
	Periploma margaritaceum	11.16				54.27				
	Petricola pholadiformis	0.16	0.94							
	Pitar morrhuanus	11.16				54.27				
	Solemya velum	25.33	1.89		5.35	98.36			0.72	
	Spisula solidissima	2.93	10.39	5.41						
	Tagelus divisus	2092.92	51.01	76.07	11.10	9381.62	112.58	8.05	154.42	
	Tagelus spp.	3.45	14.17	4.24	0.61		6.28	0.85		
	Tellina agilis	450.51	300.39	1359.49	74.19	47.48	73.92	36.45	23.20	1.03
	Tellinidae	31.79	37.78	50.00	45.27	13.57	71.99	29.66	15.22	0.29
	Veneridae	0.57		2.71						
	Yoldia limatula									0.03
Gastropoda	Acteocina canaliculata	131.31	4.72	10.36	19.64	549.47	5.31	1.27	39.15	0.09
	Astyris lunata	2.79				13.57				
	Bittium alternatum	212.11				1031.10				
	Boonea seminuda	4.88				23.74				
	Cratena pilata	2.33	3.78	0.98	3.03	3.39	1.45	4.24		
	Crepidula spp.	8.19	10.39	6.06	1.21	23.74	0.97	1.70		0.02
	Doridella obscura	0.16	0.94							
	Eupleura caudata	1.07	0.94			3.39			1.45	
	Gastropoda: Other	85.24	6.61	14.93	28.57	362.92	12.08	2.54	2.90	0.02
	Haminoea solitaria	31.71	30.23	13.81	8.33	16.96	16.43	0.42		0.39
	Ilyanassa obsoleta	0.70				3.39				0.02
	Nassarius spp.	0.69		3.26			4.83			
	Nassarius trivittatus	0.07		0.33			0.48			

Group	Name	Entire Study Area	Rehoboth Bay	Indian River	Assa-woman Bay	Chinco-teague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
	Nassarius vibex	4.16	1.89	2.29	0.91	13.57	3.38	1.27	1.45	
	Odostomia engonia	8.08	1.89	4.29		23.74	4.35		13.77	
	Odostomia spp.	5.05		8.16	0.30	6.78	12.08	0.42	13.05	
	Pyramidella crenulata	0.70				3.39				
	Pyramidella spp.	2.88								
	Pyramidellidae	0.72							5.07	
	Rictaxis punctostriatus	82.06	47.23	151.76	146.74	33.92	198.58	14.41	6.52	1.73
	Turbonilla interrupta	157.23	51.95	4.71	83.12	579.99	0.97	37.72	79.75	0.12
Oligochaeta	Aulodrilus pigueti	0.21							1.45	
	Limnodrilus claparedianus	0.21							1.45	
	Limnodrilus hoffmeisteri	1.45							10.15	
	Oligochaeta: Heads	932.09	1345.14	1166.75	86.61	1370.27	267.19	31.36	56.55	22.82
	Tubificidae with capiliform chaetae	4.35							30.45	
	Tubificidae without capiliform chaetae	0.21							1.45	
Polychaeta	Amastigos caperatus	6.69	34.01	4.06						
	Ampharetidae	23.22	1.89		0.30	108.54		0.42		
	Amphitrite ornata	2.79				13.57				0.29
	Apoprionospio pygmaea	0.16	0.94							
	Arabella iricolor-multidentata complex	3.88			0.91	16.96		1.27	1.45	
	Aricidea catherinae	11.86				57.66				
	Aricidea fragilis	0.10							0.72	
	Asabellides oculata	0.49	2.83							

Group	Name	Entire Study Area	Rehoboth Bay	Indian River	Assa-woman Bay	Chinco-teague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
	Boccardiella hamata	12.56				61.05				
	Brania clavata	20.90	18.89	9.51	34.02	33.92	12.08	10.17	13.05	
	Brania spp.	2.16								
	Brania wellfleetensis	7.57	14.17						0.72	
	Cabira incerta	4.39				20.35			1.45	
	Capitella spp.	286.74	1193.06	315.54	10.75	61.05	0.48	3.81	4.35	9.97
	Capitellidae	0.34		0.33	0.30		0.48	0.42	1.45	
	Capitellides jonesi	0.64		3.03			0.48			
	Carazziella hobsonae	453.14	0.94	1.35	35.74	2048.63		5.09	47.85	
	Ceratonereis irritabilis	69.88				339.18			0.72	
	Cirriformia grandis	0.70				3.39				
	Clymenella torquata	92.33	6.61	2.01	115.98	234.03	0.97	50.01	39.15	1.44
	Cossura longocirrata	27.19			131.44	3.39		26.70	1.45	
	Demonax microphthalmus	17.12	0.94	4.24	22.46	50.88	6.28	12.71	6.52	0.12
	Diopatra cuprea	140.67	24.56	1.68	38.16	593.56	0.48	8.48	28.27	
	Dorvillea rudolphi	12.32		1.35		57.66				
	Dorvillea socialis	7.68				37.31				
	Drilonereis longa	1.27	0.94	0.33		3.39	0.48			
	Eumida sanguinea	29.46	5.67		9.29	125.50		5.51	2.17	
	Eunicidae	26.51				128.89				
	Exogone dispar	556.40	51.01	1.68	12.41	2367.45	0.48	17.38	213.14	
	Glycera americana	63.58	15.11	10.12	29.48	193.33	0.97	3.81	21.75	0.29
	Glycera dibranchiata	3.13				13.57				0.25
	Glycera spp.	15.70	9.45	6.76	5.35	54.27			2.90	

Group	Name	Entire Study Area	Rehoboth Bay	Indian River	Assa-woman Bay	Chinco-teague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
	Glycinde solitaria	410.41	113.35	136.38	254.30	1305.83	121.76	56.36	143.55	2.53
	Goniadidae	3.99	12.28	0.65	0.91	6.78	0.97	1.27		0.01
	Harmothoe extenuata	1.34	4.72		2.68					
	Heteromastus filiformis	168.50	236.16	169.70	58.10	339.18	72.96	10.17	2.90	6.60
	Hobsonia florida									0.04
	Hydroides dianthus	280.87	1.89		0.30	1363.49		0.42		
	Hydroides spp.	0.54			2.68					
	Hypereteone foliosa	1.63		0.65	0.91	3.39	0.97	1.27	0.72	0.11
	Hypereteone heteropoda	15.61	34.95	26.54	8.12	3.39	21.26	7.63	4.35	2.68
	Laeonereis culveri	19.28	76.51	2.71	1.21	20.35		1.70	5.80	8.88
	Leitoscoloplos robustus	31.99	15.11	89.56	13.73	30.53	30.44	4.24	1.45	1.82
	Leitoscoloplos spp.	65.11	56.68	164.94	6.91	88.19	45.90	5.93	0.72	1.44
	Lepidonotus squamatus	2.79				13.57				
	Loimia medusa	0.21							1.45	
	Lumbrineridae	102.37	238.04	29.81	28.92	203.51	12.08	6.78	2.90	8.80
	Macroclymene zonalis	92.70	1.89	8.12	47.05	271.34		5.93	36.97	
	Magelona spp.	0.29		1.35						
	Maldanidae	148.72	7.56	7.74	78.53	539.29	1.45	50.01	44.22	3.46
	Marphysa sanguinea	4.42			0.30	20.35		0.42		
	Mediomastus ambiseta	3230.09	1138.27	823.67	436.08	10880.78	398.13	44.92	657.56	3.95
	Mediomastus californiensis	49.84		0.65	0.30	240.82	0.97	0.42	0.72	
	Mediomastus spp.	4923.19	1335.69	756.60	519.52	18264.65	583.18	60.60	2406.21	1.74
	Melinna maculata	179.39	4.72	2.99	235.32	501.98	2.42	37.29	104.40	0.86
	Melinna spp.	10.47				50.88				

Group	Name	Entire Study Area	Rehoboth Bay	Indian River	Assa-woman Bay	Chinco-teague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
	Microphthalmus sczelkowii	4.16	1.89	14.83		3.39	1.93			
	Neanthes arenaceodentata	7.29	17.00	5.97		10.18	4.83			
	Neanthes succinea	54.62	24.56	51.49	163.54	6.78	52.18	49.16	13.05	2.00
	Nephtyidae	0.29		1.35						
	Nephtys incisa	1.11		2.71	2.68					
	Nephtys picta	1.26	5.67	1.35						
	Nephtys spp.	0.17								
	Nereididae	20.24	46.29	1.96	1.82	50.88	2.90	2.54		0.25
	Notomastus sp. A Ewing	248.54	99.19	233.36	177.87	508.76	153.16	54.24	112.37	0.58
	Notomastus spp.	0.06			0.30			0.42		
	Odontosyllis fulgurans	84.25				407.01			3.62	
	Onuphidae	17.12	1.89	1.31	1.82	71.23	1.93	2.54	0.72	
	Orbiniidae	0.70				3.39				
	Owenia fusiformis	11.07			48.16					
	Parahesione luteola	15.23	9.45	29.43	11.96	6.78	41.55	5.51		
	Paranaitis speciosa	4.29				20.35			0.72	
	Paraonis fulgens	2.97	5.67	9.47						
	Parapionosyllis longicirrata	26.58	77.46			57.66				
	Paraprionospio pinnata	195.84	61.40	33.49	129.17	603.73	27.54	12.29	172.55	
	Pectinaria gouldii	7.75	11.34	10.82	6.26	10.18		1.27		
	Pherusa affinis	0.82		1.35	2.68					
	Phyllodoce arenae	7.95	1.89	9.80	2.72	20.35	0.48	3.81	0.72	
	Pista palmata	241.83				1173.55			2.90	
	Platynereis dumerilii	3.49				16.96				

Group	Name	Entire Study Area	Rehoboth Bay	Indian River	Assa-woman Bay	Chinco-teague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
	Podarke obscura	192.70			0.61	936.13		0.85		
	Podarkeopsis levifuscina	58.12	58.57	25.33	47.79	125.50	29.47	40.68	18.85	0.29
	Polychaeta: Other	0.07	0.00	0.33	0.00	0.00	0.48	0.00	0.00	0.00
	Polycirrus spp.	11.85	5.67		1.21	50.88		1.70		
	Polydora cornuta	125.05	179.48	83.44	85.91	267.95	101.46	22.88	13.77	0.53
	Polydora socialis	2.63			2.68	10.18				
	Polydora spp.	7.55	1.89	2.01	32.11		0.97		1.45	
	Polynoidae	0.70				3.39				
	Prionospio heterobranchia	121.54			2.68	556.25			0.72	0.04
	Prionospio perkinsi	2.95	0.94	8.12	5.35					
	Pygospio elegans	17.99	98.24	5.41						
	Sabaco elongatus	115.71	12.28	15.11	122.80	332.39	4.35	48.31	97.15	
	Sabellaria vulgaris	7.14	0.94			33.92				
	Sabellidae	118.77			5.65	559.64		0.42	10.15	0.12
	Scolelepis bousfieldi	8.68				40.70			2.17	
	Scolelepis spp.	1.56	0.94			6.78				
	Scolelepis texana	41.90	68.96	1.31	10.70	122.10	1.93			1.38
	Scoletoma tenuis	58.51	64.23	16.33	52.40	98.36	10.15	5.93	6.52	5.03
	Scoloplos rubra	1.56	0.94			6.78				
	Scoloplos spp.	0.70				3.39				
	Serpulidae	5.58				27.13				
	Sigambra tentaculata	1.07			5.35					
	Sphaerosyllis taylori	15.53	2.83		23.57	40.70		6.78	10.15	0.04
	Spio setosa	0.32	1.89							0.02

Group	Name	Entire Study Area	Rehoboth Bay	Indian River	Assa-woman Bay	Chinco-teague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
	Spiochaetopterus costarum	91.80	47.23	3.03	51.18	298.48	0.48	26.70	30.45	
	Spiophanes bombyx	7.08	18.89	5.41	2.68					
	Spirorbidae	1.40				6.78				
	Spirorbis spp.	6.28				30.53				
	Sthenelais boa	3.49				16.96				
	Streblospio benedicti	1811.87	3283.50	2178.77	929.59	1027.70	485.58	1207.78	819.23	217.37
	Streptosyllis pettiboneae	6.14	25.50		8.33			0.42	0.72	0.11
	Syllidae	4.35	1.89		2.68	16.96				
	Syllides spp.	0.29		1.35						
	Terebellidae	12.87		1.35		57.66				
	Tharyx sp. A Morris	102.09	312.67	102.12	2.68	50.88	0.97		2.17	1.92
Amphipoda	Ampelisca abdita	8774.03	3587.67	14763.49	8053.75	7794.28	12019.18	5038.77	3740.91	1.67
	Ampelisca abdita-vadorum complex	9010.89	2563.70	12843.25	6294.69	9011.92	14198.73	6168.14	3812.68	0.51
	Ampelisca vadorum	49.49	11.34		6.56	183.16		1.70	19.57	
	Ampelisca verrilli	695.93	444.92	8.44	164.46	2570.96	0.48	5.51	40.60	0.03
	Ampithoe longimanna	3.56	20.78							
	Ampithoe spp.	2.73		2.71	0.30	10.18		0.42		
	Ampithoidae	20.71	30.23	66.29	0.61	6.78		0.85		
	Batea catharinensis	78.32	144.53	5.74	14.89	223.86	0.48	2.12	13.05	
	Caprella penantis	27.51	103.91	6.67	6.56	33.92	3.87	1.70		
	Caprella spp.	2.16								
	Caprellidae	0.86	0.94			3.39				
	Cerapus tubularis	15.14			0.30	37.31		0.42	1.45	

Group	Name	Entire Study Area	Rehoboth Bay	Indian River	Assa-woman Bay	Chinco-teague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
	Corophium acherusicum	352.13	17.00	1519.18	0.30	128.89	586.56	0.42		
	Corophium acutum	0.16	0.94							
	Corophium simile	0.10							0.72	
	Corophium spp.	281.26	14.17	1208.64	0.61	78.01	32.86	0.85	24.65	
	Corophium tuberculatum	166.59	98.24	169.99	37.05	295.08	5.31	14.41	239.24	
	Cymadusa compta	60.10	39.67	13.39	2.72	196.72	5.80	3.81	0.72	
	Dulichiella appendiculata	192.02	102.96	24.81		786.89	36.72		50.75	0.03
	Elasmopus laevis	662.92	473.26	246.18	147.93	2275.87	196.16	61.02	70.32	
	Eobrolgus spinosus	47.49	0.94	1.35		213.68			1.45	
	Ericthonius brasiliensis	34.19	105.80	10.82	5.35	57.66			5.80	
	Gammaridae	0.16	0.94							
	Lembos smithi	30.70				149.24				
	Leptocheirus plumulosus	1.73		8.16			12.08			
	Listriella barnardi	285.04	43.45	144.69	374.56	576.60	114.03	138.58	112.37	
	Listriella clymenellae	0.72			3.58			1.27		
	Lysianopsis alba	99.81	78.40	8.12	49.34	359.53		69.08	0.72	
	Melita nitida	2.63		9.14		3.39	13.53			
	Microdeutopus gryllotalpa	224.51	187.04	525.41	74.74	318.83	285.07	55.94	0.72	
	Microdeutopus spp.	1.60	3.78	0.33	0.91	3.39	0.48	1.27		0.02
	Microprotopus raneyi	180.60	221.99	135.74	5.65	498.59	36.72	0.42	12.32	0.03
	Monoculodes sp. 1 Watling	59.70	9.45	0.65	113.88	156.02	0.97	2.12	0.72	
	Mucrogammarus mucronatus	26.20	17.00	23.51	68.64	6.78	34.79	21.19	2.17	0.01
	Paracaprella tenuis	125.16	19.84	3.31	11.15	444.32	2.90	11.87	82.65	
	Parametopella cypris	0.46	1.89	0.65			0.97			

Group	Name	Entire Study Area	Rehoboth Bay	Indian River	Assa-woman Bay	Chinco-teague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
	Pseudohaustorius spp.	0.49	2.83							
	Rhepoxynius hudsoni	35.58				172.98				
	Stenothoe spp.	2.42		1.35		3.39				
	Synchelidium americanum	56.54				271.34			5.07	
	Unciola dissimilis	2.36		2.71	5.35					
	Unciola serrata	4.00			13.38				2.17	
	Unciola spp.	12.08	2.83	4.06	1.82	44.09		2.54	4.35	
Chiro-nomidae	Chironomus spp.	1.55							10.87	
	Paracladopelma spp.	0.10							0.72	
	Tanypus spp.	1.35							9.42	
	Tanytarsus spp.	0.10							0.72	
Cirripedia	Balanus eburneus									0.02
	Balanus spp.									0.02
Cumacea	Cyclaspis varians	27.79	3.78	37.22	0.91	81.40	55.08	1.27	2.17	
	Leucon americanus	174.51	45.34	176.59	196.21	257.77	123.21	139.85	79.02	0.64
	Oxyurostylis smithi	56.87	25.50	8.72	45.23	189.94	2.90	3.39	2.90	
Decapoda	Callinectes sapidus	6.85	4.72	6.67	3.89	13.57	3.87	1.70		0.03
	Crangon septemspinosa	2.43	3.78	1.63			2.42			0.03
	Dyspanopeus sayi	0.16	0.94							
	Hippolytidae	0.70				3.39				
	Libinia spp.	0.57		2.71						
	Ogyrides alphaerostris	10.21	0.94	5.36	11.31	30.53	1.93	0.85	1.45	
	Ovalipes ocellatus	0.29		1.35						

Group	Name	Entire Study Area	Rehoboth Bay	Indian River	Assa-woman Bay	Chinco-teague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
	Pagurus spp.	0.29		1.35						
	Pinnixa spp.	2.51			5.35					
	Upogebia affinis	0.70				3.39				
Diptera	Ceratopogonidae	0.10							0.72	
Isopoda	Cyathura burbancki	75.62	34.95	5.27		250.99	5.80		17.40	
	Cyathura polita	5.37	8.50	9.14	5.35	3.39	13.53		1.45	
	Cyathura spp.									0.04
	Edotea triloba	140.93	56.68	170.23	176.05	186.55	231.92	167.82	35.52	0.46
	Erichsonella attenuata	4.19				20.35				
	Erichsonella filiformis	2.33	13.22		0.30			0.42		
	Erichsonella spp.	2.49	0.94		4.54	3.39		6.36		
	Idotea balthica	0.29		1.35						
	Isopoda: Other	0.70				3.39				
	Paracerceis caudata	18.14				88.19				
Mero-stomata	Limulus polyphemus	0.12			0.61			0.85		0.01
Mysidacea	Heteromysis formosa	3.93	17.95	4.06						
	Mysidae	0.60		0.33	2.68		0.48			
	Mysidopsis almyra	0.29		1.35						
	Mysidopsis bigelowi	56.58	51.95	12.64	8.93	200.11	8.70	1.27	3.62	0.40
Pycnogonida	Anoplodactylus petiolatus	5.78			12.52	10.18		2.54		0.12
	Callipallene brevirostris	21.96	7.56	9.47	13.78	54.27	14.01	8.05	13.05	
	Tanystylum orbiculare	0.16	0.94							
Tanaidacea	Hargeria rapax	110.40			1.21	532.51		1.70	0.72	0.25

Group	Name	Entire Study Area	Rehoboth Bay	Indian River	Assa-woman Bay	Chinco-teague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
	Leptochelia dubia	0.70				3.39				
Phoronida	Phoronis spp.	272.92	0.94	1.35	6.86	1207.47		2.12	117.45	
Bryozoa	Amathia convoluta	0.00			0.00	0.00		0.00		
	Anguinella palmata	0.00			0.00	0.00		0.00	0.00	
Asteroidea	Asterias forbesi	0.32	1.89							
	Asterias spp.	1.07			5.35					
	Asteroidea	5.31	17.95	2.71	8.33			0.42		
Holo-thuroidea	Havelockia scabra	1.54			0.61	3.39		0.85		
	Holothuroidea	2.91			0.61	13.57		0.85		
	Leptosynapta tenuis	31.50	2.83		17.06	115.32		8.90	5.80	
	Pentamera pulcherrima	16.85				81.40			0.72	
Hemi-chordata	Saccoglossus kowalevskii	2.43	9.45		1.51			2.12		
Ascidiacea	Molgula manhattensis	0.65	3.78							
	Perophora viridis	0.00				0.00				

APPENDIX D

Minimum, Maximum, Median and Quartile Values
for All Measured Attributes

Delaware/Maryland Coastal Bays - Physical Characteristics
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Bottom Salinity (ppt)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	35.00	29.7	31.6	30.9	32.3	32.90	35.0000
PCT_75TH	31.30	26.9	30.8	28.9	30.7	31.40	33.6000
MEDIAN	29.45	25.4	29.4	27.6	29.3	30.25	31.7625
PCT_25TH	27.00	24.1	26.5	26.5	28.0	28.40	29.3000
MINIMUM	2.80	8.4	23.7	2.8	23.9	21.60	26.9000

Variable=Bottom Temperature (C)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	37.400	37.40	31.70	29.14	28.92	29.800	31.7000
PCT_75TH	27.940	28.75	28.40	27.16	28.08	28.100	26.8900
MEDIAN	26.365	27.34	27.20	25.66	27.08	26.015	25.7950
PCT_25TH	24.920	26.55	26.32	24.92	24.92	24.330	23.7225
MINIMUM	19.160	20.81	24.06	21.40	19.16	19.180	21.0000

Variable=Bottom depth (m)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	3.6576	3.6576	1.8288	2.1336	3.3528	3.3528	2.4384
PCT_75TH	1.8288	1.8288	1.5240	1.8288	1.8288	1.8288	1.8288
MEDIAN	1.5240	1.5240	1.2192	1.5240	1.5240	1.2192	1.5240
PCT_25TH	0.9525	1.2192	1.1049	1.5240	0.9144	0.9144	1.2192
MINIMUM	0.6096	0.7620	0.6096	0.7620	0.7620	0.6096	0.6096

Variable=Bottom pH (pH)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	9.49750	8.300	8.24	9.4975	8.07	8.13	8.4200
PCT_75TH	7.92500	7.845	7.99	7.8600	7.90	7.90	8.0000
MEDIAN	7.73500	7.710	7.77	7.7700	7.55	7.63	7.7675
PCT_25TH	7.58875	7.570	7.71	7.6800	7.34	7.54	7.6300
MINIMUM	7.00000	7.250	7.56	7.3100	7.00	7.16	7.2900

Delaware/Maryland Coastal Bays - Physical Characteristics
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

-- Variable=Silt-Clay Content (%) --

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	99.8721	99.8328	91.3725	95.6830	90.1008	99.7440	99.8721
PCT_75TH	80.9582	87.8411	77.7918	85.6225	83.2135	76.1398	62.3571
MEDIAN	60.4268	79.6833	69.1819	74.8226	76.9718	32.2217	28.0301
PCT_25TH	15.8627	68.8231	35.2854	49.7983	37.8057	5.2270	6.5670
MINIMUM	1.3809	3.5063	4.7382	2.5098	2.4294	2.0330	1.3809

Delaware/Maryland Coastal Bays - Water Quality Parameters
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Ammonium NH4 (uMol)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	62.400	62.40	17.30	22.70	30.10	20.30	26.40
PCT_75TH	5.925	12.40	4.42	3.94	4.17	6.42	5.77
MEDIAN	2.855	5.65	2.19	2.33	2.43	3.18	1.91
PCT_25TH	0.950	2.25	1.03	0.93	0.72	1.38	0.77
MINIMUM	0.000	0.10	0.22	0.00	0.15	0.00	0.00

Variable=Benthic chl_a (ug/g), HPLC method

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	122.10	87.3	44.90	93.7	72.8	122.1	32.00
PCT_75TH	15.05	13.8	10.80	5.1	51.8	19.8	6.50
MEDIAN	7.65	8.1	5.35	1.4	27.9	12.4	3.35
PCT_25TH	3.05	5.3	2.70	1.0	16.3	5.8	1.20
MINIMUM	0.10	2.1	0.50	0.1	5.7	2.9	0.40

Variable=Benthic chl_a (ug/g),Fluorometric method

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	115.70	24.7	52.80	35.70	68.80	115.70	32.2
PCT_75TH	17.10	14.2	10.90	4.95	45.55	26.70	6.9
MEDIAN	7.45	8.5	6.05	1.95	26.45	12.85	3.8
PCT_25TH	3.45	6.5	3.50	1.45	15.55	6.90	1.7
MINIMUM	0.50	3.3	1.00	1.10	6.20	3.00	0.5

Variable=Bottom Dissolved Oxygen (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	17.900	9.60	8.32	17.90	8.61	10.500	8.76
PCT_75TH	6.645	7.20	6.19	6.67	6.10	6.800	6.66
MEDIAN	6.065	6.02	5.82	6.17	5.00	6.115	6.10
PCT_25TH	5.400	4.58	5.38	5.71	3.30	5.550	5.77
MINIMUM	0.200	3.86	3.00	4.31	0.20	3.000	4.19

Delaware/Maryland Coastal Bays - Water Quality Parameters
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Chlorophyll a (ug/l)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	371.25	95.55	32.10	371.25	116.01	69.11	23.800
PCT_75TH	22.75	41.54	23.27	22.21	33.02	18.22	11.960
MEDIAN	14.48	31.96	18.00	13.55	21.30	11.50	5.515
PCT_25TH	7.19	18.68	15.47	9.98	15.34	7.15	3.000
MINIMUM	0.13	10.90	13.17	2.41	2.22	1.69	0.130

Variable=NO2+NO3 (uMol)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	85.900	85.90	0.42	52.20	13.20	7.940	2.19
PCT_75TH	0.485	7.83	0.16	0.20	0.28	0.410	0.52
MEDIAN	0.170	2.41	0.04	0.14	0.16	0.225	0.18
PCT_25TH	0.085	0.19	0.01	0.08	0.06	0.120	0.10
MINIMUM	0.000	0.03	0.00	0.00	0.00	0.000	0.00

Variable=Orthophosphate PO4 (uMol)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	12.70	2.17	1.24	12.70	1.57	1.85	0.940
PCT_75TH	0.55	0.61	0.34	0.47	0.35	0.68	0.460
MEDIAN	0.29	0.20	0.21	0.33	0.24	0.51	0.245
PCT_25TH	0.15	0.15	0.13	0.19	0.15	0.26	0.150
MINIMUM	0.04	0.11	0.10	0.08	0.08	0.04	0.070

Variable=Phaeophytin (ug/l)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	44.87	44.87	23.27	12.93	16.44	17.53	6.540
PCT_75TH	9.11	20.26	10.22	6.96	10.70	7.26	3.870
MEDIAN	5.60	14.25	7.79	5.60	8.18	5.35	2.555
PCT_25TH	3.22	9.11	6.26	3.40	5.55	4.03	1.970
MINIMUM	-1.20	4.65	3.17	-1.20	1.14	0.85	0.520

Delaware/Maryland Coastal Bays - Water Quality Parameters
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Secchi depth (m)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	2.67	0.98	0.82	1.07	1.95	2.67	1.89
PCT_75TH	0.81	0.79	0.62	0.78	0.75	0.91	1.10
MEDIAN	0.66	0.59	0.52	0.60	0.67	0.66	0.80
PCT_25TH	0.51	0.50	0.50	0.48	0.54	0.56	0.65
MINIMUM	0.21	0.30	0.30	0.21	0.40	0.39	0.40

Variable=Total Dissolved Nitrogen (uMol)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	102.00	89.9	48.6	102.0	70.2	57.40	60.1
PCT_75TH	36.70	46.9	37.5	37.9	37.7	31.10	33.8
MEDIAN	29.90	35.9	30.6	34.6	33.4	22.55	27.8
PCT_25TH	23.90	32.2	26.8	31.3	25.2	16.30	23.6
MINIMUM	8.08	18.2	22.2	20.9	16.5	8.08	9.0

Variable=Total Dissolved Phosphorus (uMol)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	11.000	1.88	1.65	11.00	1.75	2.53	1.56
PCT_75TH	1.140	1.22	1.21	1.03	1.14	1.23	0.94
MEDIAN	0.905	0.99	1.05	0.82	0.97	0.90	0.76
PCT_25TH	0.740	0.90	0.87	0.76	0.75	0.74	0.67
MINIMUM	0.470	0.58	0.67	0.53	0.47	0.52	0.56

Variable=Total Particulate Carbon (ug/l)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	29876.7	6876.4	10565.0	29876.7	7800.2	9001.00	4922.60
PCT_75TH	4454.4	4808.4	5893.8	4692.8	5015.4	3838.95	2432.20
MEDIAN	2674.4	3423.7	4301.8	2983.6	4394.0	2168.70	1266.35
PCT_25TH	1541.6	2489.2	3557.4	1947.2	2684.7	1368.40	866.80
MINIMUM	421.6	1164.7	2556.6	728.9	421.6	424.90	444.40

Delaware/Maryland Coastal Bays - Water Quality Parameters
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Total Particulate Nitrogen (ug/l)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	4526.00	1087.4	1472.8	4526.00	1163.20	1418.25	759.400
PCT_75TH	711.80	833.0	939.4	630.27	874.20	579.45	407.400
MEDIAN	448.00	578.6	687.6	449.40	667.48	339.23	227.260
PCT_25TH	238.17	461.2	564.2	305.50	456.08	227.94	139.200
MINIMUM	72.17	235.6	416.0	105.87	84.35	72.17	76.767

Variable=Total Particulate Phosphorus (mg/l)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	0.6813	0.1651	0.2064	0.6813	0.1840	0.2154	0.08560
PCT_75TH	0.0862	0.1097	0.1110	0.0884	0.0984	0.0755	0.05520
MEDIAN	0.0656	0.0820	0.0967	0.0553	0.0816	0.0595	0.02945
PCT_25TH	0.0382	0.0647	0.0789	0.0391	0.0632	0.0382	0.01850
MINIMUM	0.0097	0.0423	0.0633	0.0158	0.0141	0.0097	0.01100

Variable=Total Suspended Solids (mg/l)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	136.40	136.4	127.7	132.6	88.3	108.70	93.4
PCT_75TH	38.85	31.5	57.2	51.4	23.8	43.00	38.9
MEDIAN	20.95	24.7	21.9	20.9	15.6	24.45	16.8
PCT_25TH	13.30	15.4	17.6	14.9	11.5	18.20	10.4
MINIMUM	2.80	7.2	9.8	10.0	3.2	2.80	4.6

Variable=Turbidity (NTU)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	48.5	35.8	43.8	48.5	20.00	33.00	40.3
PCT_75TH	16.4	17.4	17.2	22.2	11.85	14.70	12.7
MEDIAN	11.5	12.8	14.3	15.0	10.15	10.65	9.1
PCT_25TH	8.3	11.3	11.7	12.0	7.50	8.00	5.0
MINIMUM	1.2	6.7	8.2	5.4	2.70	2.60	1.2

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=1,6,7-Trimethylnaphthalene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	23.80	23.8	0	17.8	14.30	4.05
PCT_75TH	4.82	10.4	0	11.0	6.51	0.00
MEDIAN	0.00	0.0	0	0.0	0.00	0.00
PCT_25TH	0.00	0.0	0	0.0	0.00	0.00
MINIMUM	0.00	0.0	0	0.0	0.00	0.00

Variable=1-Methylnaphthalene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	45.7	45.70	0	15.4	10.2	11.2
PCT_75TH	10.5	14.20	0	10.9	8.7	10.5
MEDIAN	0.0	13.60	0	0.0	0.0	0.0
PCT_25TH	0.0	2.81	0	0.0	0.0	0.0
MINIMUM	0.0	0.00	0	0.0	0.0	0.0

Variable=1-Methylphenanthrene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	102	2.81	0	102	5.66	4.2
PCT_75TH	0	0.00	0	0	0.00	0.0
MEDIAN	0	0.00	0	0	0.00	0.0
PCT_25TH	0	0.00	0	0	0.00	0.0
MINIMUM	0	0.00	0	0	0.00	0.0

Variable=2,6-Dimethylnaphthalene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	64.6	64.60	0	33.2	17.6	14.3
PCT_75TH	18.0	26.80	0	24.8	12.9	13.6
MEDIAN	12.2	26.10	0	18.0	0.0	4.2
PCT_25TH	0.0	12.20	0	12.5	0.0	0.0
MINIMUM	0.0	4.21	0	0.0	0.0	0.0

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=2-Methylnaphthalene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	59.8	59.80	0	37.60	23.9	28.0
PCT_75TH	23.9	33.30	0	32.40	22.4	17.8
MEDIAN	14.4	32.60	0	19.60	6.3	16.9
PCT_25TH	0.0	11.40	0	6.38	0.0	0.0
MINIMUM	0.0	9.83	0	0.00	0.0	0.0

Variable=Acenaphthene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	13.20	10.3	0	13.2	12.50	5.25
PCT_75TH	4.99	0.0	0	12.4	3.64	3.14
MEDIAN	0.00	0.0	0	0.0	0.00	0.00
PCT_25TH	0.00	0.0	0	0.0	0.00	0.00
MINIMUM	0.00	0.0	0	0.0	0.00	0.00

Variable=Acenaphthylene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	11.9	0	0	11.9	1.62	1.05
PCT_75TH	0.0	0	0	0.0	0.00	1.01
MEDIAN	0.0	0	0	0.0	0.00	0.00
PCT_25TH	0.0	0	0	0.0	0.00	0.00
MINIMUM	0.0	0	0	0.0	0.00	0.00

Variable=Acid Volatile Sulfide (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	4100.0	1210.0	183	4100	2560.0	127.000
PCT_75TH	1210.0	785.5	183	1920	1140.0	92.700
MEDIAN	201.0	256.5	156	1540	524.5	40.665
PCT_25TH	84.7	111.0	129	647	154.0	0.000
MINIMUM	0.0	70.0	129	68	78.1	0.000

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Aldrin (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	4.81	1.170	0	0.555	4.81	0.306
PCT_75TH	0.00	0.247	0	0.000	0.00	0.000
MEDIAN	0.00	0.000	0	0.000	0.00	0.000
PCT_25TH	0.00	0.000	0	0.000	0.00	0.000
MINIMUM	0.00	0.000	0	0.000	0.00	0.000

Variable=Alpha-chlordane (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	5.41	1.490	0	2.990	5.41	0
PCT_75TH	1.15	0.833	0	2.520	0.25	0
MEDIAN	0.00	0.494	0	1.370	0.00	0
PCT_25TH	0.00	0.370	0	0.851	0.00	0
MINIMUM	0.00	0.000	0	0.000	0.00	0

Variable=Aluminum (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	85600	60800	40400	85600	66700	58500
PCT_75TH	58400	59300	40400	56900	60200	56000
MEDIAN	49000	57600	33850	49000	48400	49900
PCT_25TH	27300	30000	27300	24600	24300	36600
MINIMUM	12800	25500	27300	12800	13100	13000

Variable=Anthracene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	463.0	35.80	0	463.0	13.300	11.5
PCT_75TH	24.9	23.90	0	50.6	11.600	9.1
MEDIAN	9.1	7.02	0	27.5	1.465	0.0
PCT_25TH	0.0	0.00	0	22.6	0.000	0.0
MINIMUM	0.0	0.00	0	0.0	0.000	0.0

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Antimony (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	0.786	0.5330	0.441	0.786	0.342	0.5230
PCT_75TH	0.404	0.4260	0.441	0.520	0.204	0.4040
MEDIAN	0.283	0.3130	0.375	0.371	0.000	0.2425
PCT_25TH	0.000	0.1535	0.309	0.000	0.000	0.1550
MINIMUM	0.000	0.0000	0.309	0.000	0.000	0.0000

Variable=Arsenic (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	16.80	13.600	3.71	16.80	9.25	12.100
PCT_75TH	11.90	13.000	3.71	13.50	7.95	10.200
MEDIAN	8.60	12.150	3.55	11.00	4.98	8.395
PCT_25TH	3.71	7.565	3.39	4.68	1.62	3.970
MINIMUM	0.00	3.230	3.39	0.00	1.01	2.400

Variable=Benzo[a]anthracene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	1860.0	78.7	19.10	1860.0	93.90	14.2
PCT_75TH	78.7	51.2	19.10	268.0	27.20	10.5
MEDIAN	19.1	41.7	17.75	111.0	6.45	0.0
PCT_25TH	0.0	14.0	16.40	48.9	0.00	0.0
MINIMUM	0.0	11.7	16.40	31.6	0.00	0.0

Variable=Benzo[a]pyrene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	336.0	35.40	0	336.0	44.200	17.6
PCT_75TH	39.0	33.10	0	89.3	24.800	17.6
MEDIAN	17.6	2.81	0	53.8	3.595	0.0
PCT_25TH	0.0	0.00	0	35.8	0.000	0.0
MINIMUM	0.0	0.00	0	20.4	0.000	0.0

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Benzo[b,k]fluoranthene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	864.00	103.00	17.50	864	146.00	50.6
PCT_75TH	90.80	81.90	17.50	291	68.00	48.5
MEDIAN	50.60	61.80	16.75	136	29.85	0.0
PCT_25TH	7.02	7.02	16.00	87	0.00	0.0
MINIMUM	0.00	0.00	16.00	71	0.00	0.0

Variable=Benzo[e]pyrene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	299.0	38.3	0	299.0	55.600	18.2
PCT_75TH	38.3	33.4	0	101.0	23.500	15.2
MEDIAN	18.2	24.0	0	51.5	3.395	0.0
PCT_25TH	0.0	11.2	0	32.7	0.000	0.0
MINIMUM	0.0	0.0	0	27.1	0.000	0.0

Variable=Benzo[g,h,i]perylene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	220.0	50.1	13.20	220.0	55.4	21.2
PCT_75TH	39.0	48.6	13.20	63.7	26.1	19.6
MEDIAN	16.7	21.5	12.65	35.0	0.0	0.0
PCT_25TH	0.0	0.0	12.10	0.0	0.0	0.0
MINIMUM	0.0	0.0	12.10	0.0	0.0	0.0

Variable=Biphenyl (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	104.00	104.00	0	12.4	6.76	4.60
PCT_75TH	3.15	13.60	0	0.0	3.59	3.15
MEDIAN	0.00	9.90	0	0.0	0.00	0.00
PCT_25TH	0.00	2.81	0	0.0	0.00	0.00
MINIMUM	0.00	0.00	0	0.0	0.00	0.00

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Cadmium (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	0.760	0.274	0.2400	0.4020	0.7600	0.228
PCT_75TH	0.284	0.274	0.2400	0.2960	0.6230	0.185
MEDIAN	0.186	0.260	0.1725	0.1860	0.2725	0.073
PCT_25TH	0.092	0.203	0.1050	0.1550	0.0920	0.000
MINIMUM	0.000	0.119	0.1050	0.0698	0.0000	0.000

Variable=Chromium (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	76.80	68.8	21.7	75.70	76.80	61.00
PCT_75TH	60.90	67.5	21.7	64.00	60.90	60.90
MEDIAN	53.80	63.6	20.0	54.10	33.55	54.80
PCT_25TH	21.20	23.7	18.3	25.60	11.30	19.50
MINIMUM	2.86	15.8	18.3	4.75	2.86	4.43

Variable=Chrysene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	2130.00	101.00	25.4	2130.0	71.40	19.3
PCT_75TH	101.00	64.80	25.4	344.0	50.70	17.2
MEDIAN	25.40	64.00	22.6	242.0	10.65	0.0
PCT_25TH	1.05	13.20	19.8	74.5	0.00	0.0
MINIMUM	0.00	8.42	19.8	42.3	0.00	0.0

Variable=Copper (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	88.10	28.80	5.820	88.10	22.100	15.70
PCT_75TH	28.80	23.30	5.820	68.00	19.600	14.50
MEDIAN	13.70	22.40	4.725	38.00	8.805	10.80
PCT_25TH	5.82	7.97	3.630	13.70	2.460	2.87
MINIMUM	0.00	4.37	3.630	4.47	0.800	0.00

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Dibenz[a,h]anthracen (ppb)e

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	66.00	10.7	0	66.0	5.18	3.82
PCT_75TH	3.38	0.0	0	21.3	0.00	0.00
MEDIAN	0.00	0.0	0	0.0	0.00	0.00
PCT_25TH	0.00	0.0	0	0.0	0.00	0.00
MINIMUM	0.00	0.0	0	0.0	0.00	0.00

Variable=Dibutyltin (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	20.8	.	.	0	14.40	20.8
PCT_75TH	0.0	.	.	0	7.71	16.7
MEDIAN	0.0	.	.	0	0.00	0.0
PCT_25TH	0.0	.	.	0	0.00	0.0
MINIMUM	0.0	.	.	0	0.00	0.0

Variable=Dieldrin (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	9.040	3.770	0.628	9.040	1.14	0
PCT_75TH	1.870	2.900	0.628	4.170	0.00	0
MEDIAN	0.302	2.290	0.465	1.870	0.00	0
PCT_25TH	0.000	0.395	0.302	0.944	0.00	0
MINIMUM	0.000	0.000	0.302	0.000	0.00	0

Variable=Endosulfan I (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	2.2700	1.0300	0.356	1.280	2.27	0.9170
PCT_75TH	0.9555	0.9665	0.356	0.999	2.27	0.5930
MEDIAN	0.3125	0.4515	0.178	0.537	0.00	0.1345
PCT_25TH	0.0000	0.0000	0.000	0.000	0.00	0.0000
MINIMUM	0.0000	0.0000	0.000	0.000	0.00	0.0000

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Endosulfan II (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	1.440	0.352	0	1.44	1.010	0.326
PCT_75TH	0.329	0.342	0	0.29	1.010	0.163
MEDIAN	0.000	0.166	0	0.00	0.517	0.000
PCT_25TH	0.000	0.000	0	0.00	0.000	0.000
MINIMUM	0.000	0.000	0	0.00	0.000	0.000

Variable=Endosulfan Sulfate (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	9.700	9.700	7.90	9.37	0	0
PCT_75TH	8.145	9.565	7.90	8.29	0	0
MEDIAN	5.430	9.150	7.23	6.64	0	0
PCT_25TH	0.000	6.515	6.56	4.92	0	0
MINIMUM	0.000	4.160	6.56	0.00	0	0

Variable=Endrin (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	1.650	1.6500	0	1.4200	0	0
PCT_75TH	0.835	1.5250	0	0.6900	0	0
MEDIAN	0.371	1.1735	0	0.5545	0	0
PCT_25TH	0.000	0.6590	0	0.3210	0	0
MINIMUM	0.000	0.3710	0	0.0000	0	0

Variable=Endrin Aldehyde (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	1.43	1.430	0	0.368	0	0
PCT_75TH	0.00	0.715	0	0.000	0	0
MEDIAN	0.00	0.000	0	0.000	0	0
PCT_25TH	0.00	0.000	0	0.000	0	0
MINIMUM	0.00	0.000	0	0.000	0	0

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Endrin Ketone (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	2.3900	2.1300	0	2.390	0	0.5690
PCT_75TH	0.6575	1.4745	0	0.834	0	0.2845
MEDIAN	0.3645	0.7320	0	0.551	0	0.0000
PCT_25TH	0.0000	0.5495	0	0.000	0	0.0000
MINIMUM	0.0000	0.4540	0	0.000	0	0.0000

Variable=Fluoranthene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	1670.0	178.0	44.9	1670.0	235.0	51.3
PCT_75TH	204.0	106.0	44.9	542.0	70.2	32.0
MEDIAN	51.3	86.8	33.4	259.0	38.2	25.2
PCT_25TH	21.9	25.3	21.9	164.0	0.0	0.0
MINIMUM	0.0	17.5	21.9	86.5	0.0	0.0

Variable=Fluorene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	109.00	46.8	0	109.00	28.500	12.60
PCT_75TH	17.40	17.7	0	25.20	12.100	7.92
MEDIAN	7.29	15.6	0	16.50	1.795	0.00
PCT_25TH	0.00	0.0	0	7.29	0.000	0.00
MINIMUM	0.00	0.0	0	0.00	0.000	0.00

Variable=Heptachlor (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	2.400	0.608	0	0.486	2.400	0.493
PCT_75TH	0.259	0.334	0	0.275	0.259	0.000
MEDIAN	0.000	0.000	0	0.000	0.000	0.000
PCT_25TH	0.000	0.000	0	0.000	0.000	0.000
MINIMUM	0.000	0.000	0	0.000	0.000	0.000

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Heptachlor Epoxide (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	0.534	0.339	0	0	0.534	0.265
PCT_75TH	0.000	0.000	0	0	0.000	0.000
MEDIAN	0.000	0.000	0	0	0.000	0.000
PCT_25TH	0.000	0.000	0	0	0.000	0.000
MINIMUM	0.000	0.000	0	0	0.000	0.000

Variable=Hexachlorobenzene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	0.917	0.917	0	0.897	0.607	0.14
PCT_75TH	0.372	0.915	0	0.794	0.060	0.00
MEDIAN	0.000	0.000	0	0.372	0.000	0.00
PCT_25TH	0.000	0.000	0	0.000	0.000	0.00
MINIMUM	0.000	0.000	0	0.000	0.000	0.00

Variable=Inden[1,2,3-cd]pyrene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	279.0	49.0	13.0	279.0	66.7	24.8
PCT_75TH	39.8	47.8	13.0	78.8	31.4	22.2
MEDIAN	13.0	39.6	12.1	39.8	3.0	0.0
PCT_25TH	0.0	0.0	11.2	0.0	0.0	0.0
MINIMUM	0.0	0.0	11.2	0.0	0.0	0.0

Variable=Iron (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	38800	38800	12000	32800	33500	29500
PCT_75TH	29000	36000	12000	27100	30100	28400
MEDIAN	23000	32800	10240	23900	16900	24400
PCT_25TH	10300	19800	8480	10300	7890	11000
MINIMUM	4190	8540	8480	4190	4550	4640

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Lead (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	58.60	45.0	21.80	46.4	58.60	41.80
PCT_75TH	40.50	43.9	21.80	40.6	40.50	36.20
MEDIAN	24.00	41.5	18.65	38.0	19.05	23.70
PCT_25TH	15.80	19.0	15.50	18.6	14.50	12.60
MINIMUM	6.56	15.8	15.50	8.2	8.87	6.56

Variable=Lindane - Gamma-BHC (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	5.320	5.320	0.586	2.300	3.37	0.432
PCT_75TH	0.862	1.470	0.586	1.530	0.00	0.000
MEDIAN	0.000	0.862	0.293	0.809	0.00	0.000
PCT_25TH	0.000	0.558	0.000	0.536	0.00	0.000
MINIMUM	0.000	0.000	0.000	0.000	0.00	0.000

Variable=Manganese (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	372	293	167.0	239	354	372
PCT_75TH	293	289	167.0	235	325	366
MEDIAN	235	275	155.5	202	236	335
PCT_25TH	147	269	144.0	128	180	254
MINIMUM	64	117	144.0	64	144	127

Variable=Mercury (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	0.0965	0.026	.	0	0.09650	0.0761
PCT_75TH	0.0638	0.026	.	0	0.08800	0.0540
MEDIAN	0.0523	0.026	.	0	0.05785	0.0514
PCT_25TH	0.0151	0.026	.	0	0.03900	0.0000
MINIMUM	0.0000	0.026	.	0	0.00000	0.0000

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Mirex (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	1.02	0.357	0	0.44	0.496	1.02
PCT_75TH	0.00	0.000	0	0.00	0.000	0.00
MEDIAN	0.00	0.000	0	0.00	0.000	0.00
PCT_25TH	0.00	0.000	0	0.00	0.000	0.00
MINIMUM	0.00	0.000	0	0.00	0.000	0.00

Variable=Monobutyltin (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	73.3	.	.	0	73.3	0
PCT_75TH	0.0	.	.	0	46.7	0
MEDIAN	0.0	.	.	0	0.0	0
PCT_25TH	0.0	.	.	0	0.0	0
MINIMUM	0.0	.	.	0	0.0	0

Variable=Naphthalene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	131.0	131.0	0	44.4	39.50	28.8
PCT_75TH	20.8	39.2	0	29.3	21.60	21.7
MEDIAN	16.8	33.7	0	19.6	16.05	16.6
PCT_25TH	0.0	31.3	0	0.0	2.04	0.0
MINIMUM	0.0	12.6	0	0.0	0.00	0.0

Variable=Nickel (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	27.70	26.50	7.69	27.00	27.70	24.1
PCT_75TH	23.90	26.00	7.69	23.90	22.90	21.6
MEDIAN	17.40	25.70	7.25	20.70	14.15	17.4
PCT_25TH	6.81	8.95	6.81	8.52	0.00	0.0
MINIMUM	0.00	5.94	6.81	0.00	0.00	0.0

Delaware/Maryland Coastal Bays — Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=PCB Congener 101 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	2.570	2.570	0	1.950	1.060	0.75
PCT_75TH	0.493	0.822	0	0.524	0.467	0.36
MEDIAN	0.000	0.588	0	0.000	0.000	0.00
PCT_25TH	0.000	0.436	0	0.000	0.000	0.00
MINIMUM	0.000	0.000	0	0.000	0.000	0.00

Variable=PCB Congener 105 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	3.720	1.800	0.3350	3.720	0.469	0.233
PCT_75TH	1.060	1.360	0.3350	1.890	0.322	0.000
MEDIAN	0.322	1.090	0.1675	1.060	0.000	0.000
PCT_25TH	0.000	0.344	0.0000	0.805	0.000	0.000
MINIMUM	0.000	0.000	0.0000	0.000	0.000	0.000

Variable=PCB Congener 118 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	1.700	1.230	0	1.700	1.210	0.491
PCT_75TH	0.759	0.596	0	1.040	0.847	0.452
MEDIAN	0.262	0.580	0	0.383	0.329	0.000
PCT_25TH	0.000	0.400	0	0.000	0.000	0.000
MINIMUM	0.000	0.000	0	0.000	0.000	0.000

Variable=PCB Congener 128 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	3.450	0.27	0.1230	3.450	0.209	0
PCT_75TH	0.123	0.00	0.1230	0.449	0.000	0
MEDIAN	0.000	0.00	0.0615	0.362	0.000	0
PCT_25TH	0.000	0.00	0.0000	0.000	0.000	0
MINIMUM	0.000	0.00	0.0000	0.000	0.000	0

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=PCB Congener 138 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	2.100	1.030	0.386	2.060	2.100	0.581
PCT_75TH	0.803	1.030	0.386	1.190	0.568	0.428
MEDIAN	0.000	0.864	0.193	0.504	0.000	0.000
PCT_25TH	0.000	0.000	0.000	0.000	0.000	0.000
MINIMUM	0.000	0.000	0.000	0.000	0.000	0.000

Variable=PCB Congener 153 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	3.250	1.780	0	3.250	1.9300	0.540
PCT_75TH	0.931	1.500	0	1.660	0.8760	0.441
MEDIAN	0.372	0.931	0	0.634	0.4715	0.324
PCT_25TH	0.000	0.240	0	0.326	0.0000	0.000
MINIMUM	0.000	0.000	0	0.000	0.0000	0.000

Variable=PCB Congener 170 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	2.580	1.130	0	2.580	1.29	0.633
PCT_75TH	0.633	0.505	0	0.969	0.00	0.000
MEDIAN	0.000	0.000	0	0.549	0.00	0.000
PCT_25TH	0.000	0.000	0	0.000	0.00	0.000
MINIMUM	0.000	0.000	0	0.000	0.00	0.000

Variable=PCB Congener 18 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	1.770	1.77	0	1.690	0.658	1.090
PCT_75TH	0.528	0.00	0	0.866	0.463	0.365
MEDIAN	0.000	0.00	0	0.399	0.000	0.000
PCT_25TH	0.000	0.00	0	0.000	0.000	0.000
MINIMUM	0.000	0.00	0	0.000	0.000	0.000

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=PCB Congener 180 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	1.790	1.160	0	1.110	1.790	0
PCT_75TH	0.254	0.972	0	0.648	0.243	0
MEDIAN	0.000	0.818	0	0.000	0.000	0
PCT_25TH	0.000	0.000	0	0.000	0.000	0
MINIMUM	0.000	0.000	0	0.000	0.000	0

Variable=PCB Congener 187 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	3.180	1.860	0	3.18	0.7620	0.293
PCT_75TH	0.762	0.902	0	1.50	0.4810	0.252
MEDIAN	0.252	0.327	0	1.08	0.1395	0.000
PCT_25TH	0.000	0.000	0	0.00	0.0000	0.000
MINIMUM	0.000	0.000	0	0.00	0.0000	0.000

Variable=PCB Congener 195 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	1.69	0	1.690	1.210	1.5	0
PCT_75TH	0.30	0	1.690	0.622	0.0	0
MEDIAN	0.00	0	0.845	0.440	0.0	0
PCT_25TH	0.00	0	0.000	0.000	0.0	0
MINIMUM	0.00	0	0.000	0.000	0.0	0

Variable=PCB Congener 206 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	0.62	0.351	0	0.244	0.62	0.208
PCT_75TH	0.00	0.286	0	0.000	0.00	0.000
MEDIAN	0.00	0.247	0	0.000	0.00	0.000
PCT_25TH	0.00	0.060	0	0.000	0.00	0.000
MINIMUM	0.00	0.000	0	0.000	0.00	0.000

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=PCB Congener 209 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	0.583	0.274	0	0	0.583	0.288
PCT_75TH	0.000	0.140	0	0	0.390	0.286
MEDIAN	0.000	0.000	0	0	0.000	0.000
PCT_25TH	0.000	0.000	0	0	0.000	0.000
MINIMUM	0.000	0.000	0	0	0.000	0.000

Variable=PCB Congener 28 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	16.300	0	0	16.30	3.2700	0.677
PCT_75TH	0.677	0	0	8.08	1.5400	0.641
MEDIAN	0.000	0	0	0.00	0.1575	0.000
PCT_25TH	0.000	0	0	0.00	0.0000	0.000
MINIMUM	0.000	0	0	0.00	0.0000	0.000

Variable=PCB Congener 44 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	3.280	0	0.324	3.280	1.570	0
PCT_75TH	0.324	0	0.324	0.451	0.417	0
MEDIAN	0.000	0	0.162	0.000	0.106	0
PCT_25TH	0.000	0	0.000	0.000	0.000	0
MINIMUM	0.000	0	0.000	0.000	0.000	0

Variable=PCB Congener 52 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	15.400	5.110	0.58	15.400	1.450	0.231
PCT_75TH	1.450	0.481	0.58	4.170	0.442	0.000
MEDIAN	0.255	0.255	0.29	2.660	0.000	0.000
PCT_25TH	0.000	0.000	0.00	0.805	0.000	0.000
MINIMUM	0.000	0.000	0.00	.000	0.000	0.000

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=PCB Congener 66 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	3.340	2.880	0	3.340	1.0700	0.558
PCT_75TH	0.713	0.427	0	1.490	0.4490	0.522
MEDIAN	0.000	0.321	0	0.713	0.1525	0.000
PCT_25TH	0.000	0.000	0	0.000	0.0000	0.000
MINIMUM	0.000	0.000	0	0.000	0.0000	0.000

Variable=PCB Congener 8 (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	2.06	0	0	2.06	1.150	0.969
PCT_75TH	0.00	0	0	0.00	0.607	0.463
MEDIAN	0.00	0	0	0.00	0.000	0.000
PCT_25TH	0.00	0	0	0.00	0.000	0.000
MINIMUM	0.00	0	0	0.00	0.000	0.000

Variable=Perylene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	127.0	127.0	17.4	127.0	117.00	63.9
PCT_75TH	66.1	119.0	17.4	78.4	54.50	53.1
MEDIAN	35.1	22.5	8.7	55.9	13.35	0.0
PCT_25TH	0.0	19.6	0.0	35.1	0.00	0.0
MINIMUM	0.0	0.0	0.0	0.0	0.00	0.0

Variable=Phenanthrene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	329.0	71.50	18.5	329.0	72.0	70.3
PCT_75TH	70.3	66.50	18.5	118.0	45.9	31.6
MEDIAN	31.6	38.40	17.8	73.3	27.5	20.8
PCT_25TH	17.1	13.90	17.1	32.0	13.7	0.0
MINIMUM	0.0	2.81	17.1	21.0	0.0	0.0

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Pyrene (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	1210.0	128.0	31.50	1210.0	155.00	36.7
PCT_75TH	155.0	79.4	31.50	338.0	61.10	24.9
MEDIAN	38.1	58.6	23.15	201.0	24.05	11.5
PCT_25TH	12.9	18.2	14.80	114.0	0.00	0.0
MINIMUM	0.0	12.9	14.80	58.1	0.00	0.0

Variable=SEM - Cadmium (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	1.1800	0.5060	0.24	0.713	1.18	0
PCT_75TH	0.4845	0.4810	0.24	0.549	1.18	0
MEDIAN	0.1200	0.4395	0.12	0.393	1.13	0
PCT_25TH	0.0000	0.2115	0.00	0.000	0.00	0
MINIMUM	0.0000	0.0000	0.00	0.000	0.00	0

Variable=SEM - Copper (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	16.700	7.150	1.2	16.70	0	3.6900
PCT_75TH	3.645	5.600	1.2	4.83	0	3.3150
MEDIAN	1.905	3.825	0.6	2.98	0	1.5695
PCT_25TH	0.000	2.004	0.0	0.00	0	0.0995
MINIMUM	0.000	0.408	0.0	0.00	0	0.0000

Variable=SEM - Lead (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	23.700	10.500	4.170	13.30	23.7	13.4000
PCT_75TH	10.600	9.770	4.170	10.70	23.7	11.7000
MEDIAN	9.005	9.005	2.085	9.35	18.7	5.4705
PCT_25TH	2.700	5.505	0.000	7.67	0.0	0.4705
MINIMUM	0.000	2.040	0.000	0.00	0.0	0.0000

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=SEM - Nickel (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	18.200	3.750	2.24	18.20	7.66	2.350
PCT_75TH	4.270	3.395	2.24	6.42	7.66	1.890
MEDIAN	2.785	2.925	2.08	3.16	4.62	0.715
PCT_25TH	1.760	2.205	1.92	2.30	0.00	0.000
MINIMUM	0.000	1.600	1.92	0.00	0.00	0.000

Variable=SEM - Zinc (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	114.000	48.00	14.300	52.80	114.00	31.700
PCT_75TH	39.150	41.10	14.300	40.30	114.00	28.850
MEDIAN	29.700	32.75	10.415	33.20	66.30	16.170
PCT_25TH	8.195	19.32	6.530	26.40	8.57	4.145
MINIMUM	1.950	7.34	6.530	4.68	8.57	1.950

Variable=Selinium (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	1.1500	0.3770	0	0.930	1.150	0.684
PCT_75TH	0.6570	0.3475	0	0.633	0.983	0.657
MEDIAN	0.3525	0.3095	0	0.482	0.682	0.164
PCT_25TH	0.0000	0.1505	0	0.000	0.180	0.000
MINIMUM	0.0000	0.0000	0	0.000	0.000	0.000

Variable=Silver (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	0.2710	0.2060	0.0545	0.2710	0.0932	0.1120
PCT_75TH	0.1220	0.1980	0.0545	0.1750	0.0752	0.0863
MEDIAN	0.0745	0.1370	0.0445	0.1220	0.0404	0.0365
PCT_25TH	0.0316	0.0655	0.0345	0.0814	0.0000	0.0203
MINIMUM	0.0000	0.0000	0.0345	0.0000	0.0000	0.0000

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Tin (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	3.58	2.260	1.1100	2.96	3.580	2.640
PCT_75TH	2.57	2.110	1.1100	2.57	2.820	2.630
MEDIAN	1.91	1.605	0.9775	2.38	1.900	2.020
PCT_25TH	1.11	1.018	0.8450	1.21	0.728	1.120
MINIMUM	0.00	0.786	0.8450	0.00	0.535	0.693

Variable=Total 2-Ring PAHs (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	439.20	439.20	0	136.10	90.880	82.30
PCT_75TH	85.10	123.40	0	118.80	74.500	67.22
MEDIAN	53.90	114.00	0	55.30	38.645	48.70
PCT_25TH	2.04	70.90	0	27.18	2.040	0.00
MINIMUM	0.00	32.26	0	0.00	0.000	0.00

Variable=Total 3-Ring PAHs (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	1003.00	125.00	18.5	1003.00	113.200	89.20
PCT_75TH	113.20	113.30	18.5	231.60	71.300	47.22
MEDIAN	48.42	77.90	17.8	114.70	31.345	28.80
PCT_25TH	17.10	13.90	17.1	55.79	13.700	0.00
MINIMUM	0.00	12.64	17.1	30.90	0.000	0.00

Variable=Total 4-Ring PAHs (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	4740.0	384.7	95.5	4740.0	483.9	98.5
PCT_75TH	483.9	236.6	95.5	1053.0	158.5	71.1
MEDIAN	100.0	187.1	74.3	554.6	68.7	36.7
PCT_25TH	42.0	57.5	53.1	310.4	0.0	0.0
MINIMUM	0.0	42.1	53.1	176.2	0.0	0.0

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Total 5-Ring PAHs (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	4101.00	453.70	66.20	4101.00	500.900	192.30
PCT_75TH	389.90	389.90	66.20	996.70	286.480	179.72
MEDIAN	190.20	190.20	60.15	577.57	74.395	1.05
PCT_25TH	34.19	51.95	54.10	301.00	0.000	0.00
MINIMUM	0.00	32.80	54.10	238.80	0.000	0.00

Variable=Total 6-Ring PAHs (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	220.0	50.1	13.20	220.0	55.4	21.2
PCT_75TH	39.0	48.6	13.20	63.7	26.1	19.6
MEDIAN	16.7	21.5	12.65	35.0	0.0	0.0
PCT_25TH	0.0	0.0	12.10	0.0	0.0	0.0
MINIMUM	0.0	0.0	12.10	0.0	0.0	0.0

Variable=Total Butyl tins (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	167.40	.	.	0	167.40	73.6
PCT_75TH	13.45	.	.	0	83.19	37.0
MEDIAN	0.00	.	.	0	26.90	0.0
PCT_25TH	0.00	.	.	0	0.00	0.0
MINIMUM	0.00	.	.	0	0.00	0.0

Variable=Total Chlordane (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	11.120	2.630	0.6900	5.575	11.120	0.493
PCT_75TH	1.888	1.888	0.6900	3.610	0.430	0.000
MEDIAN	0.493	1.102	0.4475	2.431	0.125	0.000
PCT_25TH	0.000	0.852	0.2050	1.580	0.000	0.000
MINIMUM	0.000	0.370	0.2050	0.000	0.000	0.000

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Total DDD (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	11.310	2.680	0	10.740	11.310	0.538
PCT_75TH	2.890	1.994	0	4.550	3.017	0.480
MEDIAN	0.576	1.812	0	2.890	0.257	0.190
PCT_25TH	0.000	0.482	0	1.261	0.000	0.000
MINIMUM	0.000	0.000	0	0.576	0.000	0.000

Variable=Total DDE (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	17.89	1.630	0	2.640	17.8900	1.370
PCT_75TH	1.51	1.387	0	1.510	3.4500	1.140
MEDIAN	1.04	1.190	0	1.140	1.6755	0.547
PCT_25TH	0.00	1.040	0	0.784	0.0000	0.000
MINIMUM	0.00	0.000	0	0.000	0.0000	0.000

Variable=Total DDT (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	23.670	5.011	0	14.970	23.6700	2.060
PCT_75TH	5.868	4.844	0	7.730	8.6570	1.665
MEDIAN	2.379	3.199	0	5.868	2.5025	1.085
PCT_25TH	0.576	2.769	0	2.379	0.0000	0.000
MINIMUM	0.000	1.040	0	0.576	0.0000	0.000

Variable=Total DDT parent (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	3.462	2.287	0	3.462	2.190	0.73
PCT_75TH	1.140	1.660	0	1.590	0.942	0.00
MEDIAN	0.000	0.701	0	0.572	0.000	0.00
PCT_25TH	0.000	0.000	0	0.321	0.000	0.00
MINIMUM	0.000	0.000	0	0.000	0.000	0.00

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Total High Molecular Weight PAHs (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	9061.0	887.00	161.7	9061.00	1040.20	310.40
PCT_75TH	887.0	676.60	161.7	2014.00	412.58	267.52
MEDIAN	310.4	398.80	147.1	1223.57	182.48	37.75
PCT_25TH	74.9	109.45	132.5	582.00	0.00	0.00
MINIMUM	0.0	74.90	132.5	451.20	0.00	0.00

Variable=Total Low Molecular Weight PAHs (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	1135.6	552.5	18.5	1135.6	181.29	147.95
PCT_75TH	187.5	248.4	18.5	334.2	162.18	114.44
MEDIAN	111.1	191.9	17.8	187.5	69.99	91.80
PCT_25TH	30.9	84.8	17.1	108.5	13.70	0.00
MINIMUM	0.0	44.9	17.1	30.9	2.04	0.00

Variable=Total OPDDT (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	8.600	4.070	0	8.600	5.0400	0.377
PCT_75TH	2.890	3.741	0	4.710	0.4550	0.000
MEDIAN	0.437	2.260	0	2.543	0.1135	0.000
PCT_25TH	0.000	0.767	0	1.742	0.0000	0.000
MINIMUM	0.000	0.000	0	0.000	0.0000	0.000

Variable=Total Organic Carbon (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	61400	24700	13700	40000	61400	18400
PCT_75TH	22100	21300	13700	27400	22100	18100
MEDIAN	17000	20900	11640	21900	16600	14000
PCT_25TH	7560	11800	9580	14900	6710	4700
MINIMUM	1200	4950	9580	3590	1200	1490

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Total PAHs (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	10196.60	1135.40	180.2	10196.60	1204.00	402.20
PCT_75TH	1075.10	951.30	180.2	2349.00	574.76	381.96
MEDIAN	402.20	868.50	164.9	1306.54	236.22	185.70
PCT_25TH	154.35	159.70	149.6	815.20	69.20	0.00
MINIMUM	0.00	154.35	149.6	600.80	2.04	0.00

Variable=Total PCBs (Sum) (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	47.257	15.253	3.114	47.257	11.350	5.001
PCT_75TH	13.576	13.576	3.114	21.173	9.136	3.967
MEDIAN	5.001	9.033	1.719	14.380	5.634	1.414
PCT_25TH	0.840	1.035	0.324	9.253	0.000	0.000
MINIMUM	0.000	0.840	0.324	0.726	0.000	0.000

Variable=Total PPDDT (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	20.480	2.002	0	6.370	20.480	2.060
PCT_75TH	2.820	1.270	0	3.020	8.220	1.665
MEDIAN	1.085	1.040	0	1.864	2.363	1.085
PCT_25TH	0.402	0.939	0	0.637	0.000	0.000
MINIMUM	0.000	0.774	0	0.402	0.000	0.000

Variable=Trans-Nonachlor (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	3.310	1.140	0.6900	2.650	3.31	0
PCT_75TH	0.848	0.852	0.6900	1.390	0.43	0
MEDIAN	0.205	0.721	0.4475	0.848	0.00	0
PCT_25TH	0.000	0.000	0.2050	0.622	0.00	0
MINIMUM	0.000	0.000	0.2050	0.000	0.00	0

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Tributyltin (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	153.000	.	.	0	153.00	56.9
PCT_75TH	4.945	.	.	0	15.00	16.2
MEDIAN	0.000	.	.	0	9.89	0.0
PCT_25TH	0.000	.	.	0	0.00	0.0
MINIMUM	0.000	.	.	0	0.00	0.0

Variable=Zinc (ppm)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	148.00	148.0	33.00	145.0	136.00	91.30
PCT_75TH	116.00	136.0	33.00	131.0	106.00	86.90
MEDIAN	86.30	126.0	32.55	114.0	65.65	76.90
PCT_25TH	32.10	52.4	32.10	41.6	21.70	22.00
MINIMUM	6.19	29.9	32.10	12.2	9.66	6.19

Variable=o,p, DDD (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	4.37	1.41	0	4.370	2.510	0
PCT_75TH	1.12	1.22	0	3.200	0.188	0
MEDIAN	0.00	1.12	0	1.030	0.000	0
PCT_25TH	0.00	0.00	0	0.624	0.000	0
MINIMUM	0.00	0.00	0	0.000	0.000	0

Variable=o,p, DDE (ppb)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	2.890	1.63	0	2.640	2.890	0.377
PCT_75TH	1.190	1.19	0	1.510	0.267	0.000
MEDIAN	0.227	1.14	0	1.140	0.000	0.000
PCT_25TH	0.000	0.00	0	0.784	0.000	0.000
MINIMUM	0.000	0.00	0	0.000	0.000	0.000

Delaware/Maryland Coastal Bays - Sediment Chemistry Variables
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

------------------------------ Variable=o,p, DDT (ppb) ------------------------------

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	2.570	1.660	0	2.570	0	0
PCT_75TH	0.331	0.767	0	1.590	0	0
MEDIAN	0.000	0.701	0	0.331	0	0
PCT_25TH	0.000	0.000	0	0.000	0	0
MINIMUM	0.000	0.000	0	0.000	0	0

------------------------------ Variable=p,p, DDD (ppb) ------------------------------

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	8.800	1.270	0	6.370	8.800	0.538
PCT_75TH	1.270	0.774	0	2.820	2.580	0.480
MEDIAN	0.514	0.692	0	0.981	0.215	0.190
PCT_25TH	0.000	0.482	0	0.637	0.000	0.000
MINIMUM	0.000	0.000	0	0.402	0.000	0.000

------------------------------ Variable=p,p, DDE (ppb) ------------------------------

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	15.000	1.040	0	0	15.000	1.370
PCT_75TH	0.683	0.247	0	0	3.450	1.140
MEDIAN	0.000	0.000	0	0	1.562	0.547
PCT_25TH	0.000	0.000	0	0	0.000	0.000
MINIMUM	0.000	0.000	0	0	0.000	0.000

------------------------------ Variable=p,p, DDT (ppb) ------------------------------

Quantiles	Entire Population	Upper Indian River	St. Martin River	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	2.19	1.52	0	1.410	2.190	0.73
PCT_75TH	0.50	0.00	0	0.892	0.942	0.00
MEDIAN	0.00	0.00	0	0.000	0.000	0.00
PCT_25TH	0.00	0.00	0	0.000	0.000	0.00
MINIMUM	0.00	0.00	0	0.000	0.000	0.00

Delaware/Maryland Coastal Bays - Benthic Macroinvertebrate Parameters
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

Variable=Abundance (#/m**2)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	184431.82	184431.82	114068.18	50477.27	22568.18	87022.73	86977.27
PCT_75TH	25500.00	92318.18	59409.09	25136.36	5909.09	23822.73	23590.91
MEDIAN	11500.00	47954.55	13795.45	11909.09	2613.64	12590.91	11340.91
PCT_25TH	5147.73	25500.00	7045.45	6840.91	68.18	6909.09	5954.55
MINIMUM	0.00	500.00	181.82	454.55	0.00	22.73	1500.00

Variable=Biomass (g Dry Wt/m**2)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	174.831	20.2970	53.7045	40.8048	5.36257	174.831	112.566
PCT_75TH	7.274	10.4020	5.1955	12.1592	0.81483	4.226	10.875
MEDIAN	4.060	5.1155	3.7580	6.5559	0.18491	2.493	6.843
PCT_25TH	1.409	4.1808	2.3019	3.8658	0.00489	1.005	3.915
MINIMUM	0.000	0.0783	0.0028	0.0047	0.00000	0.001	1.030

Variable=EMAP Benthic Index 2

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	3.4737	0.7980	3.0169	2.46465	0.85263	2.76206	3.47374
PCT_75TH	1.1320	-0.4086	1.1290	1.07552	-0.42279	0.50863	1.79299
MEDIAN	0.0295	-2.7806	-0.0804	0.41072	-0.68184	-0.03619	1.39092
PCT_25TH	-0.8010	-8.3618	-5.1567	-0.22690	-0.79143	-0.68513	0.60137
MINIMUM	-18.1057	-18.1057	-11.4257	-2.68575	-2.17413	-6.94729	-6.18198

Variable=Mean No. of Infaunal Taxa (Per Sample)

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	52	26	37	35	17	34	52
PCT_75TH	26	22	25	27	10	23	31
MEDIAN	20	20	18	25	3	18	26
PCT_25TH	13	15	15	22	2	13	22
MINIMUM	0	4	1	6	0	1	13

Delaware/Maryland Coastal Bays - Benthic Macroinvertebrate Parameters
Maximum, 75th Percentile, Median, 25th Percentile, and Minimum

---------- Variable=Shannon-Weaver Diversity Index (Log2) ----------

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	4.21070	3.51785	4.13478	3.69036	3.40164	3.75709	4.21070
PCT_75TH	2.92631	2.25428	3.00386	3.03434	1.62581	2.62079	3.41694
MEDIAN	2.34430	1.85164	2.15141	2.41593	0.73060	2.36955	2.99799
PCT_25TH	1.61280	1.57057	1.25627	1.98673	0.04541	1.96065	2.59517
MINIMUM	0.00000	1.11562	0.00000	1.39176	0.00000	0.00000	1.72043

---------- Variable=Silt-Clay Content (%) ----------

Quantiles	Entire Population	Upper Indian River	St. Martin River	Trappe Creek Newport Bay	Artificial Lagoons	Remaining Delaware	Remaining Maryland
MAXIMUM	99.8721	99.8328	91.3725	95.6830	90.1008	99.7440	99.8721
PCT_75TH	80.9582	87.8411	77.7918	85.6225	83.2135	76.1398	62.3571
MEDIAN	60.4268	79.6833	69.1819	74.8226	76.9718	32.2217	28.0301
PCT_25TH	15.8627	68.8231	35.2854	49.7983	37.8057	5.2270	6.5670
MINIMUM	1.3809	3.5063	4.7382	2.5090	2.4294	2.0330	1.3809

APPENDIX E

Benthic Macroinvertebrate Survey
of Turville Creek, Maryland

One of the benefits of the coastal bays project was the identification of baseline conditions which were established using consistent methods across the entire system. This baseline allows for a rigorous, statistically-based evaluation of local issues, based upon comparison to a broader reference condition than can be achieved with the resources typically allocated to evaluation of local issues.

EPA Region III recently availed itself of that benefit to evaluate current benthic macroinvertebrate conditions in Turville Creek, a small tributary to Assawoman Bay. Residential development, including construction of artificial lagoons, has been proposed for that area. On 14 September 1994, 25 benthic invertebrate samples were collected in Turville Creek by W. Muir of EPA Region III using the same sampling design, field methods, and laboratory methods that were used in the coastal bays joint assessment. A summary of those sample results are presented here.

Turville Creek was found to be in poorer condition than the coastal bays as a whole, but in better condition than artificial lagoons that have already been constructed in the coastal bays. The average number of species collected per grab in Turville Creek was almost two-thirds less than in the remaining coastal bays, but was more than twice that in artificial lagoons (Table E-1). Invertebrate abundance was about one-sixth that in the remaining coastal bays, but twice that of artificial lagoons. Biomass was 50 times lower than in the coastal bays, but not significantly different from the artificial lagoons (Table E-1).

Based on EMAP's benthic index (Schimmel et al. 1994), 60% (± 9) of the area in Turville Creek was estimated to have degraded benthic invertebrate communities. This was twice the percent of area containing degraded benthos in the rest of the coastal bays (28% ± 8), but significantly less than that for artificial lagoons (85% ± 16).

Appendix Table E-1. Area-weighted means of benthic macroinvertebrates parameters (90% confidence intervals)			
	Entire Population	**Artificial Lagoons**	**Turville Creek**
Abundance (#/m^2)	18,724 ± 2,551	1,917 ± 1,354	3,111 ± 627
Biomass (g/m^2)	10.57 ± 3.03	0.43 ± 0.33	0.29 ± 0.09
Number of Species (#/sample)	24.25 ± 1.19	3.6 ± 2.6	8.76 ± 1.39
Shannon-Wiener Index	2.73 ± 0.10	0.59 ± 0.49	1.68 ± 0.31
EMAP Index	0.48 ± 0.25	-0.57 ± 0.25	-0.10 ± 0.14

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