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Example Environmental Assessment Report for Estuaries

EMAP

Environmental Monitoring and Assessment Program

EPA/600/4-91/026

EXAMPLE ENVIRONMENTAL ASSESSMENT REPORT FOR ESTUARIES

by

Jeffrey B. Frithsen
Versar, Inc.
Columbia, MD 21045

Mary C. Fabrizio
ManTech Environmental Techology, Inc.
Research Triangle Park, NC 27709

Jeroen Gerritsen
Versar, Inc.
Columbia, MD 21045

A. Frederick Holland
Versar, Inc.
Columbia, MD 21045

Gary Saul
FTN Associates, Ltd.
Austin, TX 78741

Stephen B. Weisberg
Versar, Inc.
Columbia, MD 21045

Project Officers

Linda Kirkland (Contract Nos. 68-DO-0093 and 68-D9-0094)
Office of Modeling, Monitoring Systems and Quality Assurance
Washington, DC 20460

Tom Murray (Contract No. 68-D9-0166)
Office of Toxic Substances
Washington, DC 20460

Seymour Hochheiser (Contract No. 68-02-4444)
Atmospheric Research and Exposure Assessment Laboratory
Research Triangle Park, NC 27711

Marijon Bufalini (Contract No. 68-D-00-106)
Atmospheric Research and Exposure Assessment Laboratory
Research Triangle Park, NC 27711

ENVIRONMENTAL MONITORING AND ASSESSMENT PROGRAM
OFFICE OF RESEARCH AND DEVELOPMENT
ATMOSPHERIC RESEARCH AND EXPOSURE ASSESSMENT LABORATORY
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

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PREFACE

A year ago, EMAP scientists assembled to discuss the value of assessment reports and to produce an example of such a report. The example was intended to demonstrate to EMAP clients the type of information provided by the monitoring program and the interpretation of that information in a policy-relevant context. This example report for an estuarine province is the result of those efforts. The purpose of this preface is to examine some of the issues and questions that emerged during this initiative, especially those which require further consideration by program scientists. Briefly, the three issues are: "environmental" versus "ecological" assessments, use of nominal-subnominal designations for exposure indicators, and the construction of ecological indices. The approaches demonstrated in this report represent a possible strategy; however, other possibilities merit consideration.

Environmental Versus Ecological Assessments

The question of the appropriate name for assessment reports arose because this is the first report concerning "EMAP data" (note that data for the example report were simulated). Two names are under consideration: an environmental assessment or an ecological assessment. Although this may appear to be a simple semantics issue, it is not. The program is the *Environmental* Monitoring and Assessment Program and its name reflects the desire to monitor ecological indicators that can be used to make statements about attributes of the environment valued by society (e.g., biodiversity, sustainability of resources, and aesthetics). These attributes, termed "assessment endpoints" in EMAP, guide the selection of ecological indicators actually measured by the field monitoring program. Because EMAP indicators are selected to reflect attributes valued by society, the reports are "environmental assessments." This designation is consistent with use of this term by other EPA programs, where the term "environmental" often refers to human health issues. Although EMAP assessments are *not directly* concerned with human health, the focus tends to be human use of the environment and societal values associated with ecological resources.

In contrast, some scientists have argued that assessment reports should be termed "ecological assessments" to reflect EMAP's unique approach. EMAP monitoring focuses on measures of the condition of organisms, populations, communities, or ecosystems (response indicators); EMAP assessments present interpretations of these measures and make statements concerning the condition of our nation's resources. Analogous to retrospective risk assessments, this approach has been described as a "top-down" (or inductive) approach because the program will identify biological communities and populations characterized by subnominal (unacceptable) condition and then associate observed condition with various indicators of exposure to physical, chemical, or biological stress (exposure indicators). These associations, in turn, are examined in light of indicators of stress (pollutant discharges, effluents, etc.). Traditionally, monitoring programs have focused on measuring sources of physical or chemical stress such as emissions, discharges, and effluents. The use of the term "ecological assessment" emphasizes the importance of measuring resource *responses* rather than pollutant discharges.

The current document is titled an "environmental assessment" for reasons stated previously and because assessment reports will likely contain information on human use, and indirectly, human health. An example to consider is the assessment of shellfish populations in estuarine environments with respect to condition of the population (biomass, density, etc.). Although the population may be judged in nominal or acceptable condition, these same shellfish beds may be closed to commercial and recreational harvesting due to exposures to improperly treated sewage. Human use of this resource is diminished (due to possible human health issues related to consumption of contaminated shellfish) and it may be desirable to report such cases.

Although the designation of assessment reports as either "ecological" or "environmental" is not, in itself, a major issue, it reflects programmatic considerations of EMAP's scope and the emphasis of future assessments which invite further thought.

Exposure Indicators and Nominal-Subnominal Designations

In this example report, the authors present and summarize information on exposure indicators using nominal-subnominal designations. The EMAP indicator strategy clearly identifies these designations for response indicators only. Nominal conditions exist where ecological resources are acceptable relative to a measurement or assessment endpoint. Those resources that do not meet these conditions are characterized as having subnominal conditions. Thus, these terms are used to describe the condition of the biosphere. The use of nominal-subnominal to differentiate between two levels of an exposure indicator implies knowledge of the biotic effects of a particular exposure indicator. For example, subnominal concentrations of mercury in estuarine sediments implies that these concentrations are associated with deleterious effects on the biotic component (e.g., benthic communities). These relationships are simply not known for many of the indicators of exposure and response measured by EMAP. Dissolved oxygen in the water column is, however, a noteworthy exception. Concentrations below 2 mg O_2/l are generally considered lethal to most marine organisms; similarly, concentration between 2 and 5 mg O_2/l adversely affect some aquatic organisms. The example report uses the term subnominal to refer to dissolved oxygen concentrations below 2 mg/l (marginal [2-5 mg/l], and nominal [above 5 mg/l] categories are also defined). Ignoring this knowledge about the general relationship between dissolved oxygen concentrations and stress in marine organisms would detract from the power of the assessment and place arbitrary limitations on EMAP's ability to share important information about estuarine condition.

In addition, the term subnominal was used to designate fish tissues with contaminant concentrations above a certain level, depending on the contaminant. Here, subnominal is in reference to FDA action limits currently available for some contaminants. The authors reasoned that in the future, many more contaminants would have FDA action limits and that action limits would be available for sediment contaminants as well. The relationship between action limits for fish tissue (or sediment) contaminants and condition of organisms, populations, or communities is not known. When these relationships become well known, they may be treated in a manner similar to the dissolved oxygen-biotic response relationships.

Perhaps the use of nominal-subnominal designations for exposure indicators is unwarranted. Ideally, these terms should be reserved for descriptions of ecological condition (response indicators). However, the analysis of exposure indicators requires the use of categories (above or below a particular concentration) in order to make interpretations concerning the relationship between condition of a resource and environmental exposure. By categorizing exposure indicator data, EMAP can enhance analysis and facilitate interpretation of multidimensional monitoring data. For this reason, the approach itself is recommended -- that is, use of categories of exposure levels, but the names of those categories should be descriptive ones such as "below 2 mg/l" or "above 5 ppm," rather than value-oriented ones such as subnominal or nominal.

Index Construction

Lastly, the construction of an index for estuarine condition is a challenge put forth by this example report. Indices are attractive because they offer simple summaries and readily communicate information about environmental values - the principal reason for preparing assessment reports. The public is familiar with indices such as the Index of Leading Economic Indicators, an index used to assess the state of our nation's overall economy. In recent years, fishery biologists have used the Index of Biotic Integrity (IBI) to examine changes in stream fish communities. The IBI summarizes information on species diversity (e.g., number of sucker species) and community composition (e.g., percent of individuals as top carnivores) and is used to assess the quality of streams and rivers for fishes. The Index of Leading Economic Indicators and the IBI are examples of indices developed from measures of similar attributes (economic factors and fish, respectively). Applying the concept of indices to ecological communities requires an understanding of the functional relationship of vastly different measures -- for example, benthic biomass, fish tissue contaminants, and aesthetic aspects of estuarine environments.

The suggestion that such an index may be developed is intriguing and points to at least three directions for future research. First, should there be multiple indices for describing overall estuarine condition, each one keyed to a single value such as biodiversity or productivity? Second, what are the elements (indicators) necessary for compilation of such an index? And, third, what are the appropriate social science methodologies required in order to consider aesthetic indicators? The rigorous treatment of ecological data with respect to biotic integrity (e.g. benthic communities, fish tissue contaminants), must be paralleled by equally rigorous efforts to assign meaning to various aesthetic indicators or indicators of human use of estuaries. For example, how does one quantify an acceptable amount of trash in estuarine systems? These three questions invite further discussions of the role EMAP will play in communicating ecological information.

This example report for an estuarine province represents a first attempt to illustrate, and thereby define, EMAP assessment reports. It is highly unlikely that future assessments will closely resemble this example. However, this report has contributed a wealth of information to the process of defining assessments. Perhaps it has generated more questions than it answered. But knowing how to ask the right question is the first step in finding a solution.

This example report has identified ways that EMAP scientists and EMAP clients can refine and direct the program so that relevant ecological information is communicated in an effective manner. We are currently developing an example integrated assessment that addresses overall ecological condition of entire biogeographic regions. Actual data from our Near-Coastal and Forest Demonstration Projects are presently being interpreted. Not only are we learning how to improve monitoring, but also how to address assessment needs and goals. These efforts, coupled with significant progress throughout EMAP, will continue to improve the quality of our environmental assessments.

For additional information regarding EMAP's assessment efforts, please contact Daniel A. Vallero, Technical Coordinator for Integration and Assessment, Atmospheric Research and Exposure Assessment Laboratory, MD-75, U. S. Environmental Protection Agency, Research Triangle Park, N. C. 27711.

Gary J. Foley, Director
Atmospheric Research and Exposure
Assessment Laboratory
Research Triangle Park, NC

Frederick W. Kutz, Acting Director
Environmental Monitoring and
Assessment Program
Washington, DC

DISCLAIMER

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NOTICE

The data used to create the example assessment report in Section 2 are fictional. They do not represent actual ecological status or trends for any region of the nation. The analyses, conclusions, and interpretations are based on synthetic data; therefore, text, tables, and figures should not be used or cited in any other document.

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CONTENTS

CONTENTS (Cont'd)

LIST OF BOXES

LIST OF FIGURES

FIGURES (Cont'd)

LIST OF TABLES

SECTION 1
FOREWORD

This nation expends considerable resources on environmental protection and monitoring. The costs for pollution abatement in the United States are estimated to be about $77 billion annually, whereas regulation and monitoring activities cost approximately $1.5 billion (CEQ 1990). Environmental monitoring by the U.S. Environmental Protection Agency (EPA) alone costs $350 million annually (Hunsaker and Carpenter 1990). Despite these expenditures, no conclusive statements can be made about the cumulative effectiveness of regulatory programs, the overall condition of the nation's environmental resources, or long-term trends in ecological condition.

The need to assess the condition of the nation's environmental resources has been emphasized by EPA, Congress, and private environmental organizations. Responding to this need, and to recommendations made by the EPA Science Advisory Board (USEPA 1988), EPA initiated the Environmental Monitoring and Assessment Program (EMAP) (USEPA 1990).

EMAP is being designed by EPA and other federal agencies and is coordinated by EPA's Office of Research and Development. The program represents a long-term (decades) commitment to assess and document the condition of the nation's ecological resources at national, regional (e.g. EPA Regions, the Northeast), and subregional scales.

EMAP is designed to provide answers to the following questions (USEPA 1990):

- What is the current status, extent, and geographic distribution of the nation's ecological resources?
- What proportions of these resources are degrading or improving, where, and at what rate?
- What are the possible reasons for adverse or improving conditions?
- Are adversely affected ecosystems responding as expected to control and mitigation programs?

EMAP will work with a broad spectrum of collaborators to provide information on the status and the change in status (trends) of the nation's ecological resources. The program will be implemented in seven types of ecosystems or ecological resources: estuaries and coastal waters, inland surface waters, the Great Lakes, wetlands, forests, arid lands, and agricultural lands.

Information on the condition of each resource category will be provided in the form of statistical summaries and environmental assessment reports. Statistical summaries will be produced annually and will provide timely dissemination of EMAP data in the form of tabular and graphic data summaries.

Environmental assessment reports will be issued periodically and will integrate EMAP data with other monitoring programs and with environmental data of other types (e.g. NPDES permit discharge reports, USGS National Water Quality Assessment Program (NAWQA), NOAA Status and Trends Program). Assessment reports will

- assess the extent and magnitude of pollution impacts,
- report trends,
- describe the relationships among indicators of ecological condition, exposure, and stress,
- identify the likely causes of poor ecological condition,
- help identify emerging problems, and
- evaluate the overall effectiveness of regulatory and control programs on regional scales.

As currently envisioned, assessment reports will be completed at four levels of environmental complexity. At the first level, assessments will be completed for a particular environmental resource (forests, for example) within one biogeographic province or region. At the second level of integration, assessments will be completed for a particular environmental resource across multiple regions. For example an assessment might be made of all east coast estuaries by integrating information collected in the Acadian, Virginian, Carolinian, and West Indian Provinces. The third type of assessment activity to be conducted by EMAP requires the integration of information and data across resource groups for a complete assessment of the overall conditions within a biogeographic province or regoin. These types of assessments may be made for particular EPA regions and would not only integrate and compare conditions within multiple types of environmental resources, but also attempt to identify how conditions and changes in one resource affects another. A specific assessment, for example, might address how changes in land use in watersheds impact the condition of surface waters and estuaries.

Assessments that require integrating information about multiple resources across multiple biogeographic provinces or regions are the fourth type of assessment activity envisioned for EMAP. These assessments will describe the conditions of the nation's environmental resources.

The purpose of this report is to provide an example of an environmental assessment report for the estuaries in one biogeographic province. It is intended to illustrate some of the types of assessments and interpretations that will be possible, as well as some of the potential limitations of the program.

In this report we did not evaluate the EMAP sampling design or the indicators chosen by EMAP to monitor and assess the condition of estuaries, nor did we evaluate our ability to detect trends that are not monotonic. These evaluations and tests are necessary and have begun using historical data and various modeling and simulation techniques. Further evaluations will be made as data from the 1990 EMAP-Estuaries demonstration project become available.

This document is organized in five sections: 1) this foreword, 2) the Example Environmental Assessment Report, 3) data set simulation, 4) lessons learned, and 5) references. The example report is presented as an independent document and is written as if produced after the twelfth year of the program. We attempted to make the example report as close as possible to an actual resource-specific assessment. The data presented, although based upon actual data from the east coast of the United States, are fictional and are used for illustrative purposes only. The section on data simulation presents an overview of how we constructed the data set on which the example report is based. The concluding section in this document presents some of the most important lessons learned in the process of completing this example report.

The Example Environmental Assessment Report contains only a brief overview of EMAP and the estuarine component of EMAP. Additional information about EMAP and about the strategic approach taken for this assessment are given in the data simulation section. Although some of this information has been published previously (Holland 1990; Hunsaker and Carpenter 1990), many of these documents are not yet generally available; thus, the information warrants reiteration.

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Environmental Monitoring and Assessment Program

Assessment Report for Estuaries

EMAP

Perhaps more than any other ecological system, estuaries are subjected to increasing use by man. Our many uses of estuaries are often conflicting. We depend upon estuaries as a vehicle for commerce and transportation, as a source of food from both commercial and recreational fisheries, as a playground for swimming and boating, and we look toward the estuarine environment for aesthetic qualities. Estuaries are also a repository for society's contaminants and wastes. These human activities are often in conflict with the ecological roles of estuaries and the existence of abundant and diverse habitats and biota.

The Environmental Monitoring and Assessment Program (EMAP) was created to monitor the condition of the nation's ecological resources. EMAP monitors natural resources within large biogeographic regions. The resources include estuaries, coastal waters, wetlands, the Great Lakes, inland surface waters, forests, arid lands, and agricultural lands. The ecological condition of estuaries in the biogeographic province of *Estuaria*, the U.S. portion of Poseidon Island, is described in this report. The report includes 12 years of monitoring data for estuarine resources.

ESTUARIA

There has been an overall deterioration in environmental conditions throughout *Estuaria*. Estuarine area showing evidence of undesirable conditions has increased since 1990 (Figure 2-1) and now comprises 46% (46 ± 2%: 10,580 km^2) of the total estuarine area.

Both biological integrity (i.e., the condition of biological resources) and the suitability of the environment for human uses (e.g., consumption of fish and shellfish, swimming, boating) were affected in the degraded estuarine areas; however, declines of biological integrity were more widespread.

The major findings associated with the unacceptable conditions within the estuaries of *Estuaria* are:

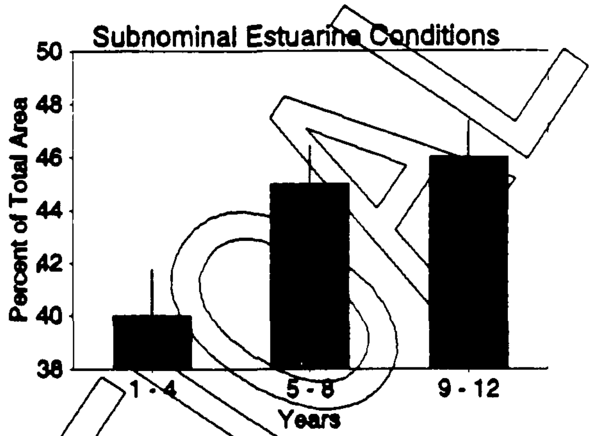

Figure 2-1. Percent of estuarine area in *Estuaria* having subnominal (unacceptable) conditions. Four year cumulative frequency and 90% confidence estimates given.

- The decline in the biological condition of estuarine resources was associated with increases in sediment toxicity; 39% of the areas with impacted biota have toxic sediments.

- The presence of Contamexx, an agricultural insecticide introduced twenty years ago, was associated with most of the estuarine area with toxic sediments.

- Low dissolved oxygen concentrations were associated with 16% of degraded biotic integrity.

- Another 16% of degraded biota could not be attributed to low oxygen concentrations or toxicity due to contaminants, suggesting that other factors also contributed to degradation.

Despite the general decline in estuarine condition in *Estuaria*, some conditions have improved moderately:

- Total estuarine area having sediments contaminated with lead and DDT has decreased by 32% and 11%, respectively (Figure 2-2).

- Total estuarine area in which levels of lead and DDT in fish tissue has decreased by 40% and 59%, respectively.

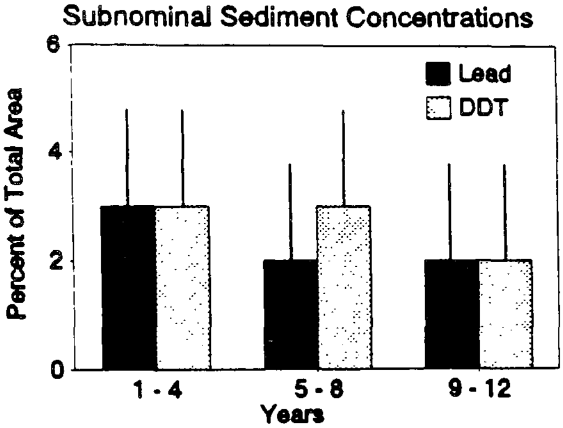

Figure 2-2. **Percent of estuarine area in *Estuaria* with subnominal concentrations of lead and DDT in sediments. Four year cumulative frequency and 90% confidence estimates given.**

EPA REGIONS

The decline in estuarine condition is most pronounced in the estuaries of northern *Estuaria* (EPA Administrative Region A), a predominantly agricultural region where degraded estuarine area has increased more than threefold.

- Toxic sediments are now found in 79% of the estuarine area in Region A (Figure 2-3).
- Subnominal sediment concentrations of Contamexx are associated with all of the degraded estuarine areas within Region A.
- Contamexx is entering the food chain in northern *Estuaria*. Levels of Contamexx exceeding the FDA action limits in fish tissue were found in 21% of this area.

ESTUARY CLASSES

Three classes of estuaries were monitored: large estuaries (broad estuaries larger than 260 km^2), large tidal rivers (narrow estuaries larger than 260 km^2), and small estuaries (estuaries smaller than 260 km^2). Findings on these estuary classes were:

- The areal extent of low dissolved oxygen decreased markedly in large tidal rivers (Figure 2-4). Improving oxygen conditions were associated with decreases in conventional pollutant loadings.
- The extent of estuarine waters with low dissolved oxygen problems increased in small estuaries, possibly as a result of increased urbanization and development in the watersheds of these estuaries.
- Small estuaries have the worst environmental conditions and have undergone the most degradation over the past 12 years. Degraded areas were associated with toxic sediments.

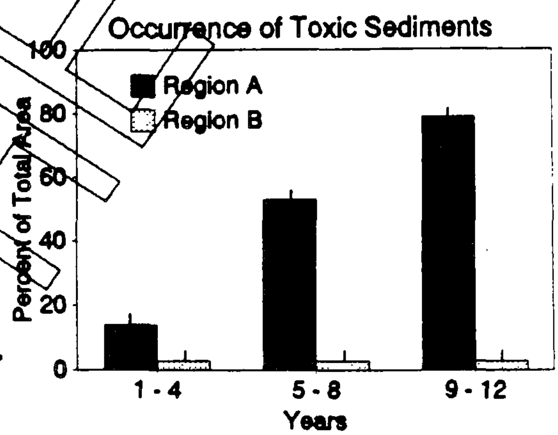

Figure 2-3. **Percent of estuarine area in Regions A and B with toxic sediments. Four year cumulative frequency and 90% confidence estimates given.**

CONCLUSIONS

EMAP data suggest that use of some agricultural chemicals and increasing urbanization are having deleterious effects on estuaries. Based upon these results, the following conclusions are drawn:

- The presence of contaminants, particularly the insecticide Contamexx and its decomposition products, is strongly associated with subnominal estuarine conditions.

- Point source controls of conventional pollutant loadings appear to have contributed to improving dissolved oxygen conditions.

- Degradation of biological resources in small estuaries appears to be associated with changing land use (urbanization) and increased contaminant inputs by non-point sources.

- Attempts should be made to identify other contributing factors in those areas with degraded resources and for which EMAP was unable to identify apparent environmental stresses (16% of degraded area).

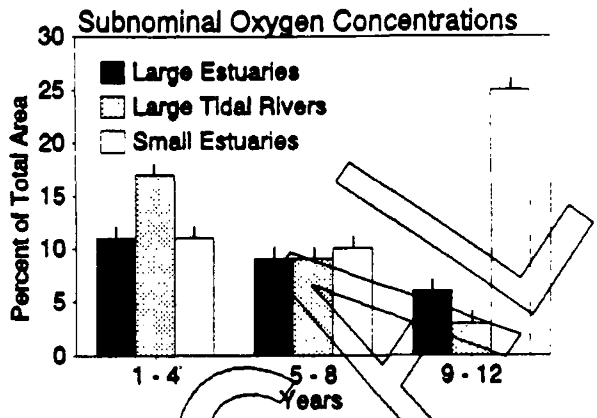

Figure 2-4. Percent of estuarine area in the three classes of estuaries with subnominal concentrations of dissolved oxygen. Four year cumulative frequency and 90% confidence estimates given.

INTRODUCTION

The Environmental Monitoring and Assessment Program (EMAP) is a comprehensive, multiagency program designed to assess the condition of U.S. ecological resources. EMAP represents a long-term commitment to environmental monitoring to evaluate the overall success of current pollution abatement policies and to identify problems before they become wide-spread or irreversible. EMAP provides the nation with information that can be used to develop a strategy for reducing degradation of the environment.

EMAP is designed to provide answers to the following questions:

- What is the current status and geographical extent of the nation's ecological resources?
- What resources have changed, where, and at what rate?
- To what levels of stress or pollution are the resources exposed in each region?
- What are the possible reasons for degrading or improving conditions?
- What resources are at current or future risk?
- Are affected resources responding to control and regulatory programs?

EMAP monitoring activities in estuaries were initiated in 1990 by the U.S. Environmental Protection Agency and the National Oceanic and Atmospheric Administration (NOAA). This EMAP assessment will interpret the condition of estuarine resources from their confluence with offshore waters to the head-of-tide. EMAP also produces resource-specific assessments of inland surface waters, wetlands, the Great Lakes, forests, arid lands, and agroecosystems. EMAP is specifically designed to assess changes in ecological condition over large biogeographical regions (e.g., *Estuaria*, the Virginian Province, the Gulf of Mexico), and over long time periods (e.g., decades) in each of these resource categories.

Coastal and estuarine ecosystems are among the most productive ecological systems and have significant social, aesthetic, and economic value. Estuaries provide critical feeding, spawning, and nursery habitat for many commercially and recreationally important fish, shellfish, birds, and mammals (*4,7*). More than 70% of all commercial and recreational landings of fish and shellfish are taken from these systems. In addition, over $7 billion is spent annually on outdoor marine recreation in the 22 coastal states, and many resort economies depend on the condition of the surrounding natural resources. Over 75% of the nation's population lives within 80 kilometers (50 miles) of the estuarine environment, and lands adjacent to these waters are among the most industrially developed.

Perhaps more than any other ecological system, estuaries are subjected to increasing use by man. Our many uses of estuaries are often conflicting. For example, we depend upon estuaries as corridors for commerce and transportation, as sources of food from both commercial and recreational fisheries, as recreational sites for swimming and boating, and, although less tangible, we appreciate the estuarine environment for its aesthetic qualities. Estuaries are also a repository for society's contaminants and wastes. These human activities often affect the ecological function of estuaries and interfere with the existence of abundant and diverse habitats and biota.

Estuarine waters are the final repository for many of the pollutants entering surface waters. Besides receiving municipal and industrial waste discharges from adjacent cities, estuaries also receive the cumulative impacts of pollutants from a variety of more diffuse origins. These include atmospheric pollutants that are deposited in estuaries and their watersheds, and contaminants entering the waters of the rivers and streams which flow into near coastal water bodies. Therefore, man's activities in areas far removed from the coast can affect the ecological condition of the entire coastal ecosystem, particularly estuaries. EMAP provides information to assess the combined effectiveness of environmental regulations that protect coastal ecosystems from competing interests.

OBJECTIVES OF THIS REPORT

This report summarizes and evaluates the condition of the estuarine resources within the province of *Estuaria*. Using data from the first 12 years of EMAP and other monitoring programs, this report addresses four EMAP questions:

- What is the condition of estuarine resources within *Estuaria*?
- Have estuarine conditions changed over the past 12 years and if so, to what extent?
- What are the possible reasons for changing conditions?
- Are adversely affected ecological resources responding as expected to control and mitigation programs?

The reader is referred to other publications for specific details concerning the general sampling design of EMAP (*8*) and its estuarine component (*16-19*) and to the preceding annual statistical summaries for the estuaries within *Estuaria*.

ESTUARIA

The geopolitical region and biogeographic province of *Estuaria* is located on Poseidon Island, approximately 200 nautical miles from the mainland in the Great Ocean. *Estuaria* (Figure 2-5) comprises the western portion of the island; it is mainly agricultural in the north and forested in the south. The eastern portion of the island is foreign territory, part of *Fredonia*, and is arid and sparsely populated (Figure 2-6). Major population centers are in the agricultural and industrial north and northwest and in the southwest. The climate is warm and temperate throughout most of the island. Marine and estuarine fauna are similar throughout *Estuaria's* coast, placing the island in a single biogeographic province. *Estuaria* is comprised of two EPA administrative regions, Region A in the north and Region B in the south (Figure 2-5).

PROGRAM DESIGN

Indicators

It is not possible to monitor all environmental resources of concern to the nation. Therefore, selected parameters which have been shown to be key indicators of overall environmental quality are measured by EMAP to assess environmental condition. These indicators are quantifiable, valued by society, applicable across a range of habitats and geographic distances, and clearly related to ecological condition. The four types of indicators used by EMAP are response, exposure, habitat, and stressor (see Box 2-1).

The EMAP indicator strategy (*3*) is to use response indicators to define the overall condition of a region. Exposure indicators are used to define pollutant exposure and identify possible reasons for poor condition. Changes in response and exposure variables over time are compared to changes in stressors to identify possible causes among the stressors. Habitat indicators are used to interpret variations in response and exposure indicators due to physical attributes of the environment. The relationships among the types of indicators are summarized in Figure 2-7.

The focus on environmental condition, rather than on pollutant sources or ambient concentrations, reflects the unique goals of EMAP. Compliance monitoring involves identifying individual polluters with a high degree of confidence, which focuses attention on polluting activities and pollutant concentrations that can be linked unequivocally to individual sources. Information provided by EMAP compliments compliance monitoring activities by assessing the overall cumulative effectiveness of environmental regulations for protecting environmental resources. New pollutants, synergistic and antagonistic effects, and imperfect knowledge of cause and effect relationships in complex ecosystems makes the biological focus essential. EMAP provides information to help identify emerging problems and regional resources most in need of research, assessment, or remediation resources.

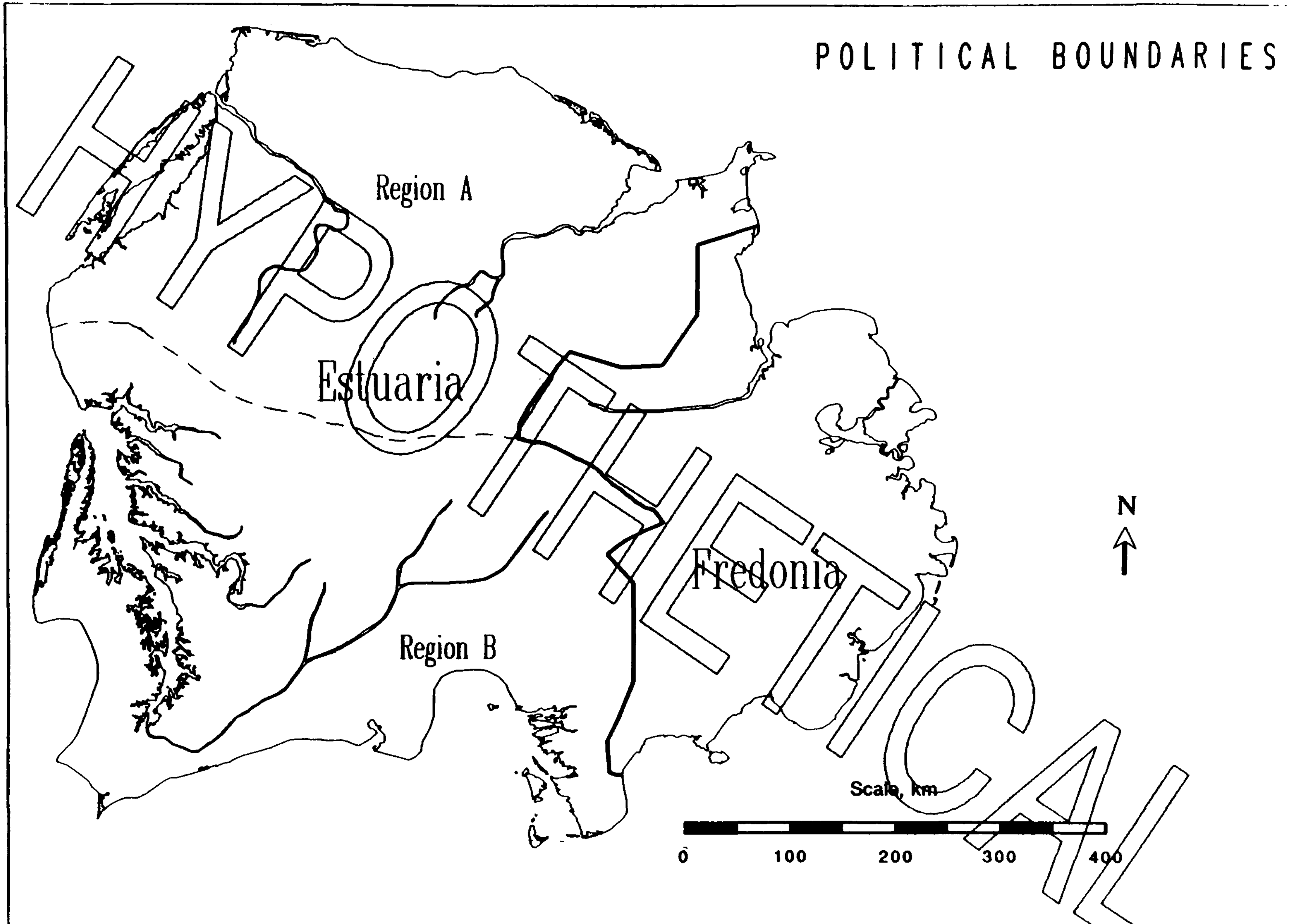

Figure 2-5. Political boundaries for *Estuaria* and *Fedonia*

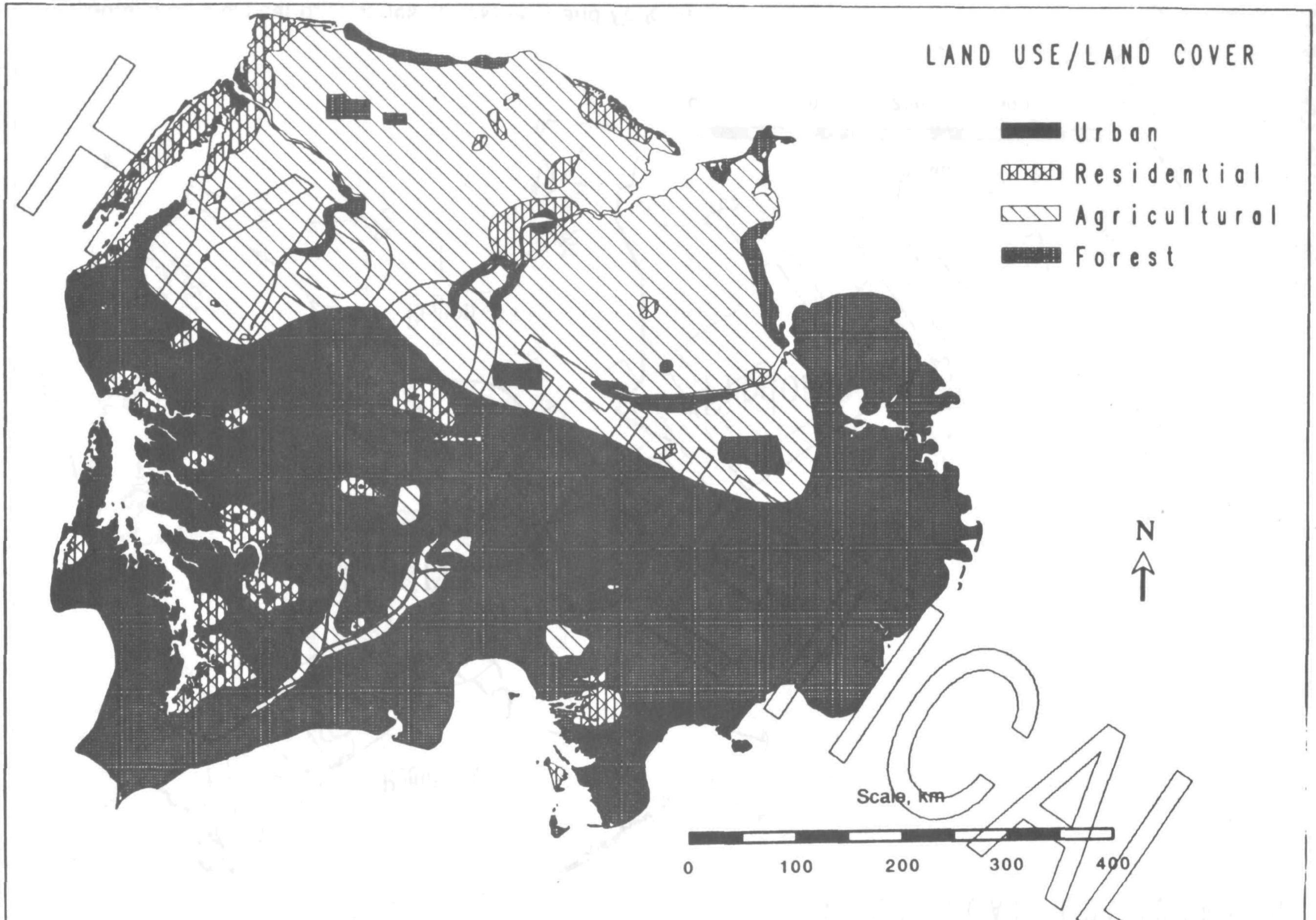

Figure 2-6. Land use pattern for *Estuaria*

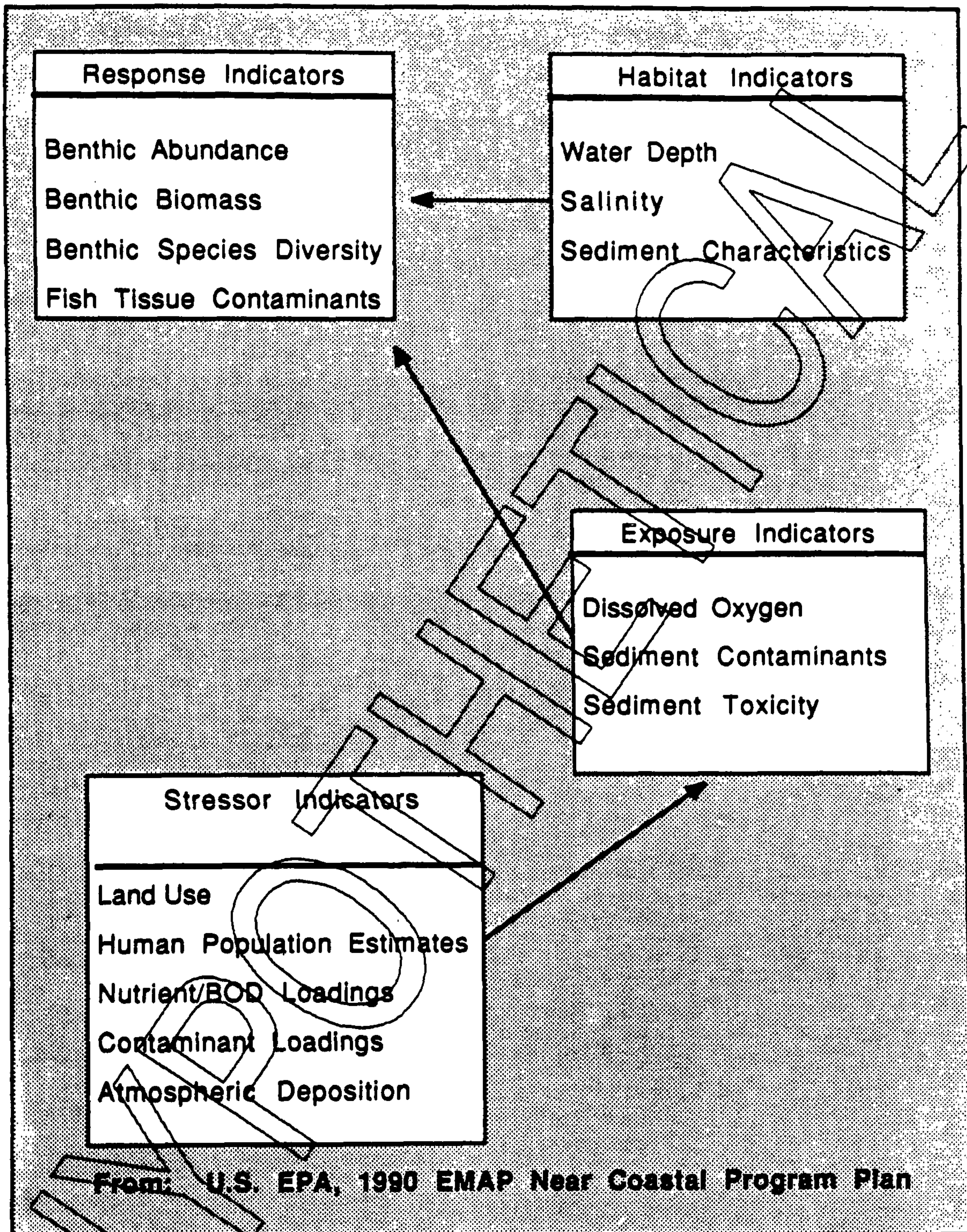

Figure 2-7. Relationships between EMAP indicators

Indices

EMAP uses an integrated approach to make statements concerning the condition of environmental resources. Indices, which are mathematical aggregations of response indicators, have been developed to integrate information concerning the status and trends in the condition of environmental resources (Figure 2-8). Indices are used to relate EMAP data directly to both the integrity of biological resources, and quality of the environment for human use.

The concept of balanced indigenous populations introduced in the Clean Water Act requires the presence of native species whose populations are persistent over decades. This implies that species composition is a subset of possible native species, that the organisms are abundant enough to maintain a population, and that the individuals (and the population) are reasonably healthy.

The desired human uses supported by estuaries are swimming, fishing, boating, and aesthetic appreciation. Society values water that has no floating algal mats, trash or noxious odors, is relatively clear, safe to swim in, and supports finfish and shellfish populations that are safe to eat.

> **Box 2-1**
>
> **EMAP Indicator Types**
>
> - Response Indicator: A measure of the condition of a resource at the organism, population, community, or ecosystem level of organization (e.g., benthic abundance and biomass).
> - Exposure Indicator: Environmental characteristics that provide evidence of the occurrence or magnitude of a response indicator's contact with physical, chemical, or biological stress (e.g., dissolved oxygen concentrations or sediment contaminants).
> - Habitat Indicator: Physical attributes that may influence the way organisms, populations, and communities respond to stresses or perturbations (e.g., salinity or sediment type).
> - Stressor Information: Natural processes, environmental hazards, or management activities that change exposure or habitat.

Indicator Thresholds

Criteria established for indicators of biological response allow resources in good or desirable condition to be differentiated from those in poor or undesirable condition. In EMAP, the more general terms nominal and subnominal are used to refer to desirable and undesirable conditions, respectively. Nominal conditions represent healthy estuarine systems inhabited by native species whose populations are persistent over time or are desirable to society (e.g., diverse and uncontaminated fish and shellfish communities, dissolved oxygen concentrations sufficient to support normal biotic populations). Subnominal conditions represent degraded and undesirable status (e.g., reduced diversity and abundance of native fish and shellfish communities, contaminated habitats, fish, or shellfish, or insufficient levels of dissolved oxygen to support balanced indigenous populations).

Although it is relatively easy to differentiate between the extremes of good (nominal) and poor (subnominal) condition, it is not always easy to designate the value at which the transition from nominal to subnominal occurs. The term **marginal** is used to classify conditions that are not clearly nominal or subnominal. For example, dissolved oxygen concentrations above 5 ppm are generally accepted as nominal, and concentrations below 2 ppm are generally accepted as being subnominal; dissolved oxygen concentrations between 2 and 5 ppm are stressful to some aquatic organisms, but not to all. This intermediate range of dissolved oxygen concentrations is considered marginal.

Two thresholds have been defined for response and exposure indicators based on the results of

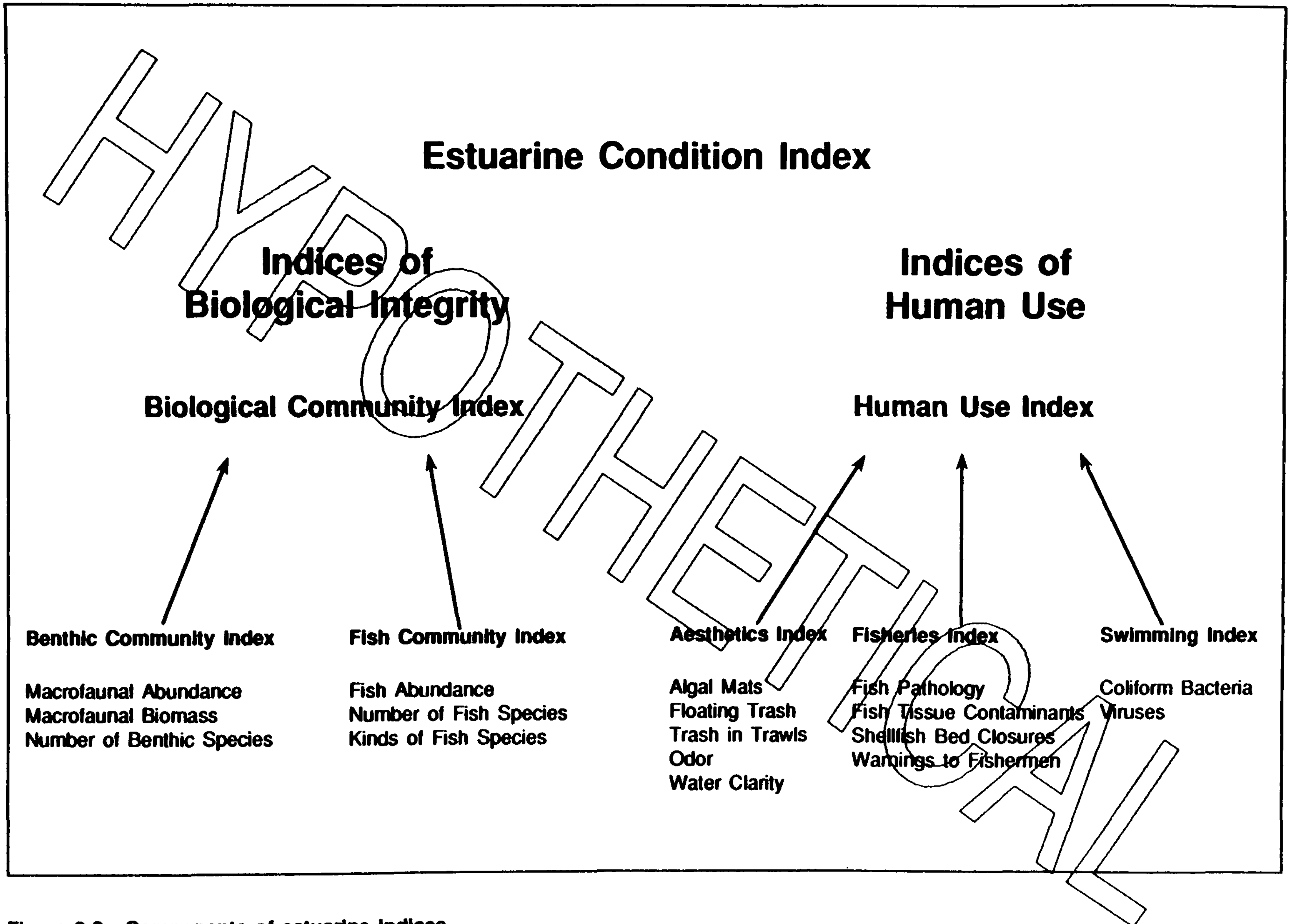

Figure 2-8. Components of estuarine indices.

indicator testing and evaluation (*9*). One threshold marks the boundary between subnominal and marginal indicator values. The other marks the boundary between marginal and nominal values. Threshold values for selected indicators are given in Table 2-1.

SAMPLING AND ANALYSIS

A central goal of EMAP is to make representative estimates of status and trends in ecological condition with known confidence. To attain this objective, the EMAP estuaries sampling network uses a probability based sampling design that incorporates regionalization and classification concepts (*16*). Descriptions of status and trends are accompanied by estimates of the 90% confidence bounds for each index and indicator (see Box 2-2).

The sampling design is arranged in sampling units (i.e., biogeographic regions, or provinces such as the Gulf of Mexico, the Virginian Province, or *Estuaria*) with similar ecological properties. This report analyzes and interprets the status and trends (changes in status) for EPA Regions A and B in the biogeographic province of *Estuaria* (Figure 2-5).

Table 2-1. Subnominal, Marginal, and Nominal Ranges for Indicators and Indices

	Subnominal	Marginal	Nominal
Response Indicators and Indices			
Benthic Index	3 - 4	5 - 7	> 7
Number of Benthic Species	0 - 6	6 - 10	> 10
Benthic Abundance (No./m²)	0 - 500	500 - 1000	> 1000
Benthic Biomass (dry wt./m²)	0 - 2	2 - 4	> 4
Fisheries Index	0	1	2
Fish Mercury (ppm)	≥ 0.5		< 0.5
Fish Lead (ppm)	≥ 0.5		< 0.5
Fish DDT (ppm)	≥ 0.25		< 0.25
Fish Contamexx (ppm)	≥ 100	1 - 100	0 - 1
Exposure Indicators			
Dissolved Oxygen (ppm)	0 - 2	2 - 5	> 5
Sediment Mercury (ppm)	≥ 1.0	0.5 - 1.0	0 -0.5
Sediment Lead (ppm)	≥ 150	50 - 150	0 - 50
Sediment DDT (ppb)	≥ 50	20 - 50	0 - 20
Sediment Contamexx (ppm)	≥ 1.0	0.5 - 1.0	0 - 0.5
Sediment Toxicity	Positive		Negative

Box 2-2

Statistical Confidence

One of the goals and strengths of EMAP is to make estimates of environmental condition with known confidence. For descriptions of status, 90% confidence limits are presented (i.e., there is 90% confidence that the actual value falls within the ranges given). Confidence limits were calculated from bionomial distributions. For temporal trends, a non-parametric test (a variation of Kendall-Tau) was applied using estimates for each of the 12 years available. In many instances, data were summarized using four year averages.

Using information about physical dimensions and knowledge of estuarine ecology, estuarine waters of the province were classified into three categories: large estuaries, large tidal rivers, and small estuaries. These classes represent estuaries with potentially different responses to pollution due to different dilution capacities, flushing characteristics, and other factors (Table 2-2). The estuaries have been sampled systematically over the past 12 years to obtain representative measures of pollutant exposure and ecological responses with known confidence.

At each sampling site, the numbers, species, and biomass of bottom dwelling organisms were measured. Sediments were analyzed for toxicity and contaminant concentrations. Fish were captured to determine species composition and tissue contaminant concentrations in the dominant species. Dissolved oxygen concentration at the bottom was measured continuously during the summer index period at each sampling station. (See Box 2-3).

Table 2-2. Characteristics of Estuarine Classes

Characteristics	Large Estuaries	Large Tidal Rivers	Small Estuaries
Surface Area	> 260 km²	> 260 km²	2.6 - 260 km²
Shape (ratio of length to width)	≤ 20	> 20	Any
Salinity	Strong salinity gradients	Partial salinity gradients	Lack strong salinity gradients
Sediments	Heterogeneous	Heterogeneous	Relatively homogeneous
Watersheds	Large, complex	Large, complex	Small
Management Regions	Multi-state	Multi-state	Single state
Contaminant Sources	Multiple	Multiple	Limited

Box 2-3

Sampling Methods

Sampling and processing methods are described briefly below. Detailed methods are described elsewhere (*18,19*).

Sediment samples for benthic biota, sediment contaminants, and sediment toxicity indicators were collected using a 400 cm² Young-modified Van Veen grab. Biological samples were sieved through a 0.5 mm screen and preserved in formalin. Sediment contaminant and toxicity samples were held at 4 °C and shipped to the laboratory overnight for analysis. Biological samples were held for 60 days; then the organisms they contained were identified to the lowest practical taxonomic level, enumerated, and their dry weight estimated.

Sediment toxicity was measured using 10-day acute tests with two organisms, an amphipod of the genus *Ampelisca* and a larval fish of the genus *Oryzias* (*14*). Five replicate tests using each species were conducted for each sample station.

Chemical analysis of sediment contaminants was conducted for a suite of inorganic and organic chemicals.

Fish tissue contaminants were measured from skinless portions of the dorsal muscle tissue of several species of bottom feeding fish. Fish were collected using 16 m high-rise trawls. The contaminants measured were the same as for sediment. Tissue concentrations were normalized to account for species-specific metabolic differences in assimilation, storage, and depuration rates, using data collected during previous indicator testing and validation studies (*9*).

Dissolved oxygen concentrations were measured using polaro-graphic probes deployed for 10-day periods and set to record measurements at 30-minute intervals. All dissolved oxygen meters were deployed one meter from the bottom from 1 July to 31 August.

Estuarine resources within *Estuaria* represent over 23,000 km^2 of ecologically diverse and important habitats. However, nearly one-half of the estuarine environment is degraded. These areas fail to meet environmental quality objectives based on the integrity of biological communities or the ability to support human activities valued by society. Overall, 10,120 to 11,040 km^2 (46 ± 2%) of the total estuarine area is categorized as having subnominal or undesirable conditions with respect to at least one of these two environmental values. Over the past 12 years, the estuarine area with subnominal conditions has increased by about 3450 km^2 (Figure 2-9).

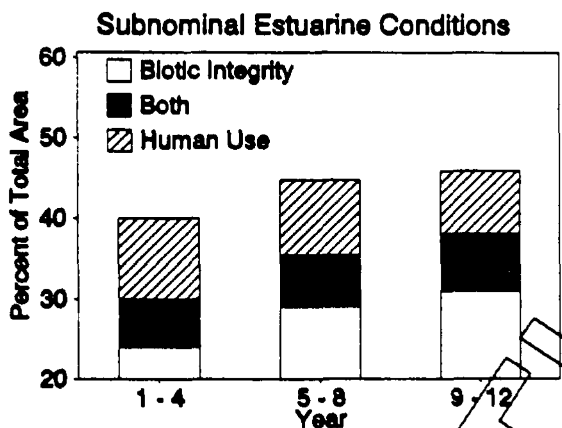

Figure 2-9. **Percent of estuarine area in *Estuaria* having subnominal conditions. Four year cumulative frequency and 90% confidence estimates given.**

Although almost half of the estuarine area within *Estuaria* has undesirable conditions, only 20 ± 2% is clearly desirable (nominal), showing no significant degradation of biological communities or restrictions of human use (Figure 2-10). The remainder of estuarine area (34 ± 2%) shows some signs of environmental degradation.

Subnominal biological communities are a more widespread problem than the restriction of human activities (Figs. 2-9, 2-10). Approximately 38 ± 2% of all estuarine area contains biological communities classified as subnominal; 15 ± 2% of the estuarine area in the province is impaired with respect to human use. Only 7 ± 2% of all area shows both problems.

The overall condition of the estuarine resources within *Estuaria* has declined over the past twelve years (Figures 2-9 and 2-11). The area that is subnominal or unacceptable has increased, and the area that is nominal has decreased. Overall, almost 14,400 km^2 of estuarine area has degraded. Changes over the 12 years were due largely to the decline in the condition of biological communities, not to further impacts on human use. The area containing subnominal biological communities has increased (Figure 2-9), and the estuarine area impaired for human use has remained relatively constant.

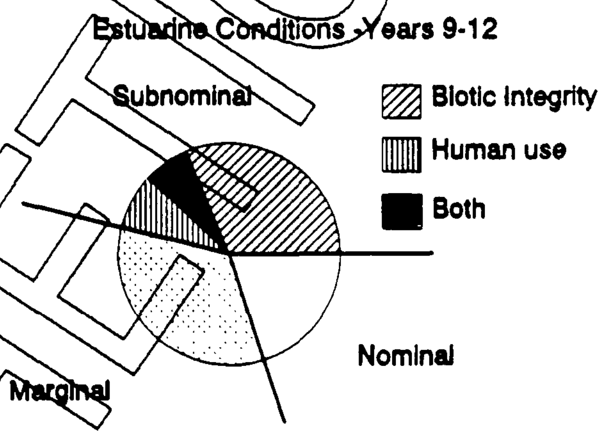

Figure 2-10. **Percent of estuarine area with subnominal, marginal, and nominal conditions (years 9-12).**

EVALUATING SUBNOMINAL CONDITION: BIOLOGICAL COMMUNITIES

The integrated responses of biological communities to various environmental stresses have been assessed using indicators that measure the responses of bottom dwelling (benthic) communities. Benthic communities are sensitive indicators of both natural and anthropogenic disturbance and stress (*1, 10*). They can respond quickly to disturbance (*2, 11*) and, in some cases, can manifest changes for years after other components of an ecosystem have recovered (*12*). The benthic indicators are number of species, their abundance, and their biomass. The benthic community index (Figure 2-8) integrates these indicators into a single measure representing the overall condition of biological communities.

Degraded biological communities in *Estuaria* are associated with toxic sediments and low dissolved oxygen concentrations. Toxic sediments are more prevalent then low dissolved oxygen and are present at 39 ± 2% of those areas exhibiting subnominal benthic communities; low dissolved oxygen concentrations are associated with 16 ± 2% of the estuarine area exhibiting subnominal benthic communities. Very few areas with degraded biological communities (2%) have both toxic sediments and low dissolved oxygen concentrations.

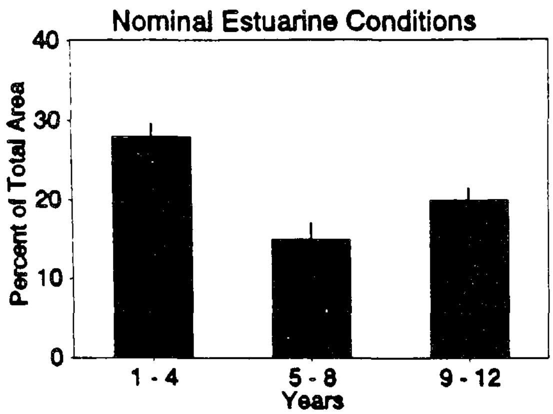

Figure 2-11. Percent of estuarine area in *Estuaria* with nominal conditions. Four year cumulative frequency and 90% confidence estimates given.

Toxic Sediments

The toxicity of sediments is a function of the concentration and types of contaminants within those sediments. In turn, the concentration of contaminants within estuarine sediments represents a long-term integration of inputs, burial, biological modification, and cycling. Metals, organic chemicals, and fine-grained sediments entering estuaries from freshwater inflows, point sources of pollution, and various nonpoint sources (including atmospheric deposition) generally are retained within estuaries and accumulate in the sediments (*5,13*). Chemical and microbial contaminants generally adsorb to fine-grained materials in the water and are deposited on the bottom, accumulating in areas with low current velocity, deep basins, and zones of maximal turbidity. The concentration of contaminants in sediments is dependent upon interactions between habitat conditions (salinity, sediment grain size, etc.), biological activity (bioturbulation, biodegradation, etc.), and anthropogenic factors (e.g., type and volume of contaminant loadings) (*15*).

Estuarine area with toxic sediments has increased threefold during the past 12 years (Figure 2-12). High concentrations of mercury, lead, total DDT, and Contamexx were associated with almost all (93 ± 2%) of those areas with toxic sediments. The contaminants are toxic to estuarine biota in controlled laboratory studies. The threefold

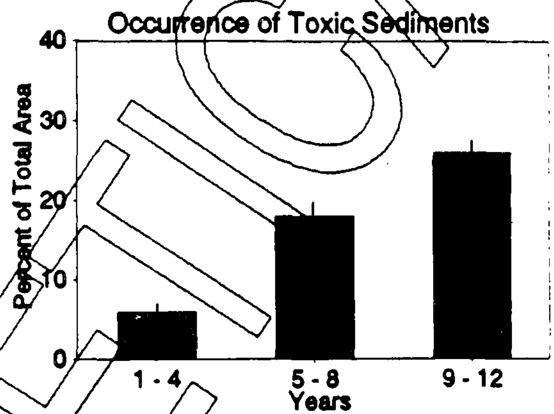

Figure 2-12. Percent of estuarine area in *Estuaria* with toxic sediments. Four year cumulative frequency and 90% confidence estimates given.

increase in toxic sediments was clearly associated with increasing Contamexx pollution, and not with the other contaminants. The total estuarine area with subnominal sediment concentrations of Contamexx has nearly doubled over the past 12 years (Figure 2-13).

Region A has been monitoring Contamexx concentrations in selected estuaries at finer spatial resolution than that of EMAP. Sediment concentrations in some areas have reached levels that are nearly 1000 times the EPA sediment criterion.

Use of Contamexx as an agricultural insecticide has expanded greatly since its introduction, over 20 years ago. Earlier studies showed that this compound was not toxic at the low concentrations normally used in farming. Subsequent studies have shown that the decomposition of Contamexx is greatly retarded in certain soil types, especially in the marine environment; therefore, the expanded use of Contamexx has

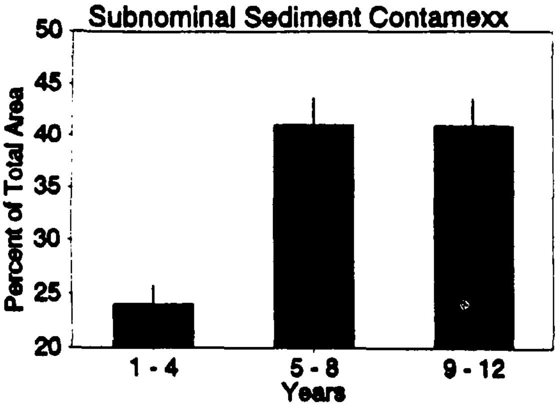

Figure 2-13. **Percent of estuarine area in *Estuaria* with subnominal concentrations of Contamexx in sediments. Four year cumulative frequency and 90% confidence estimates given.**

led to the accumulation of this compound and its toxic by-products in estuarine sediments. Following the decline in use of Contamexx that began in year 7 (Figure 2-14), mean sediment concentrations have fallen nearly 20% but remain at levels potentially toxic to benthic biota.

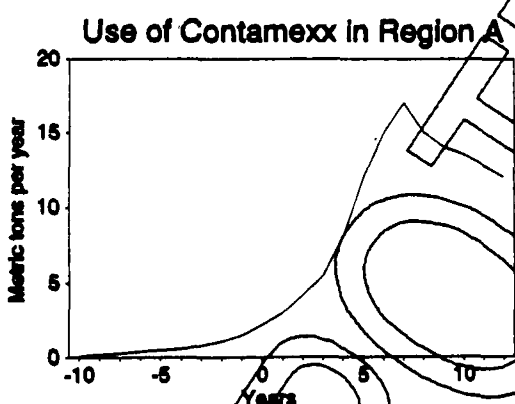

Figure 2-14. **Annual use in metric tons of Contamexx in Region A. Year 1 corresponds to year 1 of monitoring completed by EMAP. Source: USEPA Office of Pesticide Programs.**

There has been no change in the mean concentration of mercury in sediments during the past 12 years, nor have there been significant changes in the distribution of values at the regional scale. The extent of mercury contamination remains approximately 2 ± 2%. Mercury appears to be a localized contaminant; concentrations in sediments continue to be highest around urbanized areas, since the principle anthropogenic sources of mercury are fossil fuel burning and industrial discharges.

Further, the percent of estuarine area with subnominal concentrations of lead decreased over 30% (Figure 2-15). The decreased concentration of lead in estuarine sediments is associated with decreased loadings, which are associated with the decrease of tetraethyl lead in gasoline (Figure 2-16).

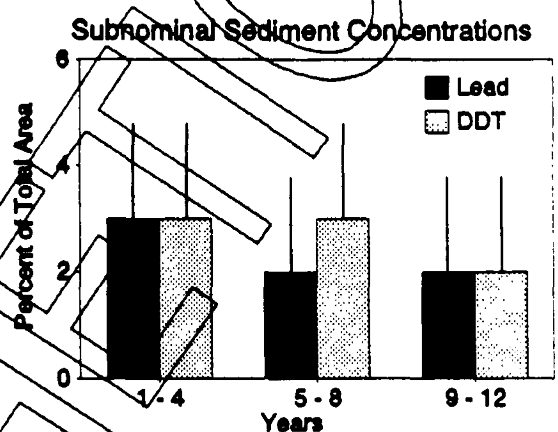

Figure 2-15. **Percent of estuarine area in *Estuaria* with subnominal concentrations of lead and DDT in sediments. Four year cumulative frequency and 90% confidence estimates given.**

The concentrations of DDT (Dichlorodiphenyltrichloroethane; commonly reported as Total DDT = DDT + DDD + DDE) in estuaries also decreased throughout *Estuaria*. Mean concentrations decreased over the 12 year period, and the area with subnominal DDT concentrations decreased. The decreased concentration of DDT in estuarine sediments also appears to be a result of decreased loadings (Figure 2-17).

Dissolved Oxygen

The second major problem affecting the biological communities within the estuarine waters of *Estuaria* is the occurrence of low dissolved oxygen concentrations. Dissolved oxygen is necessary to sustain balanced populations of fish,

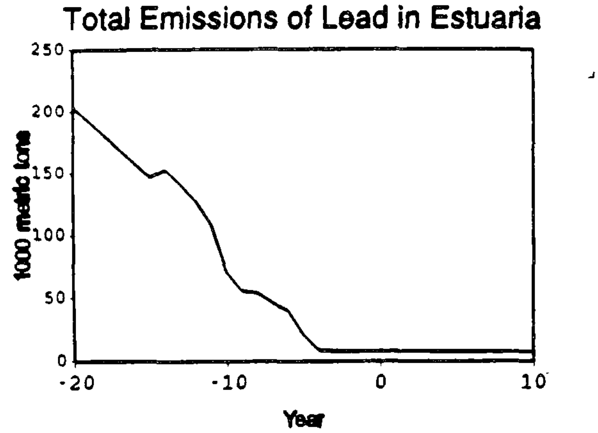

Figure 2-16. Annual atmospheric emissions of lead in *Estuaria* in metric tons. Source: USEPA Office of Air & Radiation Programs.

shellfish, and other biota in estuaries. As dissolved oxygen levels decline, so do the abundance and diversity of biota. At very low dissolved oxygen levels, few forms of life can survive.

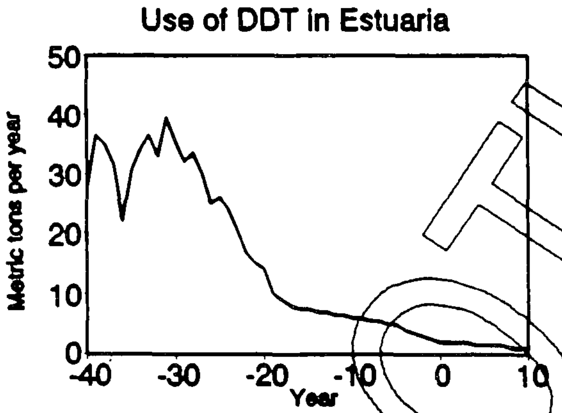

Figure 2-17. Annual use in metric tons of DDT in *Estuaria*. Year 1 corresponds to year 1 of monitoring completed by EMAP. Source: USEPA Office of Pesticide Programs.

The status of dissolved oxygen has shown both improvements and declines. In estuaries near major urban areas, oxygen concentrations generally have improved. However, oxygen concentrations in small estuaries have declined. Overall, the estuarine area with subnominal dissolved oxygen concentrations has declined from 12 ± 2% to 7 ± 2% of total estuarine area (Figure 2-18). Although the estuarine area affected by subnominal oxygen concentrations has improved, mean oxygen concentrations in *Estuaria* have fallen, causing a decrease in the area with acceptable (nominal) oxygen concentrations and an increase in marginal area (Figure 2-19).

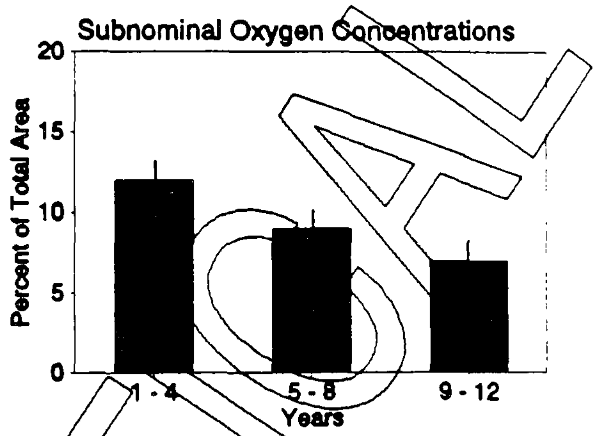

Figure 2-18. Percent of estuarine area in *Estuaria* with subnominal concentrations of dissolved oxygen. Four year cumulative frequency and 90% confidence estimates given.

Low (subnominal) oxygen concentrations are associated with a little over 16% of areas exhibiting subnominal benthic communities. Twelve years ago, low dissolved oxygen concentrations were associated with a much greater proportion of areas with unacceptable biological communities (Figure 2-20). However, the reduced extent of subnominal oxygen has been more than offset by increased sediment toxicity associated with subnominal biological communities.

Generally, improvements of dissolved oxygen concentrations are associated with decreased loadings of organic carbon and nutrients--a trend identified by NOAA's National Estuarine Inventory Program using information from the National Pollution Discharge and Elimination System (NPDES) monthly reports and USGS stream data. Total loadings have decreased as a result of more effective control of point source discharges in heavily urbanized areas, which are generally characterized by degraded biological communities.

Unknown Impacts

A significant fraction (16%) of the area that was subnominal for biological communities could not

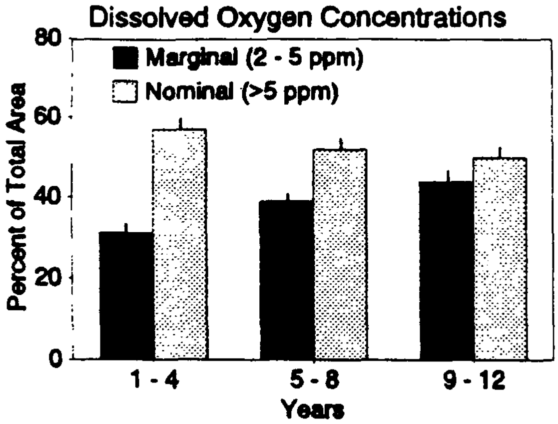

Figure 2-19. Percent of estuarine area in *Estuaria* with marginal or nominal concentrations of dissolved oxygen. Four year cumulative freqency and 90% confidence estimates given.

be associated with either toxic sediments or oxygen stress. This suggests the influence of unknown stresses on the biological communities. The area with subnominal conditions associated with unknown stressors has declined during the past 12 years from 24% to 16%. Nonetheless, further study is recommended to identify other potential causes for perceived subnominal condition.

EVALUATING SUBNOMINAL CONDITION: HUMAN USE

Society values estuarine resources for their aesthetic and recreational values and as a source of uncontaminated fish and shellfish. Approximately 15 ± 2% of the estuarine resources within the province are undesirable for human use. The main cause for these undesirable conditions is the prevalence of contaminated fish that are unfit for human consumption.

The areal extent of fish contamination has not changed in the last 12 years. However, the area with marginal fish contaminant concentrations has doubled during that period to 18 ± 2%. Consequently, the area that supports uncontaminated fish has decreased (Figure 2-21). The principle contaminants measured in fish tissues were mercury, lead, DDT, and Contamexx. The trends for these contaminants parallel those in sediments.

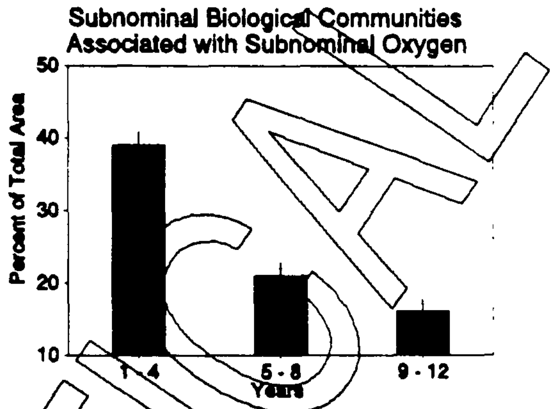

Figure 2-20. Percent of estuarine area in *Estuaria* with subnominal biological communities associated with subnominal oxygen concentrations.

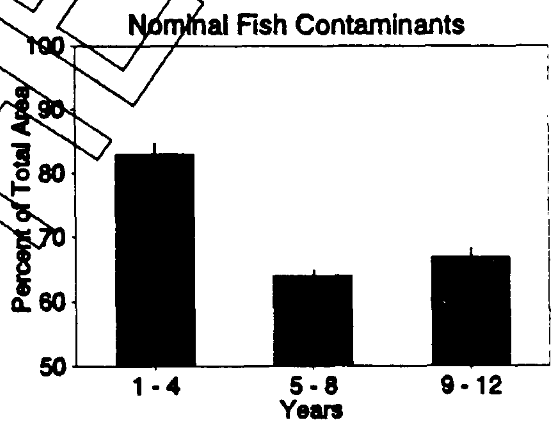

Figure 2-21. Percent of estuarine area in *Estuaria* with nominal concentrations for all measured contaminants in fish tissues.

Although some contaminants in fish tissues are declining, the contribution of Contamexx to subnominal conditions for fish tissues has increased nearly sixfold during the last 12 years. The extent of subnominal Contamexx contamination in fish is now more than 6% of all estuarine area (Figure 2-22). The use of Contamexx (Figure 2-14) and its persistence, mobility, and accumulation in the environment are responsible for the increase in subnominal and marginal contamination of fish.

Mercury remains the chief contaminant in fish tissue in *Estuaria*. However, the extent of mercury contamination has not changed significantly and remains between 6% and 8% of the total area (Figure 2-23). The extent of lead and DDT contamination in fish tissue has declined (Figure 2-23), reflecting the overall reduction in the emission of lead and the regulatory ban on the use of DDT.

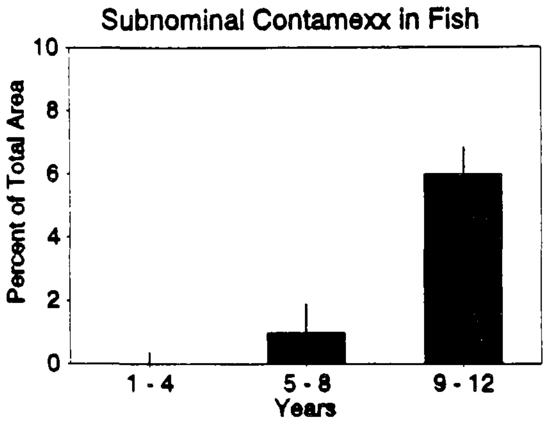

Figure 2-22. Percent of estuarine area in *Estuaria* with subnominal concentrations of Contamexx in fish tissues. Four year cumulative frequency and 90% confidence estimates given.

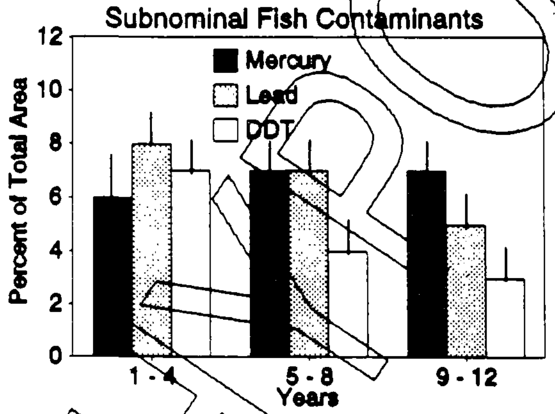

Figure 2-23. Percent of estuarine area in *Estuaria* with subnominal concentrations of mercury, lead, or DDT in fish tissues.

ASSESSMENT BY ADMINISTRATIVE REGION

Conditions within the two administrative regions of *Estuaria* (Region A and Region B) are different with respect to the integrity of biological communities and the impairment of uses valued by society. The most significant difference between the two regions is in how estuarine conditions have changed during the past 12 years.

Twelve years ago the proportion of undesirable estuarine area was approximately equal in Region A and Region B. In less than 12 years, the area with subnominal conditions attributable to either biotic integrity or human use has nearly doubled in Region A but has remained about the same in Region B (Figure 2-24). Conditions have declined to the extent that, in the last four years, EMAP sampling has shown no estuarine area within Region A that can be considered as desirable or nominal (Figure 2-25).

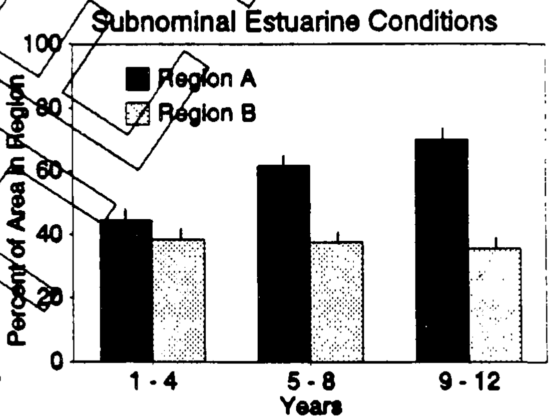

Figure 2-24. Percent of area in Regions A or B with subnominal estuarine conditions. Four year cumulative frequency and 90% confidence estimates given.

The biological decline of Region A is strongly associated with the increased occurrence of toxic sediments contaminated with Contamexx. The extent of toxic sediments has increased more than five-fold in Region A during the past 12 years (Figure 2-26). The widespread use of Contamexx in Region A has led to the accumulation of the pesticide in sediments at concentrations demonstrated to be toxic (Figure 2-27). Contamexx is not widely used in Region B, where agriculture is a small percentage of total land use.

Therefore, the extent of toxic sediments and Contamexx contamination is less prevalent in that region (Figure 2-28).

The widespread use of Contamexx in Region A has led to its accumulation both in estuarine sediments, and in fish tissue (Figure 2-29). Thus, Contamexx is associated with both the decline of biological communities and with contaminated fisheries.

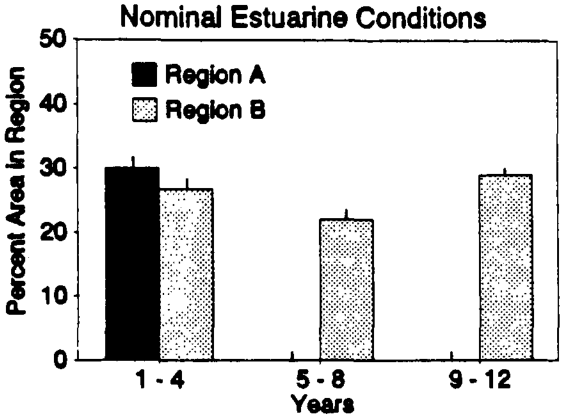

Figure 2-25. Percent of estuarine area in Regions A or B with nominal estuarine conditions. Four year cumulative frequency and 90% confidence estimates.

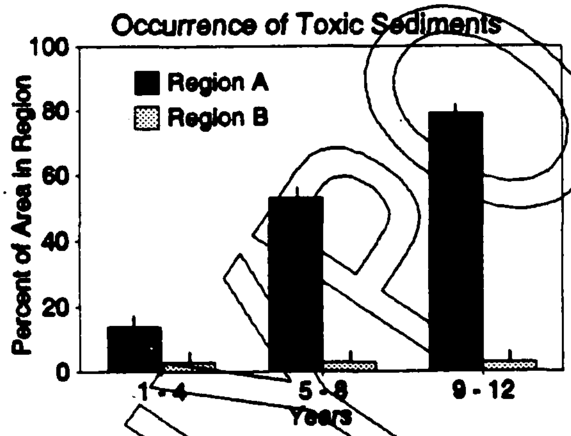

Figure 2-26. Percent of estuarine area in Regions A or B with toxic sediments. Four year cumulative frequency and 90% confidence estimates.

ASSESSMENT BY RESOURCE CLASS

The various problems faced by the estuarine resources of *Estuaria* generally affect all types of estuaries. However, the severity of each problem may depend on the type of estuary. Large estuaries are generally different from tidal rivers and small estuaries for reasons demonstrated previously (see Table 2-2). Because of these fundamental differences, many environmental problems are manifested differently in each estuarine class, and the best solutions to environmental problems may also differ among estuarine classes.

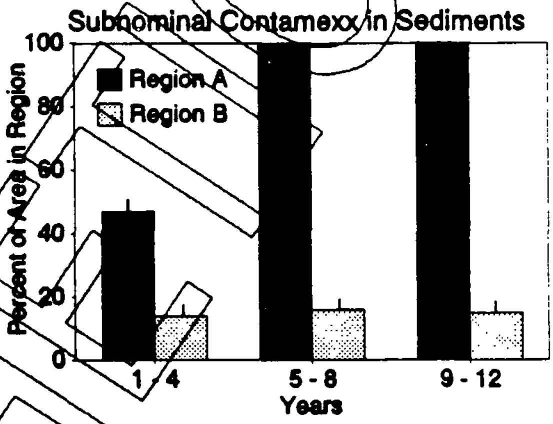

Figure 2-27. Percent of estuarine area in Regions A or B with subnominal concentrations of Contamexx in sediments. Four year cumulative frequency and 90% confidence estimates given.

Overall, the condition of large estuaries and small estuaries has been declining, reflecting the trend for *Estuaria* as a whole. However, there has been significant improvement in the environmental condition of tidal rivers (Figure 2-30), due to the improving status of biological communities. The area with subnominal communities in tidal rivers has decreased by almost 50%, whereas that area has significantly increased in other classes of estuaries.

The improving status of biological communities in tidal rivers is associated with improving oxygen concentrations. Over the last 12 years, the area with low oxygen concentrations (<2ppm) in tidal rivers has declined greatly (Figure 2-31).

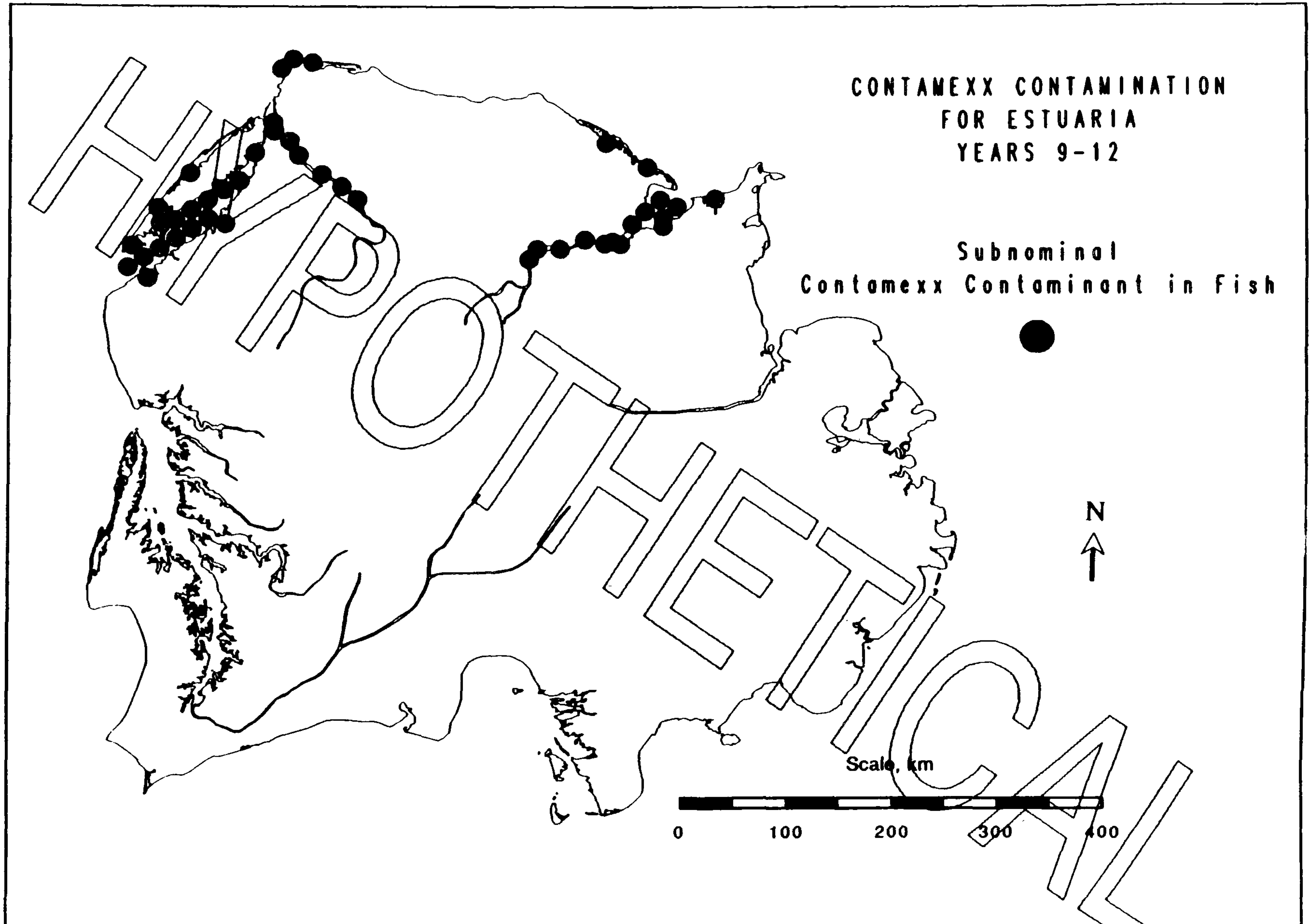

Figure 2-28. Distribution of areas with subnominal concentrations of Contamexx

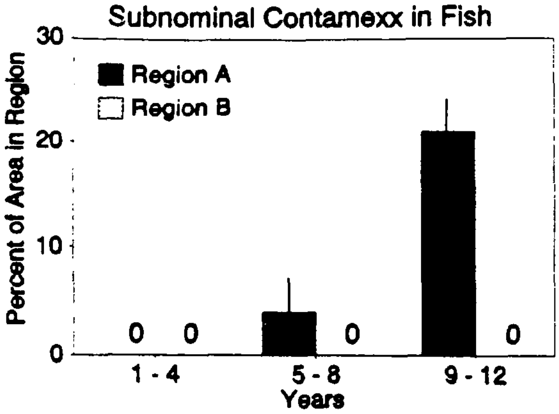

Figure 2-29. Percent of estuarine area in Regions A or B with subnominal concentrations of Contamexx in fish tissues. Four year cumulative frequency and 90% confidence estimates given.

In contrast to large tidal rivers, small estuaries generally have the worst environmental conditions and have undergone the most degradation during the past 12 years. Small estuaries have proportionally more subnominal area (Figure 2-30) than any other estuarine class.

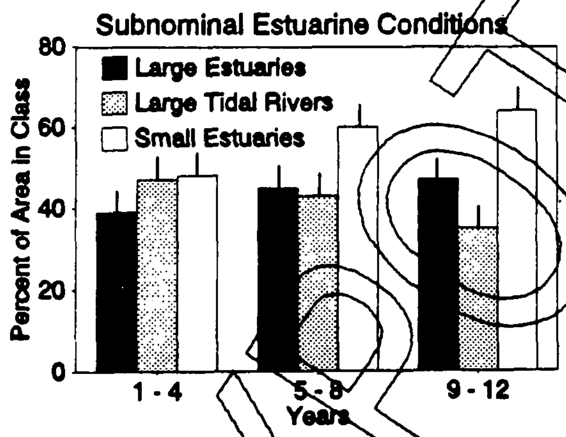

Figure 2-30. Percent of area in resource classes with subnominal estuarine conditions. Four year cumulative frequency and 90% confidence estimates.

Small estuaries have a greater proportion of area with toxic sediments than either large estuaries or large tidal rivers (Figure 2-32). The large extent of toxic sediments in small estuaries is associated with higher concentrations of all sediment contaminants and a higher percentage of sites with sediment contaminant concentrations exceeding recommended levels. The improving trend identified for some contaminants (lead and DDT, for example) for *Estuaria* as a whole was not apparent in small estuaries.

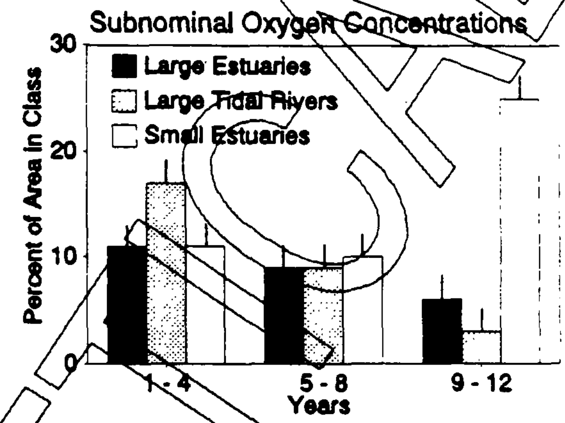

Figure 2-31. Percent of area in resource classes with subnominal oxygen concentrations. Four year cumulative frequency and 90% confidence estimates.

Although much of the decline in the biotic condition of small estuaries is associated with toxic sediments, low dissolved oxygen concentrations were also a significant factor associated with degraded conditions. With respect to dissolved oxygen concentrations, the most degraded areas in large estuaries and tidal rivers generally improved, and the area classified as subnominal declined. In small estuaries, however, dissolved oxygen concentrations significantly declined (Figure 2-31). Fully one quarter of the area in small estuaries is subnominal with respect to dissolved oxygen. Including marginal concentrations, almost three quarters of the area in small estuaries has less than desirable oxygen concentrations.

The declining conditions of small estuaries are associated with rapid increases in human population and development activity in the coastal zone. Overall, development within *Estuaria* has led to a decrease in forested and agricultural lands and an increase in urbanized and residential land (Figure 2-33). Development has concentrated along the fringes of estuaries, particularly small estuaries. Declines in condition in small estuaries are associated with this development. Small estuaries generally have a smaller capacity to assimilate wastes. Due to their small volumes and lower flushing rates, the greater accumulation of contaminants in small estuaries generally leads to greater concentrations and a higher probability of subnominal conditions, a conclusion supported by the EMAP data set.

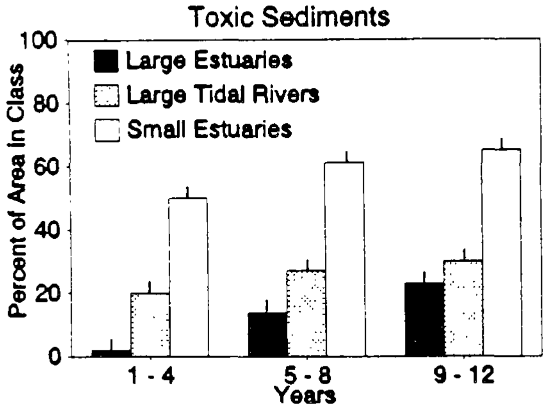

Figure 2-32. **Percent of estuarine area in resource classes toxic sediments. Four year cumulative frequency and 90% confidence estimates.**

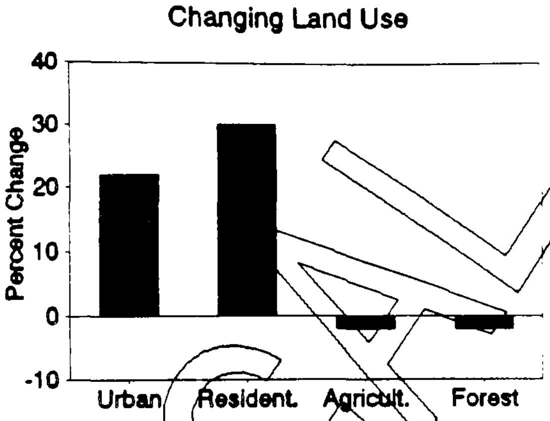

Figure 2-33. Percent change throughout *Estuaria* for four land use classifications. Differences between mean areas for years 1-4 and years 9-12.

From an overall perspective, regulatory programs do not appear to be achieving their desired effectiveness in ***Estuaria***:

- Almost half (46 ± 2%) of the estuarine area shows clear evidence of environmental degradation.
- The amount of degraded area has increased by approximately 0.5% per year since EMAP monitoring began.

EFFECTIVENESS OF REGULATORY PROGRAMS

One of the goals of EMAP is to assess the overall effectiveness of regulatory programs for protecting the quality of the environment. The design of EMAP provides several advantages over other, monitoring programs for doing so: (1) EMAP's principal response indicators are ecologically based, which allows integration of many more types of effects than chemical or impact-specific monitoring programs; (2) EMAP collects an array of response, exposure, and stressor measures, providing more comprehensive perspective on likely causes for observed effects; and (3) EMAP is focused regionally, allowing a broader perspective than is available from local monitoring programs. Local, site-specific monitoring programs or those directed towards specific contaminant or impact types provide insight on the effectiveness of environmental regulatory programs that address specific problems; EMAP provides a means for assessing the cumulative effects of regulatory programs.

The two principal problems being addressed by existing regulatory programs are control of toxic contaminants and control of conventional pollutants.

Controls of conventional organochlorine pesticides appear to be successful. For example, inputs of DDT to estuaries have been reduced by more than 99% since the 1970s and are now beginning to be expressed as improvements in the environment. There has been a 50% reduction over the last 12 years in the percentage of estuarine area that contains subnominal levels of DDT in the sediment and in fish tissue.

Regulatory controls on point sources of heavy metals, combined with regulations limiting their production by mobile sources, also have decreased total loadings to estuaries. For example, the percentage of estuarine area with unacceptable concentrations of lead in fish tissue has declined from 8% to 5% over the last eight years.

Use and manufacture of Contamexx have declined in the past six years, and the levels in estuarine sediments and fish are not increasing. In some areas, Contamexx concentrations are decreasing.

With respect to conventional pollutants, regulatory programs appear to be effective at reducing problems in severely affected areas. Over 70% of the sites with dissolved oxygen concentration below 2 ppm in the first four years of EMAP have improved during the past eight years. These sites are generally at the heads of estuaries, near urban centers and have benefitted from local reduction of organic carbon and nutrient loadings through point source controls. These improvements represent a success story for existing environmental regulations and the enforcement actions of regional offices.

However, as the bad sites got better with respect to dissolved oxygen, some of the best sites got worse. The net result is that a greater proportion of estuaries became part of the marginal category. Oxygen conditions at more than 30% of sites previously having acceptable dissolved oxygen concentrations have declined. These sites are generally in small estuaries, but some are also located in the deep, central portions of large estuaries. Declines in oxygen conditions at these sites were associated with increasing population densities in counties bordering the estuaries and with changes of land use patterns to residential and urban uses.

The inability to explain why 16% of estuarine area is subnominal with respect to biotic integrity remains a problem. Previous studies with repeated sampling have shown that our sampling error is less than 5%. Therefore, it is unlikely that all the observations of subnominal condition are due to misclassification. Instead, it suggests that there is some unmeasured environmental perturbation is occurring in some areas.

CONCLUSIONS

- Contamination by the pesticide Contamexx and its decomposition products has degraded biotic integrity and impaired human use of estuarine resources in *Estuaria*. Its environmental behavior, transport, and fate should be investigated to develop a comprehensive environmental risk assessment for the substance.

- Point source controls of conventional pollutants and the removal of leaded gasoline and DDT from the market appear to have resulted in improved dissolved oxygen conditions and reduced contaminant concentrations.

- Nonpoint sources of pollutants are a continuing problem with respect to both contamination and declining oxygen concentrations. Nonpoint source pollution is the likely cause of continuing degradation in small estuaries and is associated with urban and agricultural land use.

- Approximately 16% of biologically degraded areas were not associated with monitored environmental stresses. EMAP should attempt to identify probable causes of these degraded areas and should carefully monitor the status of these areas to determine if this is an emerging problem with potentially large consequences.

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SECTION 3
DATA SET SIMULATION

The development of the example assessment report required the analysis of a data set with spatial and temporal scales similar to those expected for EMAP data sets. However, no comparable studies of estuarine systems over large regional scales and decades exists. Most existing data sets that have broad spatial coverage include only a few years of data (e.g., NOAA 1988, 1989), and data collected over long time periods have restricted geographic coverage (e.g., Holland et al. 1987). Consequently, we fabricated a data set with the spatial and temporal resolution needed to complete the example assessment report.

Analysis of trends and integration of information collected from monitoring and assessment programs is depicted best with an adequate time series of data (NRC 1990). Because some of the data required to create such a time series will be provided only periodically (e.g., land use patterns and demographic information), we elected to cover a 12 year period to permit the use of these types of data. Therefore, the fabricated data set represented three EMAP sample "cycles" of four years each (Overton et al. 1990).

We devised a fictional island on which to impose the fabricated data set. The use of fictional geography minimized the chance that analyses and conclusions will be misinterpreted to represent a real province. We simulated a data set consisting of the types of estuarine information that EMAP will collect and applied it to the estuaries of the fictitious province. The data are based on published data for real estuaries.

The data set was developed in five basic steps:

- creation of a fictional map upon which to place the fabricated data sets and from which simulated sampling would occur
- selection of a subset of indicators for which data would be simulated
- development of indices that integrate selected indicators
- development of a base data set for the selected indicators and indices
- simulation of trends and associations superimposed onto the base data set for years 2 through 12

The remainder of this chapter provides some of the details on how each of these steps were conducted.

DEVELOPMENT OF A GEOGRAPHIC MAP

The fictional island was created by rearranging portions of coastline from the Virginian Province. Land use and watershed boundaries were established arbitrarily. We postulated that the western portion of the island was part of the United States, thus sampled by EMAP. This area was called *Estuaria* and comprised of two administrative regions. Region A was located in the northwestern portion of the island and dominated by agricultural land use. Region B was located in the southwestern portion of the island and dominated by forests.

An eastern portion was required to complete the fictional island after portions of the Virginian Province coastline were arranged. This region was postulated to be foreign (*Fredonia*), and estuarine areas in this portion of the island were not included in our analyses. In some respects, this area is analogous to the Canadian coastline between Washington and Alaska - an area that would not be sampled by a national program such as EMAP.

It was necessary to identify the number and distribution of estuaries in several resource classes (i.e., large estuaries, small estuaries, tidal rivers) so that we could sample consistent with the program plan for the Demonstration Project (Holland 1990). This was accomplished by fabricating the same number of each resource class as in the Virginian Province Demonstration Project Program Plan (Holland 1990). Estimates of estuarine area, necessary to weight the individual samples for averaging over *Estuaria*, also were taken from the Program Plan.

INDICATOR AND INDEX SELECTION

It was not possible to simulate 12 years of data for all of the indicators measured by EMAP in the Virginian Province Demonstration Project. Instead, we attempted to select a group of indicators that minimized the number of variables, yet effectively demonstrated the ability to detect and explain ecological changes. For instance, more than 50 contaminants in sediments and fish tissue will be measured during the Demonstration Project. We used data for only two organic and two inorganic chemicals to portray possible analyses and interpretation scenarios.

The indicators chosen for this report are shown in Table 3-1. In selecting indicators, we recognized that the sampling strategy for EMAP is based on using exposure, habitat, and stressor indicators to identify factors potentially contributing to the observed status and trends of response indicators and indices. Our approach was to select indicators that were illustrative of each indicator category and that provided the opportunity to explore a scenario of environmental degradation and improvement analytically. The selected indicators allowed us to demonstrate the value of each indicator category and to develop associations among indicators. For example, in this report we used benthic resources as indicators of ecological condition and showed how changes in benthic community parameters were associated with dissolved oxygen stress, contamination, or a combination of these factors. Within each category, we chose to simulate indicators that were most tightly linked to the benthic response indicator and for which data were most readily available.

Early in the development of the example assessment report, it became apparent that information about various indicators would have to be integrated to make statements about the overall condition of estuaries. Such integrated statements were made using indices that were mathematical aggregations of response indications. We endeavored to retain a sufficient number of variables in the data set so that we could synthesize indices of environmental condition. Although individual response indicators provide information concerning specific aspects of environmental condition, overall statements regarding the condition of resources are more useful to managers and non-scientific audiences. Single integrated statements may be more easily communicated and understood, and are more appropriate in establishing and measuring progress towards environmental goals.

The degree to which information and data will be aggregated to create indices of ecological or environmental condition is unknown. In this example report, we did not develop an overall estuarine condition index (ECI) because there were reservations concerning combining desparate metrics such as the biological condition index and human use index. Most likely, the development of an overall index will involve a cadre of specialists from both the natural and social sciences and will not be completed by resource level scientists alone.

The conceptual framework that EMAP might use to develop an estuarine condition index is presented in Figure 3-1. Essential features of this framework are that

- the ECI will be based on several independent indices that provide information on the two environmental attributes of interest -- biological integrity and human use;

- indices that compose the ECI will be derived from indicators measured by the field program, but additional information also may be used; and

- because of the hierarchical construction of the ECI, the relative contribution (weight) of each index (or indicator) to the ECI can be determined.

Indices that attempt to reflect the overall quality of estuaries will be controversial. There will undoubtedly be conflicting views of the value of particular indicators and combinations of indicators for the assessment of condition. Moreover, the mathematical procedures (e.g., weighting schemes) that will be used to combine indicators into the various indices have not yet been developed. The reader is cautioned that the indices are conceptual and are presented for illustrative purposes only.

Table 3-1. Construction of Simulated Data Set Base Variables		
Description	**Variable Type**	**Principle References**
Descriptive Variables		
Resource Class	Categorical: Large Estuaries Large Tidal Rivers Small Estuaries	Holland 1990
Area	Continuous	Holland 1990
Administrative Region	Categorical Region A Region B	Simulation
Habitat Indicators		
Salinity Class	Categorical Tidal Fresh (0-0.5‰) Oligohaline (0.5-5‰) Mesohline (5-18‰) Polyhaline (18-25‰) Marine (> 25‰)	Holland 1990; with modifications based upon: Scott et al. 1988; Dauer et al. 1988;
Sediment Type	Categorical Mud Sandy mud Muddy Sand Sand	Scott et al. 1988; Dauer et al. 1988; McMaster 1960; Sharp 1983; Sanders 1956
Exposure Indicators		
Sediment Contaminants - Mercury	Continuous	NOAA 1988
Sediment Contaminants - Lead	Continuous	NOAA 1988
Sediment Contaminants - DDT = DDT+DDD+DDE	Continuous	NOAA 1988
Sediment Contaminants - Contamexx (Total polychlorinated biphenyls)	Continuous	NOAA 1988
Sediment Toxicity	Categorical Non-toxic Toxic	Simulation (see Table 3-3)

Table 3-1. (Continued)

Description	Variable Type	Principle References
Exposure Indicators		
Dissolved Oxygen	Categorical Hypoxic (0-2 mg/l) Low (2-4 mg/l) Medium (4-6 mg/l) High (> 6 mg/l)	Scott et al. 1988; Holland et al. 1988; Dauer et al. 1988; Oviatt 1981; Sharp 1983
Response Indicators		
Benthic Community Type	Categorical Oxygen-stressed Contaminated sediment Tidal freshwater - Oligohaline Low mesohaline High mesohaline - sand High mesohline - mud Polyhaline/marine - sand Polyhaline/marine - mud	Holland et al. 1988; Dauer et al. 1988; TetraTech 1985
Fish Contaminants - Mercury	Continuous	Sloan (NYSDEC) pers. comm.
Fish Contaminants - Lead	Continuous	NOAA 1989; Sloan (NY-SDEC) pers. comm.
Fish Contaminants - DDT = DDT + DDD + DDE	Continuous	Sloan (NYSDEC) pers. comm.
Fish Contaminants - Contamexx (Total poly-chlorinated biphenyls)	Continuous	Sloan (NYSDEC) pers. comm.
Stressor Indicators		
Population Density	Continuous	1980 Census
Atmospheric Nitrogen Deposition	Continuous	1987 NADP/NTN (unpublished data)
Land Use Classification	Categorical Urban Residential Agricultural Forest	Assigned

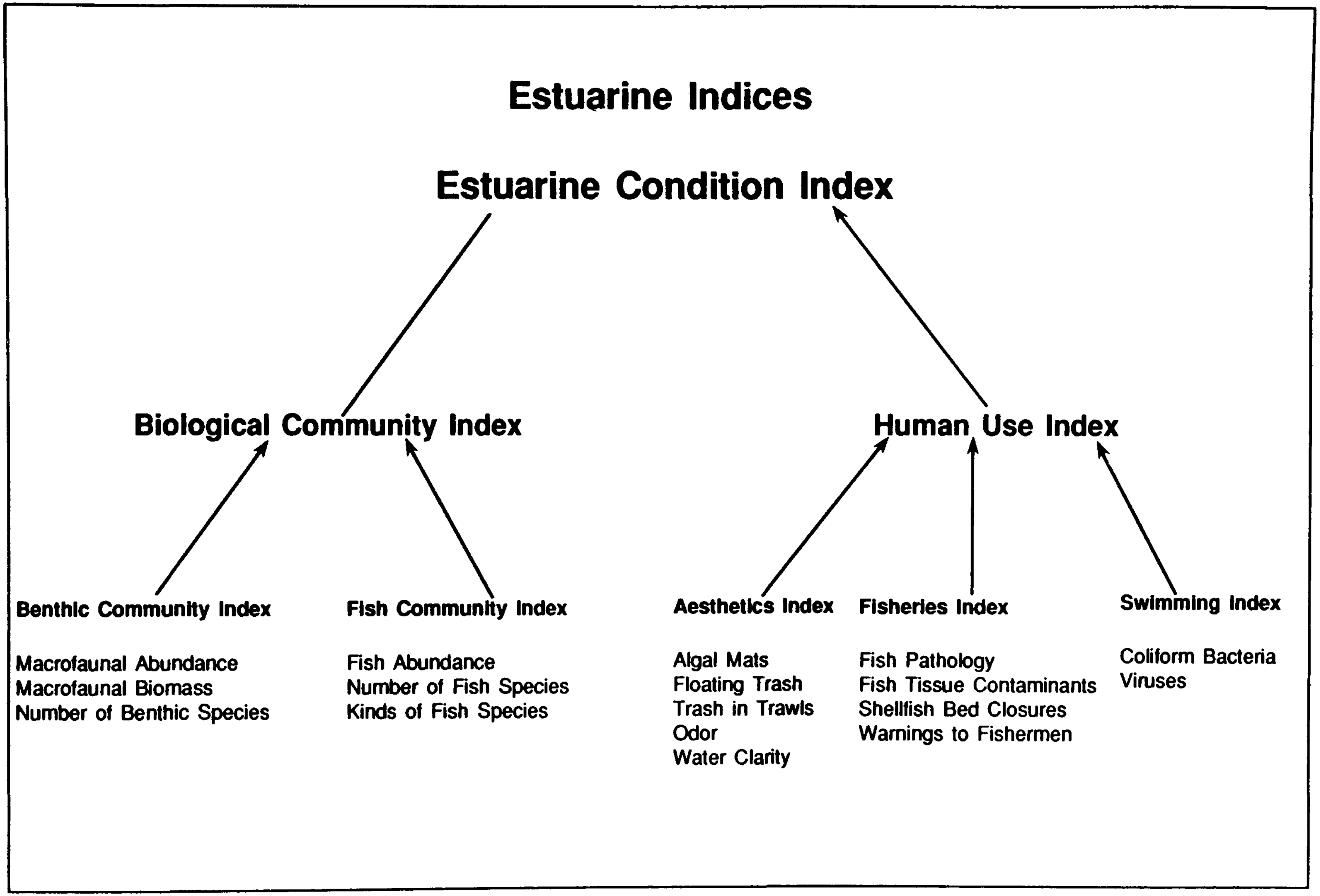

Figure 3-1. Components of estuarine indices proposed for EMAP (after Holland 1990).

BASE DATA SET

Fabrication of the base data set required developing both spatial pattern and variability estimates for each of the selected indicators. Spatial pattern information was intended to describe indicator response along gradients (e.g., latitude, salinity) or as a function of natural or anthropogenic influence (i.e., identifying that there are both good and bad locations with respect to environmental quality). This activity provided the mean response for each indicator at any station on our geographical map of *Estuaria*. Variability estimates were added to include small-scale spatial variability and sampling or analytical error. Inclusion of variability is crucial for development and testing of an analytical approach using the kinds of data that EMAP will obtain.

We used existing data or professional judgment to generate data sets for the first year, reproducing known spatial variability as closely as possible. Data for subsequent years (years 2 through 12) were generated randomly for each sampling station, based on the assigned classification of that station (e.g., contaminated, mesohaline, mud) and assigned distributions for each indicator (e.g., normal, negative binomial). This process produced a 12-year randomized baseline data set upon which trends were imposed (see Temporal Trends and Associations, below).

In developing the base data set, we used available information about pattern and variability for each of the indicators whenever possible. Pattern data were easily transposed to our map of *Estuaria* when eastern U.S. estuarine data were available for an indicator, since the coastline of *Estuaria* consists of mixed segments of the eastern U.S. coastline. Information was frequently incomplete for portions of the East Coast, typically for the small estuaries. Several strategies used to assign indicator values are described below.

Contaminant Indicators

EMAP proposes to analyze a suite of inorganic and organic contaminants in fish tissue and sediments based upon the list of contaminants currently measured in NOAA's Status and Trends Program (NOAA 1988). We chose three toxic contaminants (i.e., mercury, lead, and total DDT) from this list for inclusion in the data set. We chose lead and total DDT (i.e., sum of DDT, DDD, and DDE) because total emissions and environmental concentrations have decreased (USEPA 1980b, USEPA 1983, CEQ 1990, Alexander and Smith 1988). We created an example sediment contaminant that might increase over time, which we called "Contamexx". Contamexx distributions and variability were based upon those for total PCB.

The base data set for sediment contaminants includes data from NOAA's Status and Trends Program for 1984 to 1987 (NOAA 1988). NOAA stations were matched with specific stations used in the 1990 EMAP Near Coastal Demonstration Project (Holland 1990). Values for each of the EMAP stations were selected randomly from all replicate values available at the nearest NOAA site over the four years for which NOAA data are reported. Thus, an approximation of interannual variability was included in the data set. Since the NOAA Status and Trends Study did not include major rivers, decreasing gradients of contaminant concentration away from population centers were simulated, with variability based upon the nearest NOAA sample site.

Values for fish contaminants were selected from a list of NOAA monitoring stations near EMAP estuarine sampling stations using a nearest-neighbor approach. There were many gaps for tissue contaminant data. The NOAA sites were monitored for lead in shellfish; we used these estimates of lead concentrations in shellfish as estimates of lead levels in fish. In addition, we used information on fish tissue contaminants collected by the New York State Department of Environmental Conservation in New York and Rhode Island coastal waters to simulate contaminant levels in fish collected in *Estuaria*. Because of the limited spatial coverage of existing data, we assigned mean and variance estimates to "missing" sites based on the region as a whole. We also simulated areas of increased or decreased contamination by multiplying contaminant concentrations by appropriate factors. These differences reflected the general relationships observed in the sediment contaminant data.

Sediment toxicity was dependent on contaminant concentrations, with the exception that sediments near some large urbanized areas were considered toxic regardless of contaminant concentration. These methods are discussed below in the section on associations that were built-in to the data set.

Dissolved Oxygen

Dissolved oxygen data from estuaries along the U.S. East Coast were reviewed, and a spatial distribution of mean oxygen concentrations was generated for mid-summer values. Areas were categorized as having hypoxic (0-2 ppm), low (2-4 ppm), medium (4-6 ppm), or high (>6 ppm) oxygen concentrations. Each site was assigned one of the four oxygen categories, and oxygen values were assigned randomly from normal distributions centered on the mid-point of each category range.

Benthic Indicators and Index

The synthesized data set for benthic abundance, biomass, and number of species was created using data from two long-term benthic monitoring programs in Chesapeake Bay (Holland et al. 1988, Dauer et al. 1988), and one short-term study in Narragansett Bay (Tetra Tech 1985). These were used to define eight benthic community types (Table 3-1), depending on salinity, sediment type, oxygen concentrations, and the presence of contaminated sediments. Distribution parameters were estimated for each of the eight community types. Information for individual benthic species was not included in the simulated data set.

The base data set was constructed by random assignment of a value for abundance, biomass and number of species for each station from a range established for each of the eight community types. Normal distributions were assumed for numbers of species, and negative binomial distributions were assumed for abundance and biomass. If the number of species was zero, the values for abundance and biomass also were set to zero.

The benthic community index (Figure 3-1) was a linear combination of benthic abundance, biomass, and number of species. Our approach accounts for differences in community composition due to variations in salinity or sediment type. The benthic community index was computed only to illustrate an approach that may be used to integrate information from various indicators.

The benthic community index was calculated by classifying all sites into six categories defined by salinity and sediment grain size (Table 3-1). Benthic abundance, biomass, and number of species at each station were each normalized by dividing by the range for that benthic category. The three values were then summed to form the benthic community index. This index assumes that the number of species, abundance, and biomass are equally important characteristics describing benthic community structure.

Fisheries Index

An example categorical fisheries index (Figure 3-1) based on the concentrations of contaminants in fish tissues was also developed. The fisheries index was a worst-case combination of the four fish tissue contaminant indicators. If any contaminant concentration in fish tissue was above its subnominal threshold, then the fisheries index was subnominal. If the concentrations of all contaminants were nominal, then the value of the fisheries index was nominal. If any contaminant was marginal but none were subnominal, then the fisheries index was classified as marginal.

Habitat Indicators

Using available information from the Virginian Province, all EMAP stations in *Estuaria* were assigned to one of five salinity classes (Table 3-1). Values were assigned from uniform distributions for each salinity class. Sediment type was created by assigning one of four sediment types to each station using data from East Coast estuaries.

Stressor Indicators

Stressor indicators included in the fabricated data set were population density, atmospheric deposition of nitrogen, and land use classifications. We included atmospheric nitrogen because of the recent interest in this pathway as a significant source of nitrogen to estuaries and, therefore, a potential contributor to eutrophication (Fisher et al. 1988, Tyler 1988, USEPA 1989). Data for population density and land use classifications were generated for years 1 and 10 only. Data for the atmospheric deposition of nitrogen were generated for all 12 years of the base data set.

For population density, we used 1980 U.S. Census Bureau data for East Coast counties and applied these data to fictitious counties within *Estuaria*. Population surfaces were made using a geographic information system (GIS) to associate a value for population density with each sample location.

Estimates of atmospheric nitrogen deposition were based upon 1987 data from the National Acid Deposition Program/National Trends Network (NADP/NTN). A surface model was generated from nitrate wet deposition data, and the values for the specific sampling sites were back-interpolated from that model. Total deposition was calculated assuming that dry deposition was equal to wet deposition (Schwartz 1989). Land use was simulated for *Estuaria* using a GIS. Four land use categories were generated: urban, residential, agricultural, and forest.

TEMPORAL TRENDS AND ASSOCIATIONS

In addition to estimating the status of environmental conditions with known confidence, a goal of EMAP is to measure changes in status (trends). Trends were introduced into the fabricated data set by imposing proportionate changes on values in the base data set (Table 3-2). Recall that the base data set consisted of 12 years of randomized, simulated data.

Four different types of trends were imposed on the base data set:

- monotonic increases or decreases of a constant amount for each year and for all stations
- improvement of conditions at the worst stations due to overall successes of regulatory and control measure
- degradation of conditions at the best stations due to population growth and suburban development
- significant increase in the manufacture and agricultural use of Contamexx in one of the administrative regions of *Estuaria*

Descriptive variables and habitat indicators remained the same throughout the 12 years of simulation. No temporal trend was created for mercury concentrations in sediments or fish tissue. Monotonic decreases were imposed for concentrations of lead and total DDT in sediments and fish tissue. Monotonic increases were created for atmospheric nitrogen loading and population density. The magnitude of the monotonic changes ranged from 1% to 5% per year. These values were selected to help evaluate the general goal of trend detection for response indicators on the order of 1% per year over a 10 to 15 year period (Hunsaker and Carpenter 1990).

The distributions of dissolved oxygen concentrations and benthic community parameters were changed to develop the scenario of the worst sites getting better and the best sites getting worse. Oxygen concentrations were increased at 16 stations. At those stations, the number of benthic species, benthic abundance, and benthic biomass also were increased. Oxygen was decreased at 16 sites with initially high oxygen concentrations. At those sites, benthic abundance and biomass were increased, reflecting increased production in eutrophic waters not subject to hypoxia.

The 16 sites where oxygen concentrations increased were located near the more urbanized areas of *Estuaria*. The improvement of these "worst stations" reflected the assumption that environmental regulation, control, and enforcement would decrease conventional pollutant loadings in these areas. The 16 stations where oxygen concentrations decreased were located mostly in small estuaries. We postulated that population growth in coastal areas will continue to increase (OTA 1987; Culliton et al. 1990), causing an increase in the residential and urban land use classes, particularly around small estuaries. Thus, the "best stations" in *Estuaria* declined due to the influence of increasing population density.

Finally, we created a scenario for Contamexx. We postulated that Contamexx is a relatively new, highly effective pesticide used primarily in the agricultural regions in northern *Estuaria* (Region A). Contamexx is a highly mobile pesticide that is applied in low concentrations. In the scenario (Table 3-2) the use of Contamexx

Table 3-2. Simulated Temporal Trends		
Variable	**Simulated Trend**	
Descriptive Variables (see Table 3-1)	None	
Habitat Indicators (see Table 3-1)	None	
Exposure Indicators		
Sediment Contaminants - Mercury	None	
Sediment Contaminants - Lead	Monotonic decrease of 1%/yr at all stations	
Sediment Contaminants - Total DDT	Monotonic decrease of 2%/yr at all stations	
Sediment Contaminants - Contamexx	Monotonic increase of 5%/yr at stations within Region B. Region A stations increased as follows:	
	Year	Percent Increase from Previous Year
	1	
	2	50
	3	200
	4	500
	5	500
	6	500
	7	100
	8	50
	9	10
	10	2
	11	0
	12	-20
Dissolved Oxygen	Oxygen unchanged at most stations. A monotonic increase of 5%/year simulated at 16 stations having low oxygen concentrations. A monotonic decrease of 5%/year simulated at 16 stations having high oxygen concentrations.	

<table>
<tr><th colspan="3">Table 3-2. Simulated Temporal Trends (Continued)</th></tr>
<tr><th>Variable</th><th colspan="2">Simulated Trend</th></tr>
<tr><td>Response Indicators</td><td colspan="2"></td></tr>
<tr><td>Benthic Number of Species</td><td colspan="2">A monotonic increase of 5%/year simulated at 16 stations where oxygen concentrations were made to improve associations with other indicators simulated (see Table 3-3).</td></tr>
<tr><td rowspan="8">Benthic Abundance</td><td colspan="2">A monotonic increase of 5%/year simulated at the 32 stations where temporal trends were simulated for oxygen. Associations with other indicators simulated (see Table 3-3).</td></tr>
<tr><td colspan="2">Percent change for:</td></tr>
<tr><td>Year</td><td>Abundance</td></tr>
<tr><td>8</td><td>0</td></tr>
<tr><td>9</td><td>-10</td></tr>
<tr><td>10</td><td>-10</td></tr>
<tr><td>11</td><td>-5</td></tr>
<tr><td>12</td><td>-5</td></tr>
<tr><td rowspan="8">Benthic Biomass</td><td colspan="2">A monotonic increase of 5%/year simulated at the 32 stations where temporal trends were simulated for oxygen. Associations with other indicators simulated (see Table 3-3).</td></tr>
<tr><td colspan="2">Percent change for:</td></tr>
<tr><td>Year</td><td>Abundance</td></tr>
<tr><td>8</td><td>-10</td></tr>
<tr><td>9</td><td>-10</td></tr>
<tr><td>10</td><td>-10</td></tr>
<tr><td>11</td><td>-5</td></tr>
<tr><td>12</td><td>-5</td></tr>
<tr><td>Fish Contaminants - Mercury</td><td colspan="2">None</td></tr>
<tr><td>Fish Contaminants - Lead</td><td colspan="2">Monotonic decrease of 5%/year at all stations</td></tr>
<tr><td>Fish Contaminants - DDT</td><td colspan="2">Monotonic decrease of 5%/year at all stations</td></tr>
<tr><td>Fish Contaminants - Contamexx</td><td colspan="2">Simulated Temporal Trends as for Sediment Contamexx</td></tr>
</table>

Table 3-2. Simulated Temporal Trends (Continued)	
Stressor Indicators	
Atmospheric Nitrogen Loading	A monotonic increase of 1%/year at all stations
Population Density	A monotonic increase of 5%/year at all stations
Land Use	Growth of urban and residential areas at the expense of agricultural and forest areas

increased over the first 7 to 9 years of the 12 year data set, then declined. We postulated that Contamexx is toxic, enters estuarine areas primarily through non-point sources, and that concentrations in sediments and fish increase. The scenario for Contamexx is extreme. It is used as an example of a contaminant that increases in concentration and causes demonstrated toxic effects to benthic communities.

Associations between indicators were built into the fabricated data set (Table 3-3). Associations included those between oxygen concentration and benthic community structure, between sediment contaminants (i.e., mercury, total DDT, and Contamexx) and sediment toxicity, and between sediment toxicity and benthic community type. Other associations may be present because we constructed the data set using as many realistic data distributions as possible.

ASSUMPTIONS

We made a number of assumptions in developing the example assessment report for year 12 of monitoring. The two most important assumptions concern the sampling design of the program and the identification of subnominal and nominal threshold values for indicators.

Sampling Design

The sampling design for estuaries that will be used subsequent to the 1990 Demonstration Project has not been finalized. The eventual sampling design may be some modification of the interpenetrating design proposed by Overton et al. (1990). The current design outlines a four year sampling cycle (Hunsaker and Carpenter 1990). We incorporated this aspect into our simulated data set and chose to base most descriptions of status on aggregations of four years of data. This approach minimizes the short-term, climatic variability that may be introduced by a particularly wet spring, dry summer, or other meteorological event.

Indicator Thresholds

An objective of EMAP is to estimate, with known confidence, the proportion of estuarine area with undesirable or unacceptable ecological conditions. This implies that scientific knowledge of estuarine processes is sufficient to determine acceptable or desirable (nominal) conditions and unacceptable or undesirable (subnominal) conditions and to distinguish between the two. This is not a straightforward task. Although regulatory limits or thresholds are well defined for some indicators, thresholds are not well developed for most environmental quality indicators, particularly response indicators.

It is not our objective to establish thresholds for the estuarine indicators. However, since an objective of the program is to use thresholds to summarize ecological conditions within estuaries, we postulated that such thresholds exist by year 12 of the program (Table 2-1 of the example report). Many of our thresholds are based upon available scientific information and currently accepted management practices. For example, oxygen concentrations below 2 ppm (≈ mg/liter) are defined as hypoxic and are generally considered subnominal. Oxygen concentrations between 2 and 5 ppm (marginal) may be harmful to selected species, particularly fish. Concentrations above 5 ppm represent nominal conditions.

FDA and EPA action limits provided general guidance for identification of indicator thresholds for fish tissue contaminants. The FDA action limits for fish tissues are 1.0 ppm for mercury

Table 3-3. Associations Built-In to Data Set

Independent Variable	Dependent Variable	Relationship	
Sediment DDT	Sediment Toxicity	If DDT concentration ≥ 50 ppb then sediment toxicity is positive	
Sediment Mercury	Sediment Toxicity	If Mercury concentration ≥ 1.0 ppm then sediment toxicity is positive	
Sediment Contamexx	Sediment Toxicity	If Contamexx ≥ 0.5 ppb then sediment toxicity is positive	
Sediment Contamexx	Benthic Class	If Contamexx ≥ 2.0 ppb then benthic class is contaminated	
Sediment Toxicity	Benthic Class	If sediment toxicity is positive then Benthic class is contaminated	
Dissolved Oxygen	Benthic Community, Diversity, Abundance, and Biomass	Oxygen Concentration	Benthic Response
		0 - 0.5 ppm	Species No.=0 Abund.=0 Biomass=0
		0.5 - 1 ppm	Species No.<4 Abund.<250 Biomass<0.5
		1 - 2 ppm	Species No.<6 Abund.<500 Biomass<1
		2 - 3 ppm	Species No.<10 Abund. as is Biomass<2
		3 - 4 ppm	Species No.<10 Abund. as is Biomass<4
		> 4 ppm	As generated

and 5.0 ppm for total DDT. No action limit exists for lead concentrations in fish tissue. These thresholds were not useful to illustrate changes in ecological condition for the simulated data set because no samples exceeded action limits for some contaminants. Therefore, we arbitrarily chose values to define nominal and subnominal boundaries for fish tissue (see Table 2-1 in report).

There are no generally accepted criteria to judge the acceptability of contaminant concentrations in sediments. Therefore, we inspected the data in our simulated data set and conservatively defined subnominal, marginal, and nominal values for sediment contaminants, such that subnominal concentrations occurred in less than 5% of the total estuarine area of *Estuaria* for year 1. Most of these areas occurred in relatively small harbors and tidal rivers. Only a small portion of the larger estuaries had toxic sediments.

There are few guidelines to define nominal and subnominal thresholds for benthic communities. Data from the long-term benthic monitoring programs in Chesapeake Bay (Dauer et al. 1988; Holland et al. 1989) were used to define nominal and subnominal levels for benthic biomass and the number of benthic species. Subnominal boundaries for benthic parameters were set at values observed in severely contaminated habitats (e.g., inner Baltimore Harbor) and habitats consistently exposed to low dissolved oxygen concentrations (e.g., deep Channel habitats of the central Chesapeake Bay). Marginal values were set at values observed at marginally contaminated environments (e.g., outer Baltimore Harbor) and sites periodically exposed to low dissolved oxygen concentrations.

DETERMINATION OF STATUS

Annual statistical summaries will report most data in the form of cumulative distribution functions (CDFs). The CDFs in the annual statistical summaries will form the basis of subsequent analysis (Figure 3-2). Confidence intervals for CDFs are estimated from binomial proportions or from procedures of Horvitz and Thompson (1952) and Overton (1987).

The CDFs are permanent "snapshots" of resource condition and can be used directly for visual estimates of the proportion of a resource that is subnominal. If nominal-subnominal thresholds change due to new information or political pressure, then the new thresholds can be superimposed on the CDF's and status can be visually reassessed (Figure 3-2).

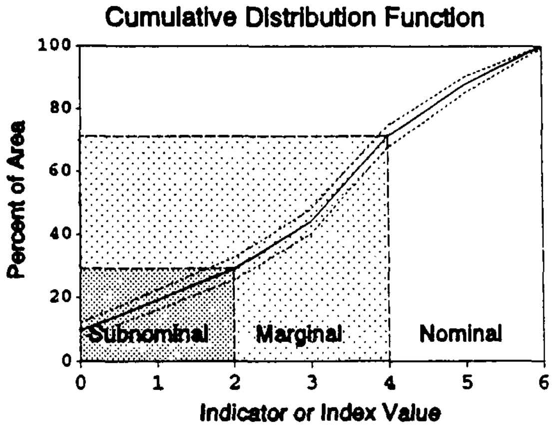

Figure 3-2. Example cumulative distribution function showing subnominal, marginal, and nominal categories.

SECTION 4
LESSONS LEARNED

Development of reports is an important part of the planning and development of a major new assessment program such as EMAP. The resulting example is valuable to potential users and performs the following important functions:

- provides a "preview" of EMAP products to potential users
- provides a tool (i.e., an example data set) for evaluating alternative analytical approaches and selected aspects of the sampling design
- identifies technical problems in program plans and helps establish priorities for addressing those problems
- trains a team of scientists for performing actual assessments

Many of the lessons learned in preparing this report may be applicable to other EMAP resource groups. The lessons learned through this effort are categorized into the following topical areas:

- delineation of differences between assessment reports and annual statistical summaries
- identification of analytical approaches for synthesis and interpretation of estuarine data into information useful for EMAP constituents
- identification of the value of a realistic synthetic data set with regional patterns and a multi-year time frame

ASSESSMENT REPORTS AND ANNUAL STATISTICAL SUMMARIES

A series of products will disseminate EMAP results to constituents: (1) annual statistical summaries, (2) special scientific reports, and (3) assessment reports. An annual statistical summary will be produced for each EMAP resource category (e.g., Surface Waters, Wetlands, Forests) and assessment reports will be prepared periodically. Special scientific reports will be prepared as needed to address technical issues (e.g., evaluation and testing of indicators or of the sampling design). This series of documents is designed to disseminate EMAP data in a timely manner to a broad range of audiences at a variety of technical levels. The contents of assessment reports and annual statistical summary reports are compared in Table 4-1.

Annual statistical summaries for EMAP will present descriptive statistics for all indicators, including cumulative frequency distributions, measurements of central tendency, measurements of uncertainty, and an evaluation of the quality of the data. They also will summarize important sampling information (e.g., number of sample sites by subpopulation, variables measured, maps of sample locations). Spatial patterns and status of key response and exposure indicators will be described. Temporal trends will be summarized in graphic form and may be analyzed for statistical significance, but no interpretations or statistical associations among indicators will be presented in the annual summaries. Information collected for other EMAP resource cateories or data collected by other environmental monitoring programs generally will not be included in EMAP annual statistical summaries. For example, atmospheric nitrogen deposition data in coastal areas probably would not be included. Annual statistical summaries are intended to be detailed and exhaustive: they will describe and summarize the data for technical audiences.

Special scientific reports will be prepared mainly for technical audiences, and the treatment of specific technical issues will be extensive. Examples of special scientific reports that will be prepared by EMAP include: methods manuals, data management reports, design and analysis evaluations, and research reports. These reports will provide the scientific basis for annual statistical summaries and assessment reports.

Assessments reports are intended to synthesize and interpret data and findings presented in annual statistical summaries and special scientific reports. Discussions presented in assessment

Table 4-1. Comparison of EMAP Annual Statistical Summaries and Assessment Reports	
Annual Statistical Summary	**Assessment Report**
Includes all indicators measured by EMAP for a resource category	Limited to selected indicators that tell a story or address specific questions
Provides a summary of sampling statistics	Does not discuss sampling statistics
Presents detailed description of sampling and processing methods	Presents short overview of sampling and processing methods; includes a brief description of analytical methods
Does not include indicator data from other sources	Includes all necessary data
Provides status summaries for all indicators	Status assessment focused on relevant response indicators
Provides trends summaries for all indicators	Trends evaluations focused on response and stressor indicators
Includes descriptive statistics only; extremely limited interpretation of results; no association analyses	Includes descriptive and interpretive statistics; association analyses leading to plausible explanations of observed status and trends
Directed toward technical audiences, with examples and major findings highlighted for a general audience	Short document, intended for general audiences and managers. Analyses and conclusions may need to be backed up by special scientific reports. Detailed scientific explanations of major findings are highlighted for technical audiences.

reports will not be exhaustive and will not attempt to interpret all data collected. Rather, summarize the condition of the nation's estuaries; additional assessments may be prepared in response to specific environmental issues.

ANALYTICAL APPROACHES

Assessing the ecological condition of resources in a region or nation is a formidable challenge. Results presented in assessment reports must be scientifically defensible and presented in a manner that can be understood by non-technical audiences. Unfortunately, ecological science has not developed measures of environmental condition that are accepted by scientists and understood by the public and other non-technical audiences. Standardized methods for assessing cumulative environmental impacts and partitioning those impacts into the contributions associated with major pollution stresses are not currently available.

Preparation of the example assessment report indicated that EMAP must conduct several analyses to accomplish its objectives. These include:

- assessment of the capacity of estuaries to support valued ecological resources and human uses (i.e., status);

- measurement of changes in condition occurring over time (i.e., trends);

- identification of factors that are likely to be contributing to observed condition and changes in condition (i.e., by statistical associations).

The overall assessment of estuarine condition is based upon these analyses.

Use of CDFs

We originally intended to use cumulative distribution functions (CDFs) to represent status and trends. However, no CDFs were presented in our example assessment report because simpler graphic displays of the data (e.g., bar charts) conveyed the necessary information more clearly. Relatively large changes, frequently in the extreme ends of distributions, were not apparent in CDFs, even when these changes were substantial (e.g., a factor of 2).

Multiple CDFs are required to present information on response indicators that vary among classes for subpopulations of interest. A single, meaningful CDF cannot be constructed. For example, a CDF based on the number of benthic species found in marine and brackish habitats (subpopulations) cannot be aggregated into a combined CDF because marine habitats have more species than brackish habitats. Ultimately, CDFs will need to be produced for response indicators that have been normalized for variations due to habitat.

Index Development

Although individual response indicators are important measures of specific aspects of environmental condition, the goal of EMAP is to provide single statements regarding estuarine condition in a province or region. Multiple statements (i.e., assessments) about the status and trends of the nation's estuaries, each based on different response indicators, fail to synthesize data sufficiently. Single, integrated statements about the overall condition of estuarine resources are easily communicated and understood. Single statements, such as those presented in the example report, are also valuable for measuring progress toward achieving an overall improvement in the environment.

Prior to preparation of the example assessment report, we had not envisioned the potential utility of indices. We initially proposed developing an overall estuarine condition index (ECI) that would aggregate the biological community index and the human use index (Figure 3-1). However, this presented the problem of how to combine the two indices and what criteria were necessary to weight one vs. the other. We realized that the development of an index based on such desperate measures would eventually involve the combined efforts of both natural and social scientists. Because of these problems, we did not develop an ECI for the example assessment report. However, we did make mention to such an index in Chapter 3 to show that the development of an overall index may be part of future assessment activities.

The development of indices that reflect the overall quality of estuaries will be controversial. There will undoubtedly be conflicting views of the value of particular indicators and combinations of indicators for assessment. EMAP will have to conduct extensive testing of the indices to demonstrate their reliability and sensitivity.

Subnominal Thresholds

For each estuarine class, we estimated the proportion that was in subnominal or unacceptable condition. The approach reduced continuous variables to categorical variables and required determining the values that were unacceptable for each environmental quality index and for each of the response indicators. Currently there are few generally accepted limits that can be used to define thresholds for the indicators that will be measured by EMAP. In the example assessment report we established these boundaries using available data and our best judgment. Because definition of these thresholds is critical, EMAP must develop a strategy for defining meaningful thresholds.

The analytical approach developed for the example assessment report (see below) required us to set subnominal and nominal thresholds for exposure indicators as well as response indicators. This approach differs from the indicator strategy previously developed for the program which implied that thresholds would only be determined for response indicators (Hunsaker and Carpenter 1990). We acknowledge that determining thresholds for exposure indicators will be difficult and possibly cannot be done in a rigorous fashion. However, the use of categories of values for exposure indicators was the only way we identified to make useful associations between response indicators and exposure indicators.

Analyses

Status and trends analyses were conducted using a "top-down" approach. An indicator or index was examined at the highest level (biogeographic province) first, followed by subsequent analyses, as necessary, at lower levels of class or at the individual system level. However, a single regional assessment requires aggregation of classes (i.e., large estuaries, large tidal rivers, and small estuaries). Since different sampling strategies were used in each class, inclusion probabilities were different and estimates of variance were not comparable. Our preliminary solution was to weight data according to the area represented by each sampling site. Clearly, the appropriate method of combining data from different resource groups and classes is a statistical problem that EMAP must address.

Prior to preparation of the example assessment report, EMAP envisioned using a systematic approach for identification of associations, including generation of correlation matrices and multiple regressions. This approach was used during initial data analysis; however, we were unable to identify meaningful relationships between indicator categories.

A decompositional approach was more productive. Indices, such as the benthic index, were decomposed into their component response indicators. These, in turn, were analyzed for associations with condition of the integrative indices. Statistical associations between response and exposure indicators were examined to explore subnominal condition in the response indicators. Association between exposure and stressor indicators were examined for further evidence in support of significant relationships. Association analysis linking subnominal condition in response indicators directly to stressors also was a powerful method for identifying factors potentially contributing to adverse effects, particularly if the presumed causal mechanism was manifested in several exposure indicators (e.g., human population growth could be associated with any number of exposure indicators).

The decompositional approach is potentially useful for directing further research or management actions because it identifies the variables that statistically contribute most to the observed subnominal condition. It does not necessarily identify the most statistically significant associations, but it can identify those likely to have contributed to a given subnominal condition.

The analytical approach used to define associations treats variables (i.e., indicators and indices) as categorical and uses multi-dimensional contingency tables as a means to explore relationships among the data. Although the approach was fruitful, we caution that it may be misleading to analyze only the marginal tables of a multi-way table [see Simpson's paradox in Agresti (1990)]. Careful and thoughtful analyses are critical, especially when indices are involved. This approach needs to be developed further and requires EMAP to establish strong statistical support as an integral part of the program.

Data From Other Sources

The example assessment report demonstrates that in order to perform an assessment for one EMAP response category, substantial data from other resource categories and other agencies will be required. These data, mainly stressor indicators, include information such as population, population growth, land use, freshwater flow, nutrient loadings, contaminant loadings, NPDES discharges into estuaries, and atmospheric deposition of pollutants (Table 4-2). Unfortunately, much of the available data for stressors may be of limited value to EMAP-E, because the fundamental unit of estuarine pollution is the watershed. Data for most stressor indicators is not available for entire watersheds at appropriate spatial and temporal scales. To interpret environmental relationships, stressor data must be arranged according to watershed, not according to regional or political boundaries.

Display of Data on Maps

Although we presented only three maps in the example assessment report, we attempted to display various aspects of estuarine condition with GIS. The actual construction of *Estuaria* was accomplished using GIS, and this provided useful illustrations of political boundaries (Figure 2-5), land use (Figure 2-6), and the regional distribution of fish tissue contamination (Figure 2-28).

Effective mapping of EMAP data for estuaries was not a trivial matter. We found that consistent and broad geographic differences, such as

Table 4-2. Estuarine Auxiliary Data Requirements and Sources		
Data	**Geographic Units**	**Sources**
Population, Population Change	Watershed	U.S. Census Bureau
Land Use	Watershed	EMAP Landscape Characterization
Flow	Major Streams; Watershed	USGS
River Nutrients and Contaminants	Major Streams; Watershed	USGS, NOAA Status and Trends
NPDES	Estuary	NOAA
Atmospheric Deposition	Watershed; Estuary	EMAP Air and Deposition
Non-point Nutrient and Contaminant Input	Watershed; Estuary	NOAA; Dept. of Agriculture; U.S. Forest Service
Wetlands Loss	Watershed; Estuary	U.S. Fish and Wildlife Service

the north-south differences in *Estuaria*, could be well-represented. However, the likelihood of this type of result from any one biogeographic province is small.

The representation of regional contamination was possible because we restricted the occurrence of subnominal conditions to Region A. However, it was difficult to portray spatial distributions of subnominal conditions with respect to other indicators or indices (e.g., benthic community index). The geographic distribution of estuaries and tidal rivers presents special problems for EMAP. For example, illustration of EMAP information for tidal rivers is difficult: few stations are sampled within a river, and unless conditions are identical at all stations, the variations (gradients) in condition must be presented. This is difficult simply because the scale of the map is more appropriate for depiction of regional information. Attempts to display gradients in tidal rivers result in the portrayal of condition at individual sites -- clearly, this type of image contradicts the EMAP objective of representation of regional condition.

Mapping of EMAP information for estuaries is problematic because estuaries are noncontinuous resources distributed along the linear boundary of a coastline. Spatial representation of data works well for a continuous two-dimensional surface with an adequate sample density. A well-known example is land use, where any one map representation may consist of thousands of 30 m pixels. The largest estuary in the United States is the Chesapeake Bay, in which 24 regular grid stations were sampled during the EMAP Virginian Province demonstration project. This sample density would be sufficient for a contour map of salinity, but for little else. Each tidal river had five sample stations, and each small estuary had a single sample station. It is not yet clear how EMAP data for discrete resources (such as estuaries) will be illustrated on maps. Because coastlines are linear, information on the three-dimensional (i.e., latitude, longitude, depth) aspect of estuarine condition is lost. This hampers the use of some common GIS techniques such as surface modeling. At best, these approaches may be attempted, but the presentation would be fundamentally different from the surface modeling of two-dimensional landscapes.

Finally, an environmental discontinuity separates estuaries from their watersheds. Investigation of associations between measured estuarine indicators and stressors requires some way to relate the stressor (e.g., poulation density) to either a specific sampling point or to an estuary. There are several possible approaches, most of which require modeling of the estuary and its watershed; this would be beyond the scope of EMAP. We attempted to project atmospheric nitrogen deposition and human population density onto estuarine sampling stations, but this required a number of assumptions. For example, we were not able to model the hydrodynamics of estuaries; therefore, the actual effect of a particular stressor was not adjusted to reflect the local hydrologic regime (e.g., flushing rate, tidal exchange, contribution of surface runoff).

The spatial representation of estuarine condition requires further thought and research. Broad, regional differences in condition can be displayed effectively. However, the scale of maps, the linear distribution of estuaries, and the discontinuity of resources must be considered in any attempt to resolve the issue of GIS mapping for estuarine provinces.

APPLICATIONS OF REALISTIC DATA SETS

We created a realistic data set based on existing Virginian Province data for development of the example assessment report. We could have prepared an example assessment report without using a realistic data set by simply developing a series of graphics to support reasonable scenarios for the status and trends of "key" indicators. The benefits of using a realistic data set justified the considerable expense of developing and analyzing the data set.

These benefits included

- development of an analysis plan for the synthesis and integration of data before data collection is completed;
- identification of analytical problems in the planning phase of the program, while there is time to solve them;
- empirical evaluation of the ability to detect monotonic trends in data collected from an EMAP sampling design;
- demonstration of the critical importance of subnominal and marginal thresholds;
- demonstration of realistic expectations for EMAP estuarine data and results.

Details of these benefits are discussed below.

Because EMAP requires timely development of assessments the analytical approaches must be well planned and tested prior to actual data acquisition. We tested several analytical approaches using the synthetic data and quickly learned the limitations and benefits associated with them. We did not exhaust all possibilities, but we were able to identify at least one approach that may provide useful information for assessments. In addition, we can now provide descriptions of specific analytical problems that we are likely to encounter; these problems can be addressed and solved prior to complete acquisition of data. Actual data for evaluations of statistically significant trends will not be available for 10 to 12 years. Because solutions to some analytical problems may require modifications to the implementation strategy, it would be disastrous to wait until data collection has been completed to identify and resolve these problems.

A critical finding was that the overall EMAP sampling design was flexible and supported a broad variety of analyses. We were able to demonstrate that monotonic, annual changes of 1% to 2% in any indicator value (e.g., sediment concentrations of lead) are detectable using nonparametric methods. However, we could not demonstrate that parametric approaches were useful or appropriate for trend detection. EMAP will use the model data set developed for this example assessment in conjunction with the actual data collected during the 1990 Virginian Province Demonstration Project to conduct a detailed evaluation of several aspects of the sampling design in the future. This detailed evaluation will include: assessment of sample allocation schemes, identification of an appropriate spatial scale for representing ecological condition by estuarine class, and determination of the likelihood of meeting program objectives (i.e., development of data quality objectives).

A realistic data set was not required to demonstrate that EMAP needs to develop environmental condition indices that integrate data for multiple response indicators. However, a realistic data set was essential for defining the types of problems that would be associated with index development, including composition of indices, development of weighting factors for variables, scaling of parameters, and adjustment of indices for habitat effects (e.g., salinity).

A realistic data set provided further evidence that the definition of subnominal and marginal thresholds for indicators and indices is a critical step. Realistic data were essential to assessing the sensitivity of analytical results to the thresholds that were established. Without a realistic data set, the consequences of misclassifications of station conditions would not have been apparent.

Undoubtedly, the most important benefit that resulted from using realistic data is confidence that the analyses and results are similar to those that will actually be achieved. This ensures that we will not build unrealistic expectations for constituents (i.e., EMAP has not been "oversold"). If the example assessment had been developed from a series of hypothetical graphics, we would not have had confidence that the final example would resemble a real assessment report. An inaccurate example report would contribute to false expectations and perhaps mislead EMAP clients.

CONCLUSIONS

Development of an example assessment report was useful, not only to the investigators involved in the project, but to the program as a whole. The production of an example report required a detailed strategic plan and a clear understanding of the objectives of EMAP.

The exercise resulted in the following guidelines for analyzing EMAP data and producing an actual assessment:

- Because of the diverse nature of the data, the approach for analyzing, interpreting, and presenting the data must be flexible. This is especially important for long-term programs such as EMAP, in which program elements may change over time.

- Assessment of condition useful to resource management and policy development requires a clear definition of nominal and subnominal conditions and the establishment of subnominal-marginal thresholds for indicators and indices.

- Investigation of associations will require applicable data for stressor indicators (e.g., human population density, atmospheric deposition, loadings)

- Statistical methods will need to be identified for investigation of associations between stressor indicators at regional or watershed resolution and exposure and response indicator data at much finer spatial resolution.

- Sufficient time must be allowed for exploratory statistical analyses and for the assessment of information. Analytical investigations of complex and varied data cannot be constrained by rigid strategies for data analysis and must be free to explore the data in ways that may be dead ends but also may form a new understanding of the relationship between natural and anthropogenic stresses and environmental condition.

Assessment reports communicate information that culminates years of effort by each resource group. The production of these reports will require far more sophisticated analyses and careful decision-making than data reporting in annual statistical summaries. As an example of this difference, we call attention to the experience of NAPAP (National Acid Precipitation Assessment Program), which required tremendous effort at the end of the program to produce an integrated assessment of acidic deposition. EMAP, with a broader scope than NAPAP, will require not only greater efforts, but continuous dedication to this endeavor in order to provide useful information and insightful assessments of ecological condition.

SECTION 5
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