NATIONAL OCEAN POLLUTION PROGRAM

FEDERAL PLAN FOR OCEAN POLLUTION RESEARCH, DEVELOPMENT, AND MONITORING
Fiscal Years 1992-1996

Prepared by the National Ocean Pollution Program Office
for the National Ocean Pollution Policy Board

SEPTEMBER 1991

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of the Chief Scientist

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SEPTEMBER 1991

U.S. DEPARTMENT OF COMMERCE
Robert A. Mosbacher, Secretary

National Oceanic and Atmospheric Administration
John A. Knauss, Under Secretary

Office of the Chief Scientist
Sylvia A. Earle, Chief Scientist

UNITED STATES DEPARTMENT OF COMMERCE
The Under Secretary for
Oceans and Atmosphere
Washington, D.C. 20230

DEC 23 1991

The President
The White House
Washington, D.C. 20500

Dear Mr. President:

I am pleased to submit the Federal Plan for Ocean Pollution Research, Development, and Monitoring: Fiscal Years 1992-1996, as required by the National Ocean Pollution Planning Act of 1978, Public Law 95-273 (as amended).

Sincerely,

John A. Knauss

Enclosure

THE ADMINISTRATOR

UNITED STATES DEPARTMENT OF COMMERCE
The Under Secretary for
Oceans and Atmosphere
Washington, D.C. 20230

DEC 23 1991

Honorable Dan Quayle
President of the Senate
Washington, D.C. 20510

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Sincerely,

John A. Knauss

Enclosure

THE ADMINISTRATOR

UNITED STATES DEPARTMENT OF COMMERCE
The Under Secretary for
Oceans and Atmosphere
Washington, D.C. 20230

DEC 23 1991

Honorable Thomas S. Foley
Speaker of the House of Representatives
Washington, D.C. 20515

Dear Mr. Speaker:

I am pleased to submit the Federal Plan for Ocean Pollution Research, Development, and Monitoring: Fiscal Years 1992-1996, as required by the National Ocean Pollution Planning Act of 1978, Public Law 95-273 (as amended).

Sincerely,

John A. Knauss

Enclosure

THE ADMINISTRATOR

Acknowledgments

Many people have taken part in the planning, drafting, and review of the *Federal Plan for Ocean Pollution Research, Development, and Monitoring: Fiscal Years 1992-1996*. The National Ocean Pollution Policy Board and the Task Force to the Board assisted in determining the scope and organization of the Plan. In addition, every department and agency represented on the Board also made available technical experts and program managers to assist in developing the informational content of the Plan. Finally, the Board contributed to the Plan process by reviewing the final draft of the Plan to ensure that both national priorities and agency interests were given proper consideration.

The Board convened two separate working groups in order to bring scientific and technical expertise to bear on the development of the Plan. The Science Working Group met in January 1991 at the State University of New York at Stony Brook, Long Island, for a 2-day conference to bring together experts in the goal areas of the Plan. Dr. R. Lawrence Swanson, Director of the Waste Management Institute at the University, was the co-chairman of the program. The result of these deliberations was the first draft Plan.

The draft Plan became the basis for the work of the Federal Working Group. Managers and scientists in the National Ocean Pollution Program met in January and in March in Washington, DC, to produce a second draft Plan, which incorporated information from each organization on the future needs and directions of the Federal program. This second draft was then sent out to the departments and agencies and to the participants at the Stony Brook meeting for a final review. About 75 people (listed in the Appendices B and C) invested considerable time and energy in the deliberations of these working groups and the review processes.

Plan preparation was assisted by Science and Policy Associates, Inc. (SPA) and Tetra Tech, Inc. (Tt). Dr. Mary C. Barber of SPA served as the Plan Manager, while Mr. Andrew Zacherle of Tt was the Project Technical Coordinator. Ms. Whitney Carroll of SPA served in several technical capacities during the Plan process. Members of the Tt staff contributed to the drafting of the Plan. They are listed below by the specific goal area with which each was associated:

Toxics	Dr. Mahmood Shivji
Nutrients	Mr. Steven Ellis
Pathogens	Mr. Mark Shibata and Dr. Esther Peters
Habitat	Ms. Sharon Gross, Ms. Margaret Wilson, and Mr. Andrew Zacherle
Ecosystems	Dr. Esther Peters and Mr. Thomas Grieb
Human Health	Mr. Sean Donahoe

The following persons were not members of the working groups but rendered in-depth reviews of various drafts of the Plan: Dr. Michael Kemp, University of Maryland Center for Environmental Studies; Dr. Garry Mayer, National Marine Fisheries Service/NOAA; Dr. Thomas Nalepa, Great Lakes Environmental Research Laboratory/NOAA; Dr. Donald Rhoads, SAIC, Inc.; Dr. John Sutherland, Office of Oceanic and Atmospheric Research/NOAA; Dr. Douglas Wolfe, National Ocean Service/NOAA; and Dr. Joy Zedler, San Diego State University.

To all those who contributed to this Plan, we acknowledge with thanks your excellent service.

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Preface

The National Ocean Pollution Planning Act of 1978 (P.L. 95-273, as amended) calls for the establishment of a comprehensive, coordinated, and effective Federal Program for ocean pollution research, development, and monitoring. As required by the Act, the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), in consultation with other agencies, prepares a 5-year *Federal Plan for Ocean Pollution Research, Development, and Monitoring* every 3 years. This document represents the fifth edition of the Plan and covers Fiscal Years 1992-1996. This Plan discusses six goals of the National Ocean Pollution Program, discusses the extent to which ongoing Federal programs are meeting these goals, and provides recommendations for improving the overall effort in marine pollution research and monitoring.

The National Ocean Pollution Program Office (NOPPO) is assigned responsibility within NOAA for updating the 5-year Plan and coordinating the implementation of recommendations in the Plan. These efforts are conducted in cooperation with the National Ocean Pollution Policy Board. NOAA established the interagency Board under the authority of Section 3A of the National Ocean Pollution Planning Act. The Board is chaired by NOAA and is composed of senior representatives from 12 Federal departments and agencies.

This update of the *Federal Plan for Ocean Pollution Research, Development, and Monitoring* has been prepared by NOPPO with assistance and review of the agencies that participate in the National Ocean Pollution Program. The Plan is submitted by NOAA to Congress with the endorsement of the departments and agencies that are represented on the National Ocean Pollution Policy Board.

W. Lawrence Pugh
Director
National Ocean Pollution Program Office

Executive Summary

The National Ocean Pollution Program is the composite of all programs funded by the Federal Government that conduct marine pollution research, development, or monitoring activities. Activities are funded by 11 Federal departments and independent agencies (a twelfth department, State, does no domestic pollution funding) and include studies pertaining to pollution in coastal areas, estuaries, open oceans, and the Great Lakes. This Plan represents the fifth document in the continuing interagency planning process called for in the National Ocean Pollution Planning Act of 1978 (P.L. 95-273), as amended. As required by the Act, a comprehensive 5-year Plan for the overall Federal effort is prepared and updated every 3 years. This Plan identifies national marine pollution needs and problems, analyzes the extent to which Federal programs assist in meeting these needs and solving the problems, and makes recommendations for improving the National Ocean Pollution Program.

Goals of the National Program

The National Ocean Pollution Program has six broad goals:

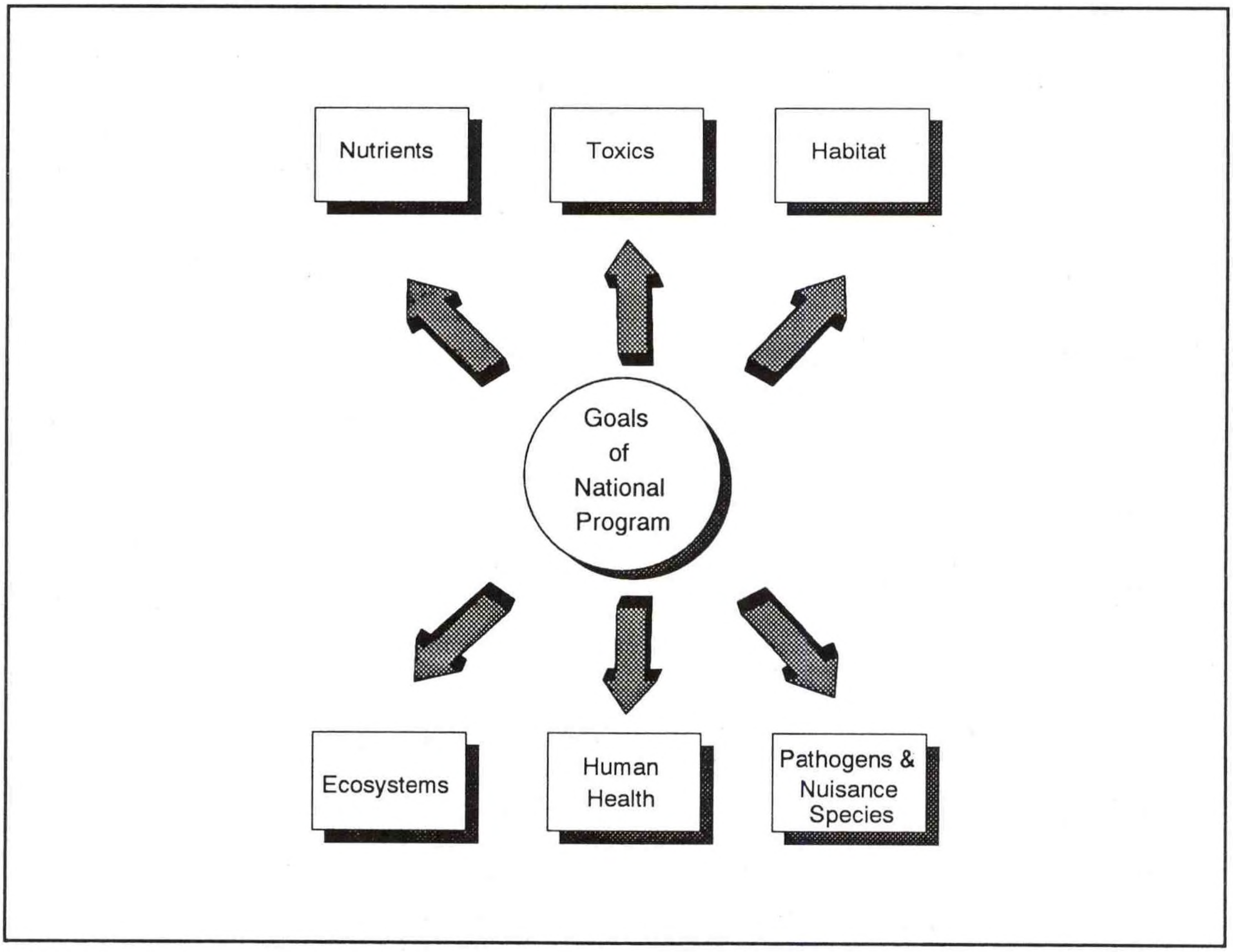
- Toxic Materials. Understand the sources, fates, and effects of toxic materials entering the marine environment as a result of human activities.
- Nutrients. Understand the sources, fates, and effects of nutrients entering the marine environment as a result of human activities.
- Pathogens and Nuisance Species. Understand the sources, fates, and effects on aquatic organisms of pathogens and nuisance species that are introduced or influenced by human activities.
- Loss or Modification of Marine Habitat. Understand the effects of losing or modifying marine habitat as a result of human activities.

- Status of Marine Ecosystems. Document the trends in the status of marine ecosystems.

- Human Health. Understand the implications of marine pollution to human health.

The ocean pollution research, development, and monitoring programs funded by the Federal agencies contribute to these six areas of endeavor. To meet these goals, the scope of the programs undertaken includes the following: assessing the state of the environment (e.g., developing basic understanding, analyzing effects, implementing monitoring systems); developing the capability to predict (e.g., impacts of human activities); and developing multipurpose program support capabilities (e.g., data management, measurement methodologies).

The 1992-1996 National Ocean Pollution Program Plan presents recommendations for research, development, and monitoring activities related to ocean, coastal, and Great Lakes pollution. These recommendations, prepared by the National Ocean Pollution Program Office, with the assistance of the Scientific and Federal Working Groups, address the most pressing research and information gaps for the next five years under each of the six goals. A more detailed discussion of research and information gaps associated with each goal and the rationale for the proposed recommendations can be found in the goal chapters. The recommendations are listed on the pages that follow.



Toxic Materials

The toxic substances, organic chemicals, and some of the metals that are released into marine waters have a wide variety of harmful effects on organisms and ecosystems. Some aspects of quantification of the routes, transformations, and especially sources of toxic materials from surface runoff, contaminated sediments, and atmospheric deposition continue to be major issues. Much work has been done to understand the processes controlling availability of sediment-associated toxic substances and the role of metabolic activities on uptake, biotransformation, bioaccumulation, and toxicity. A final major issue is the difficulty and complexity of understanding and predicting the adverse effects on ecosystems caused by toxic substances. In particular, additional efforts are needed to quantify the value of indicators to document exposure of organisms, populations, and communities to toxic materials and the sublethal deleterious effects of these materials on individuals and populations. To address these issues, the following recommendations are made:

Recommendations

1. ***To quantify the routes, transformations, and sources of toxic contaminants released to the marine environment —***

- Collect additional monitoring data in order to more accurately quantify fluxes and loading rates of toxic substances from the atmosphere, rivers, and nonpoint sources.
- Continue research to determine the role of contaminated sediments as a source of toxic substances released to the marine environment.
- Continue to develop new and improved techniques for sampling and measuring toxic substances in marine microenvironments, particularly the sea-surface microlayer, the sediment/water interface, and interstitial waters.

2. ***To determine the bioavailability and bioaccumulation of toxic contaminants —***

- Conduct basic research elucidating the interrelationships between physicochemical, physiological, and environmental processes and chemical speciation that influence bioavailability, uptake, and the bioaccumulation of toxic substances.
- Continue research to develop, refine, and validate models for predicting uptake and bioaccumulation of toxic substances, particularly for sediment-associated contaminants.
- Conduct research on the role of biotransformation and other metabolic activities on the uptake, bioaccumulation, and toxicity of chemical contaminants in the marine environment.

3. ***To determine the relationship between exposure to toxic contaminants and effects —***

- Conduct additional research to develop markers that indicate sublethal toxicological effects of pollutants on organisms in laboratory and field studies.
- Conduct additional research to determine the relationship between sublethal effects in individuals and population responses to toxic contaminants.
- Continue research addressing the links between toxic contaminants and known effects.
- Continue to conduct research on combinations of toxic substances to identify interactive effects on marine organisms.

Nutrients

Excess nutrients as a result of human activities can cause eutrophication and community structure changes in marine and Great Lakes waters. Quantification of the loading of nutrients, especially from nonpoint sources and cycling of nutrients within the system, continues to be a pressing research and management issue. The effects of excess nutrients not only in causing hypoxia but also in contributing to toxic algal blooms are also a concern. To address these issues, the following recommendations are made:

Recommendations

1. ***To quantify the amounts, rates, and sources of nutrient inputs —***

- Conduct research to determine the relative importance of nutrient sources to nutrient budgets in marine ecosystems and to characterize the spatial and temporal variability of nonpoint sources of nutrients.
- Conduct research to characterize nutrient cycling between organic and inorganic pools and the role of dissolved and particulate nutrient fractions in marine ecosystems.
- Develop improved techniques for synoptic areal coverage of nutrients and/or their indicators (e.g., algal blooms).

2. ***To determine the effects of excess of nutrients —***

- Continue research to determine conditions under which macronutrients and/or micronutrients control primary productivity.
- Conduct additional research to determine the trophic structure changes resulting from changes in nutrients inputs.
- Develop protocols and indicators that can provide advanced warning of, or document existing effects of, hypoxia at the population level.
- Conduct further research on the role of freshwater input, basin physiography, and nutrients in causing hypoxia and anoxia in marine ecosystems to support the development of models of eutrophication, prediction of hypoxia and anoxia, and quantification of the effects of hypoxia and anoxia on aquatic and marine organisms.

Pathogens and Nuisance Species

This goal addresses only pathogens affecting marine species, not humans. Pathogens that cause disease in marine animals and plants and nuisance species (problem-causing microorganisms and macroorganisms that have been introduced into an environment where they are not naturally found) have received attention in recent years as mass mortalities (e.g., widespread dolphin deaths) and ecosystem effects become better documented. Major issues related to pathogens are the need to systematically identify when the decline in a population is related to pathogens and to further understand the mechanisms or processes involved when marine organisms become infected. Major issues related to nuisance species are identification of their sources, identification of their effects on host communities, and development of control mechanisms. To address these issues, the following recommendations are made:

Recommendations for Pathogens

Pathogenic microorganisms and their impacts on aquatic resources have received relatively little attention in the past as compared to other forms of pollution. The following recommendations are made to gain a better understanding of the role of pathogens in altering marine populations and the quality of marine environments:

1. ***To determine the problems associated with pathogens —***

- Conduct research directed at identifying pathogens responsible for disease outbreaks and mass mortalities of marine organisms.
- Improve techniques for identifying and communicating the occurrence of epizootics and mass mortalities.

2. ***To determine the characteristics, requirements, and mechanisms of pathogenicity —***

- Quantify the sources of the most significant pathogens.
- Conduct research to determine the persistence and transport mechanisms of pathogens.
- Perform comprehensive studies of the ecology of indigenous and exotic pathogens.
- Conduct research to determine mechanisms of pathogenicity.
- Conduct research to determine the influence of human activities on disease susceptibility, host defenses, and host-agent interactions.

Recommendations for Nuisance Species

Nuisance species have the potential to remove or displace populations and assemblages of indemic species, thus altering ecosystem structure and function. The impacts of introduced/exotic nuisance species, however, are poorly understood. The following recommendations are made to increase our understanding of nuisance species that have been introduced or influenced by human activities:

1. ***To determine the potential sources of introduced nuisance species —***

- Develop a centralized information service for tracking introductions of nonindigenous species.
- Conduct research on the relationship among organism life histories, introduction pathways, and affected communities.

2. ***To determine the biology, ecology, and effects of nuisance species —***

- Conduct basic and applied research on the biology and ecology of nuisance species.
- Conduct research on the impacts of nuisance species on the receiving ecosystem.
- Conduct research on human activities contributing to exotic species introductions.
- Conduct research on environmental conditions facilitating the spread of and damage by nuisance species.

3. ***To develop control mechanisms for nuisance species —***

- Conduct research on natural controls of nuisance species populations as well as biological, mechanical, and chemical controls.
- Conduct research on the feasibility of monitoring nuisance species.

Loss or Modification of Marine Habitats

When marine, estuarine, and Great Lakes habitats, especially wetlands, are destroyed or degraded, the populations of organisms depending upon these habitats for feeding, spawning, and/or refuge may decline. These organisms include marine mammals, birds, and economically significant fishery species. Quantification of the amount and locations of marine habitats and their rates of destruction and degradation continues to be a pressing issue. Understanding the differences between habitat types and between natural and restored habitats in supporting resident and migratory species remains a critical research and management issue. A final major issue is the effects of habitat modification, especially changes to freshwater inflow, on marine organisms. To address these issues, the following recommendations are made:

Recommendations

1. ***To determine the status of habitat quantity and quality —***

- Develop a national protocol integrating and coordinating the activities of Federal and State agencies to determine land/habitat cover and change in the coastal region of the United States on a 1- to 5-year basis.
- Develop mechanisms to integrate Federal, State, and local data bases (including ground and remotely-sensed surveys) into geographical information systems.
- Improve cooperative efforts among Federal, State, and local groups to identify and document causes of changes in marine habitats.

2. ***To determine the function of coastal marine habitats supporting living marine resources —***

- Augment research to understand habitat processes and functions and how changes in these functions affect the support of marine organisms.
- Continue to develop new methods to measure and assess habitat function.
- Conduct research on key habitat factors for growth and survival of marine organisms and determine key trophic pathways and linkages among habitats.
- Expand efforts to develop methods for assessing the cumulative impacts of human activities in coastal marine habitats, including the development of models to predict the effects of region-wide habitat loss and modification on coastal ecosystems.
- Develop improved approaches (including long-term monitoring activities) to assess the effectiveness of habitat restoration and creation techniques.
- Improve methods for habitat restoration and creation.

3. ***To determine the effects of habitat loss and modification on marine organisms —***

- Conduct research to study the effects of sediment, salinity, and water quality changes on habitat quality/status.
- Develop a suite of interlinked models (geological, physical, and biological) to predict/describe habitat changes and effects on living marine resource productivity and economic value.
- Conduct research to study responses of populations to habitat changes.

Status of Marine Ecosystems

Because of increasing human activity and demand for aquatic resources, it is important to have the capacity to assess conditions and trends in the quality of marine ecosystems and to be aware of early warning signals of unacceptable conditions. One of the critical issues related to our ability to assess status and trends is the need for acceptable ecological endpoints to quantify an ecosystem's response to stress and to conduct ecological risk assessments. Associated with this issue is the need for effective indicators to determine spatial and temporal changes in ecosystem status and to evaluate the effectiveness of management and regulatory strategies. A further need is to ensure data and information comparability among national and regional monitoring programs. To address these issues, the following recommendations are made:

Recommendations

1. To assess status and trends by the use of indicators —

- Continue development and application of relevant biological indicators to ascertain the status and health of different ecosystems.
- Develop ecological protocols that link monitoring results with modeling to relate population, community, and ecosystem effects to environmental changes.

2. To ensure effective monitoring programs —

- Continue to develop and refine regional and national marine ecosystem monitoring programs and evaluate their ability to meet specific program objectives.
- Continue to develop protocols to ensure comparability of data and information from Federal monitoring programs with national and regional scope.

Human Health

Human health concerns related to marine pollution center on possible implications of organic chemicals and some metals, pathogenic microorganisms, and marine biotoxins. Primary issues are the limited data on concentrations of toxic substances in seafood and on seafood consumption patterns. Further, although there is increased public awareness, there is limited information on exposure and risk to humans from pathogens. To address these issues, the following recommendations are made:

Recommendations

1. To determine the threat to human health from chemical contamination —

- Develop consistent methods for sampling and analyzing fish tissue for chemical contaminants designed specifically for risk assessment purposes.
- Design and conduct appropriate surveys on seafood consumption patterns suitable for risk assessment purposes relative to commercial, recreational, and subsistence fisheries.
- Develop and recommend methods for assessing exposure and risk, particularly to high-risk groups, from seafood consumption.

2. ***To determine the exposure of humans to pathogenic microorganisms and marine biotoxins —***

- Continue research to determine which marine pollution-related pathogens are causing human health effects.
- Continue efforts to improve our ability to monitor seafood and water quality for the human pathogens and marine biotoxins associated with marine pollution, including development of rapid detection methods.
- Continue research on the survivability and transmission of pathogenic microorganisms and biotoxins.
- Develop methods to remove and/or inactivate the human pathogens such as Norwalk-like viruses found in municipal effluents and sewage sludge.
- Conduct research to develop cost-effective means for removing, reducing, and/or inactivating chemical contaminants and/or pathogens in fish.

Priorities for Action

In addition to making specific research and monitoring recommendations for achieving each of the goals of the National Program, the National Ocean Pollution Plan presents an "Action Agenda" for the National Ocean Pollution Policy Board to pursue during the interim between Federal Plans. The items presented in the agenda are specific and implementable tasks that the Board will consider addressing. To respond to this Agenda, interagency committees or work groups may be convened by the Board to address aspects of the following topics:

- Toxic algal blooms;
- Public health emergency response mechanisms;
- Marine ecosystem monitoring programs;
- Cumulative habitat loss; and
- Restoration and creation of coastal habitats.

Chapter I

Introduction

Interagency Coordination

The National Ocean Pollution Planning Act (NOPPA) of 1978, P.L. 95-273 (as amended), requires the National Oceanic and Atmospheric Administration (NOAA) to prepare a "comprehensive 5-year plan for the overall Federal effort in ocean pollution research, development and monitoring." Section 4 of the Act requires an update of the Plan every 3 years. Preparation of this 5-year Plan is the process by which a consensus is reached among scientists and environmental specialists, from both within and outside the Federal agencies, as to the future direction of Federal programs. Through the Plan process, the highest priority pollution issues and information gaps are identified and recommendations are developed for Federal activities to address these gaps.

The Act also requires the establishment of a National Ocean Pollution Policy Board as the entity responsible for coordinating interagency participation in the development of the 5-year Plan. The National Ocean Pollution Program Office (NOPPO) was established by NOAA to execute the mandate of Section 4 of the Act by providing a focal point for the Policy Board for coordination of Federal efforts in ocean pollution. To meet this mandate, NOPPO, in consultation with the Policy Board, has prepared this 5-year Federal Plan for the National Ocean Pollution Program. It is the fourth update of the first 5-year Plan, which was published in 1979.

In common usage, the term *pollution* has assumed a variety of meanings and applications. Under NOPPA, *ocean pollution* is defined as "any short-term or long-term change in the marine environment" where changes (usually adverse) are caused by human activity. The basic types of pollution effects on the marine environment that are of concern include the following:

- Negative effects on marine biota at the individual, population, community, or ecosystem level;
- Effects that decrease the continued availability of marine resources for human use (e.g., contamination of fish or drinking water resources in the Great Lakes); and
- Negative effects on human health.

A variety of human activities contribute to marine pollution and jeopardize the continued availability of marine resources. These activities include the disposal of dredged material, sewage, and industrial wastes; the recovery of oil and gas from the continental shelf; marine transportation; and marine mining. Pollution may also be linked to nonpoint sources and accidental spills. Physical alterations of marine habitats caused by human activities are also considered to be marine pollution because they often result in negative effects, such as the loss of living marine resources.

This document addresses Federal pollution research, development, and monitoring programs in coastal waters, estuaries, open oceans, and the Great Lakes and it identifies opportunities for future pollution studies.

Goals of the National Program

The National Ocean Pollution Program is the composite of all the marine pollution research, development, and monitoring programs conducted by the Federal Government. The purpose of the National Program is to provide scientists, managers, and decision makers with recommendations for research, development, and monitoring activities to improve the effectiveness of the overall National Program. The National Ocean Pollution Policy Board has identified the following broad goals for the National Ocean Pollution Program:

1) Understand the sources, fates, and effects of toxic materials entering the marine environment as a result of human activities;

2) Understand the sources, fates, and effects of nutrients entering the marine environment as a result of human activities;

3) Understand the sources, fates, and effects on aquatic organisms of pathogens and nuisance species that are introduced or influenced by human activities;

4) Understand the effects of losing or modifying marine habitat as a result of human activities;

5) Document the trends in the status of marine ecosystems; and

6) Understand the implications of marine pollution to human health.

The first four goals of the National Program address specific categories of pollutants or physical alterations to the marine environment (i.e., toxic materials, nutrients, pathogens and nuisance species, and habitat alterations). The last two goals, which are related to the status of marine ecosystems and human health, integrate the first four goals and permit the Program to take into account all of the various contributions to ocean pollution.

The Planning Process

The Federal Plan for Ocean Pollution Research, Development, and Monitoring is required by Section 4 of NOPPA to perform several functions.

- Identify national needs and problems relating to ocean pollution;
- Establish priorities in addressing these needs and problems;
- Describe the Federal programs and projects related to ocean pollution; and
- Make recommendations for changes in the overall Federal effort in ocean pollution research and monitoring to ensure that priority national needs and problems are met by Federal programs during the Plan period.

The planning process undertaken during the development of this plan is shown in Figure 1.1. As part of this process, two working groups were convened to provide new information concerning the state of the science and Federal agency programs and activities addressing today's priority ocean pollution issues. The first work group, or Scientific Work Group, was composed of scientific experts from the non-Federal sectors. The second

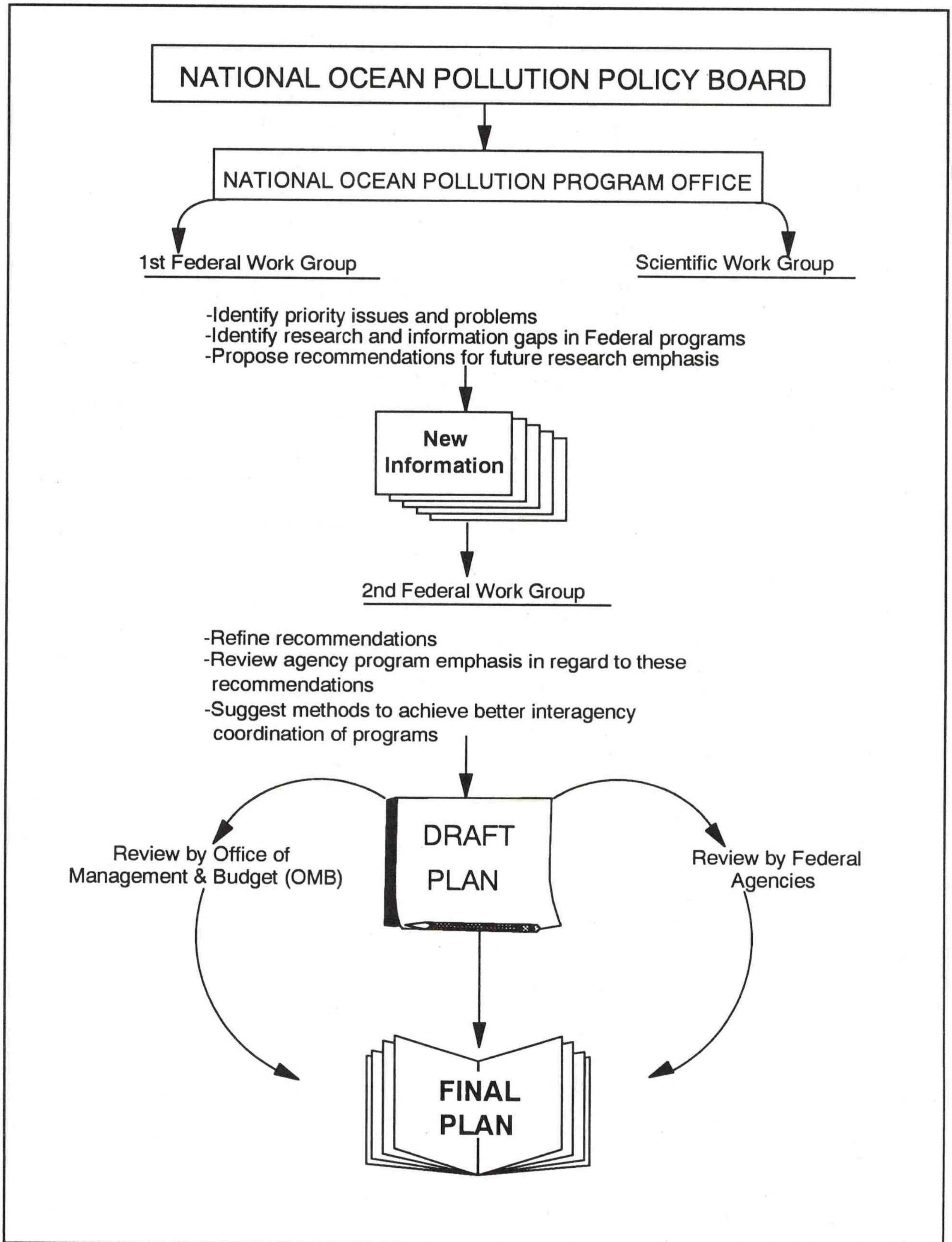


Figure 1.1. The Planning Process

work group, or Federal Work Group, was composed of Federal program managers and scientists from those Federal agencies that make up the National Ocean Pollution Program.

In January 1991, the Marine Sciences Research Center, Waste Management Institute of the State University of New York at Stony Brook, organized and sponsored the Scientific Work Group meeting. Based on their particular areas of expertise, members of this Work Group were formed into six subgroups, corresponding to the six goals of the National Ocean Pollution Program. Each subgroup was asked to review the respective goal sections of the 1988 Federal Plan and to update this information to reflect the progress that has been made in addressing the marine pollution issues identified in the 1988 Plan, identify new priority issues and information needs, and recommend future research and monitoring activities to address these issues and needs.

In February 1991, NOPPO sponsored the first of two meetings of the Federal Work Group. Members of the National Ocean Pollution Policy Board selected participants in the Federal Work Group from representatives of their respective agencies. Members of the Federal Work Group were asked to provide input on the goal sections in which their agency had an active interest. The results of the Scientific Work Group meetings were first presented to the Federal Work Group for comment. Federal Work Group members were then charged with the same tasks as the Scientific Work Group: to focus on progress that has been made in addressing the marine pollution issues identified in the 1988 Plan, identify new priority issues and information needs, and recommend future research and monitoring activities to address these issues and needs.

Based on the input from both the Scientific and Federal Work Groups, NOPPO developed first drafts for each of the goal chapters of the Plan. These drafts were presented to the Federal Work Group in April 1991 for their review and comment. Based on the recommendations made during the second Federal Work Group meeting, NOPPO revised each of the goal chapters. The revised goal chapters and the remaining chapters of the Plan were then sent out for agency-wide and Office of Management and Budget (OMB) review. The final Plan was then prepared based on all comments received. It should be noted that the discussions and findings presented in the Plan may have been altered during the official review by the National Ocean Pollution Policy Board; therefore, it should not be assumed that this final version of the Plan necessarily reflects the total consensus of the Scientific and Federal Work Groups.

Cross-Cutting Issues

A number of marine pollution issues identified during the development of this Plan are related to more than one, and in some cases all, of the six goals of the National Ocean Pollution Program. These cross-cutting issues include:

- Development of instrumentation;
- Data quality assurance; and
- Data and information management.

Although not necessarily related to any single goal of the Federal program, each of these issues has been identified by the National Ocean Pollution Program as needing additional Federal effort.

Development of Instrumentation

Improved measurement and analytical techniques and instrumentation are needed to identify and quantify the presence in the marine environment of many pollutants of concern, including toxic materials, nutrients, pathogens, marine toxins, and others. For example, improved techniques are needed for the sampling and measurement of pollutants in selected microenvironments including the surface/air interface and water/sediment interface. Also, many pollutants in the marine environment are found at concentrations below the detection limit of current measurement techniques. Even at these low concentrations, some pollutants may still pose a risk to marine resources and human health. Therefore, new techniques are needed to quantify highly toxic material that may be present at very low concentrations in the environment and/or in the tissues of marine organisms. Research is also needed to develop techniques for identifying pathogens responsible for epizootic disease and mass mortalities of living marine resources as well as human health effects. Such research is needed to develop rapid, inexpensive, and easy-to-use systems for the detection, characterization, and quantification of pathogens that cause disease among aquatic organisms and humans.

More reliable and precise estimates of pollutant concentrations and effects over spatial and temporal time scales require more efficient and cost-effective sensors, systems, and methods for laboratory analysis, field measurements, and remote sensing. The development of such techniques should provide for more precise measurements and enhance measurement reliability.

Data Quality Assurance

Quality assurance (QA) of marine measurements is critical for determining the reliability of measurements and for allowing meaningful comparison of data collected under different program sources. The first three Federal Plans identified quality assurance as an important issue that needed to be addressed by the National Ocean Pollution Program. Most agencies have addressed aspects of this issue, and NOPPO convened a Federal Work Group to address quality assurance of marine measurements. Many Federal agencies' activities have resulted in reports and publications that included recommendations to improve QA in Federal programs, and the NOPPO Work Group proposed generic guidelines for establishing quality assurance protocols for individual laboratories and programs (Taylor, 1985). However, in spite of these efforts, concern still exists as to the quality of some marine measurements.

Quality assurance is an area that requires continued attention, especially in those areas where measurements are difficult or where the potential for secondary use is high. Therefore, all Federal agencies that sponsor or conduct marine pollution research and monitoring activities should work together to identify ways in which interagency quality assurance can be improved to ensure that proper quality assurance principles and procedures are adopted for measurement programs and that these procedures are followed. In this regard, these agencies should also ensure that the level of support for such activities is adequate to meet quality assurance requirement needs.

Data and Information Management

Modern technology is dramatically improving the capability to observe, understand, describe, and predict the consequences of ocean pollution. Associated with this technological revolution is a wealth of data and information available for use in managing or regulating the ocean environment. Both the Scientific and Federal Work Groups that provided input to the development of this Plan identified the need for improved management of research and monitoring information. This includes improving protocols and procedures for data acquisition, storage, and retrieval and the dissemination of data to interested parties and the public. Such improvements will help to maintain active data bases, increase the capability for documenting models, and provide interactive access to data. The need to address these issues was also recognized in previous editions of the Plan.

The timely synthesis and dissemination of information are particularly important when related to human health issues (especially those associated with potentially catastrophic events such as spills of hazardous materials) or when episodic outbreaks of disease or mass mortalities occur in marine organisms. In such cases the timely dissemination of information is critical to determining potential impacts and causative agents and taking measures to control such agents before impacts become severe.

In addition, the synthesis and timely dissemination of information derived from ocean pollution research and monitoring are needed to reduce or eliminate unintentional duplication of effort and to make use of existing information to the maximum extent possible, thereby maximizing the efficiency of Federal ocean pollution research and monitoring programs.

Purpose and Limitations of the Plan

Many Federal departments and agencies are required by law to conduct ocean pollution studies, and each must fulfill the requirements of its specific missions and obligations. Programmatic decisions on areas of research emphasis within each agency are made through competition among many priority areas, and research programs must be related to the mandates of individual agencies. The Plan is not intended to override or interfere with the responsibilities and mandates of individual agencies. However, a responsive and efficient Federal program of ocean pollution research can be achieved by ensuring that important research areas are not overlooked if they fall between agency jurisdictions, and that related programs are carried out cooperatively and without duplication. As a strategy document, the Plan is not intended to provide a detailed tactical implementation scheme. Ultimately, it is up to the discretion of individual agencies to accept and implement the general mandate of NOPPA by cooperating in a coordinated national effort in ocean pollution research and monitoring, and it is up to the individual agencies involved in the National Ocean Pollution Program to accept and execute the recommendations offered in the Plan.

The conclusions and recommendations of this Plan have been reviewed, discussed, and accepted by the Policy Board. This ensures compatibility between the Plan and the individual mandates of each agency in order to facilitate its implementation. During the interval between editions of the Plan, the National Ocean Pollution Program Office works with the Policy Board agencies to promote implementation of recommendations in selected priority areas.

Organization of the Plan

The focus of the Federal Plan for Ocean Pollution Research, Development, and Monitoring: Fiscal Years 1992-1996 is in Chapters II through VII. These chapters discuss the goals of the National Ocean Pollution Program as cited above. The six goals take into account the various polluting activities and pollutants of concern. Chapter VIII contains an "agenda for action" by the National Ocean Pollution Policy Board during the 3-year interim between the development of 5-year plans. This agenda will help to ensure that the Plan will be used and will aid in the measurement of progress toward achieving the goals set forth in the Plan. The agenda allows for the inclusion of more detailed program evaluation and planning and provides specific opportunities for interagency and State/Federal coordination.

Appendix A of this document presents a summary of funding trends for each of the Federal agencies involved in marine pollution research, development, and monitoring and presents a description of each agency's related programs.

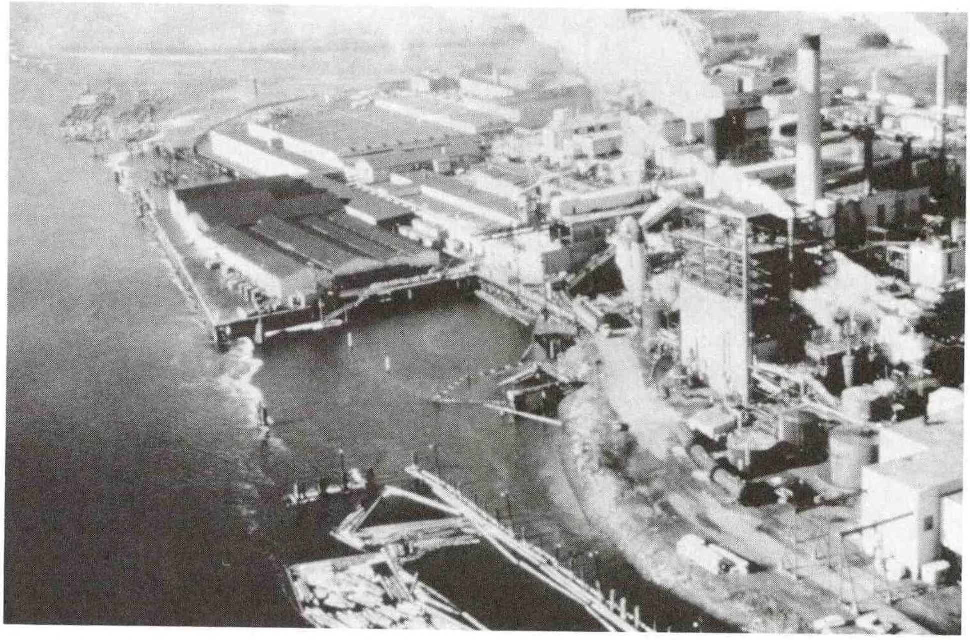
Appendices B and C present the members of the Scientific Work Group and the members of the Federal Work Group who assisted in the development of this Plan.

Each of the six goals of the National Program is discussed in a separate chapter of this Plan. For each goal, the following information is presented:

- Goal definition:
  - What is the problem?
  - Why is it a problem?
  - Where is it a problem?
- Priority issues and information needs:
  - Discussion of the priority issues;
  - Past and ongoing Federal activities that address the related information needs, and
  - Research and information gaps.
- Conclusions and recommendations.

Goals of the National Ocean Pollution Program

- Understand the Sources, Fates, and Effects of Toxic Materials Entering the Marine Environment as a Result of Human Activities (Chapter II)
- Understand the Sources, Fates, and Effects of Nutrients Entering the Marine Environment as a Result of Human Activities (Chapter III)
- Understand the Sources, Fates, and Effects on Aquatic Organisms of Pathogens and Nuisance Species That Are Introduced or Influenced by Human Activities (Chapter IV)
- Understand the Effects of Losing or Modifying Marine Habitat as a Result of Human Activities (Chapter V)
- Document the Trends in the Status of Marine Ecosystems (Chapter VI)
- Understand the Implications of Marine Pollution to Human Health (Chapter VII)



Chapter II

Understand the Sources, Fates, and Effects of Toxic Materials Entering the Marine Environment as a Result of Human Activities

The release of anthropogenic wastes into the marine environment has been occurring for as long as humans have inhabited coastal and estuarine areas. The issue of concern, however, is that explosive population growth in coastal areas, coupled with increased agricultural and industrial development, has resulted in alarming amounts and varieties of anthropogenic substances being introduced directly or indirectly into the marine and Great Lakes environments.

A significant proportion of this anthropogenic pollution consists of toxic substances, which can have a wide variety of harmful effects on individual marine organisms and, consequently, on marine ecosystems. The impacts of toxic materials on marine organisms include both sublethal and lethal effects. Observed sublethal effects include morphological, behavioral, physiological, and biochemical changes and diseases. Some of these effects may also eventually result in the organism's death. Adverse impacts on the marine environment are often translated into enormous economic costs in terms of unusable fishery and recreational resources, as well as human health considerations. Therefore, understanding the sources, fates, and effects of toxic materials in the marine environment is one of the six goals of the National Ocean Pollution Program.

Goal Definition

Toxic substances, toxics, toxicants, toxic agents, or toxic compounds are defined here as materials capable of producing an adverse response (effect) in a biological system, seriously injuring structure or function or producing death (Rand and Petrocelli, 1984). Toxicity must be expressed in terms of concentration and duration of exposure (where possible) and in relation to a specific system in order to be meaningful to resource managers and others.

Sources of anthropogenic toxic substances in the marine environment are primarily agricultural, industrial, and domestic/urban activities that generate substantial amounts of wastes. The toxic substances (e.g., metals, organic chemicals) contained in these wastes enter coastal and estuarine areas either from point discharges, streams/rivers, and specific ocean dump sites, or from nonpoint sources such as atmospheric deposition and terrestrial surface runoff resulting from precipitation. Environmental impacts resulting from point source pollution are generally easier to assess, and in some cases rectify, than impacts resulting from nonpoint source pollution.

The relative contribution of toxic substances by these different pollution sources varies considerably, depending on factors such as location, degree and type of industrialization and agricultural practices, and climatic factors. In the United States, most toxic substances entering the marine environment originate from industrial and municipal pipelines, discharging either directly into coastal areas or into rivers that subsequently flow into estuaries (OTA, 1987). Nonpoint source pollution, however, although generally difficult to quantify, is likely to be a significant contributor of toxic substances in regions adjacent to extensive industrial or agricultural development and urban environments. An additional source of toxic substances results from spills of chemicals and oil into the marine environment.

A variety of groups and agencies have identified individual chemicals or groups of compounds as potential problems when present in the marine environment. For example, lists of such chemicals have been developed by the EPA's Office of Science and Technology in an effort to identify chemicals needing water quality criteria and by EPA's Office of Wetlands, Oceans and Watersheds (OWOW) (USEPA, 1990c) to identify point source pollutants of concern in near coastal waters (Table 2.1). The toxic contaminants presented in Table 2.1 include four chemicals (DDE, DDT, dieldrin, and PCBs) that were identified by OWOW as pollutants of concern but were not included on OWOW's final list of contaminants of concern from point sources because they originate primarily from nonpoint sources or are the result of historic loadings. These chemicals have been included in Table 2.1 because this Plan is concerned with nonpoint and historic loadings of contaminants and their effects on the marine environment, as well as point sources of pollution.

Most estuarine and coastal areas in the country have experienced pollution impacts to various degrees. Marine waters adjacent to large urban/industrialized centers are, in many cases, severely polluted with toxic materials that have caused significant ecological and economic problems. Some of the most impacted areas include Puget Sound, San Francisco Bay, the Southern California Bight, the New York Bight, Chesapeake Bay, the Mississippi Sound, major portions of the coastal northern Gulf of Mexico, and the Great Lakes. Two examples of coastal sediment concentrations as reported by the NOAA National Status and Trends (NS&T) Program for mercury and PCBs are shown in Figures 2.1 and 2.2. The assessment of the data presented in these figures can be found in Robertson and O'Connor (1989).

In contrast, less concern has been focused on the health of the waters of the open ocean because few adverse pollution impacts have been documented. Recent developments using new biochemical markers to detect early pollution stress, however, suggest that impacts caused by heavy metals and organic chemicals may indeed pose a greater problem in the deep open ocean than was previously suspected (Stegeman, 1990).

The magnitude of toxic substances released into the marine environment has focused much attention on potential adverse impacts of these substances. Many of the metals and organic chemicals contained in the released wastes are persistent pollutants, and they have been documented to cause both acute and chronic toxic effects in marine organisms. The effects

Table 2.1
Near Coastal Water Pollutants of Concern (based on USEPA, 1990c)*

	PAHs	
PAHs (total)	Benzo(b)fluoranthene	Fluoranthene
Acenaphthene	Benzo(g,h,i)perylene	Fluorene
Acenaphthylene	Benzofluoranthenes	Indeno[1,2,3-cd]pyrene
Anthracene	Chrysene	Napthalene
Benzo(a)anthracene	Coronene	Perylene
Benzo(a)pyrene	Dibenzo[a,h]anthracene	Phenanthrene
		Pyrene
	Metals	
Aluminum	Copper	Nickel
Antimony	Cyanide	Selenium
Arsenic	Iron	Silver
Beryllium	Lead	Thallium
Cadmium	Manganese	Tin
Chromium	Mercury	Zinc
	Pesticides	
Aldrin	Dieldrin	Methoxychlor
Chlordane	Endrin	Mirex
DDD	Heptachlor	Toxaphene
DDE	Hexachlorocyclohexane	Trans - Nonachlor
DDT	Isophorone	
	Other Chemical Contaminants	
2,4-Dimethyl phenol	Dichlorobenzenes	PCBs
2-Methylnapthalene	1,2-Dichlorobenzene	Pentachlorophenol
2-Methylphenol	1,3-Dichlorobenzene	Phenol
4-Methylphenol	1,4-Dichlorobenzene	Phthalate Esters
Benzoic Acid	Dioxin (2,3,7,8-TCDD)	Bis (2-ethylhexyl)
Benzyl Alcohol	Diphenyl ethers	Butyl benzyl
Chlorinated benzenes	Ethylbenzene	Di-n-butyl
Cymene isomers	Hexachlorobenzene	Diethyl
meta -	Hexachlorobutadiene	Dimethyl
ortho -	Hexachloroethane	Trichloroethene
para -	Nitrosodiphenyl Amine	Trichlorophenol
		Xylene (total)

* Refer to EPA (1990c) for circumstances under which these pollutants are a concern in near coastal waters.

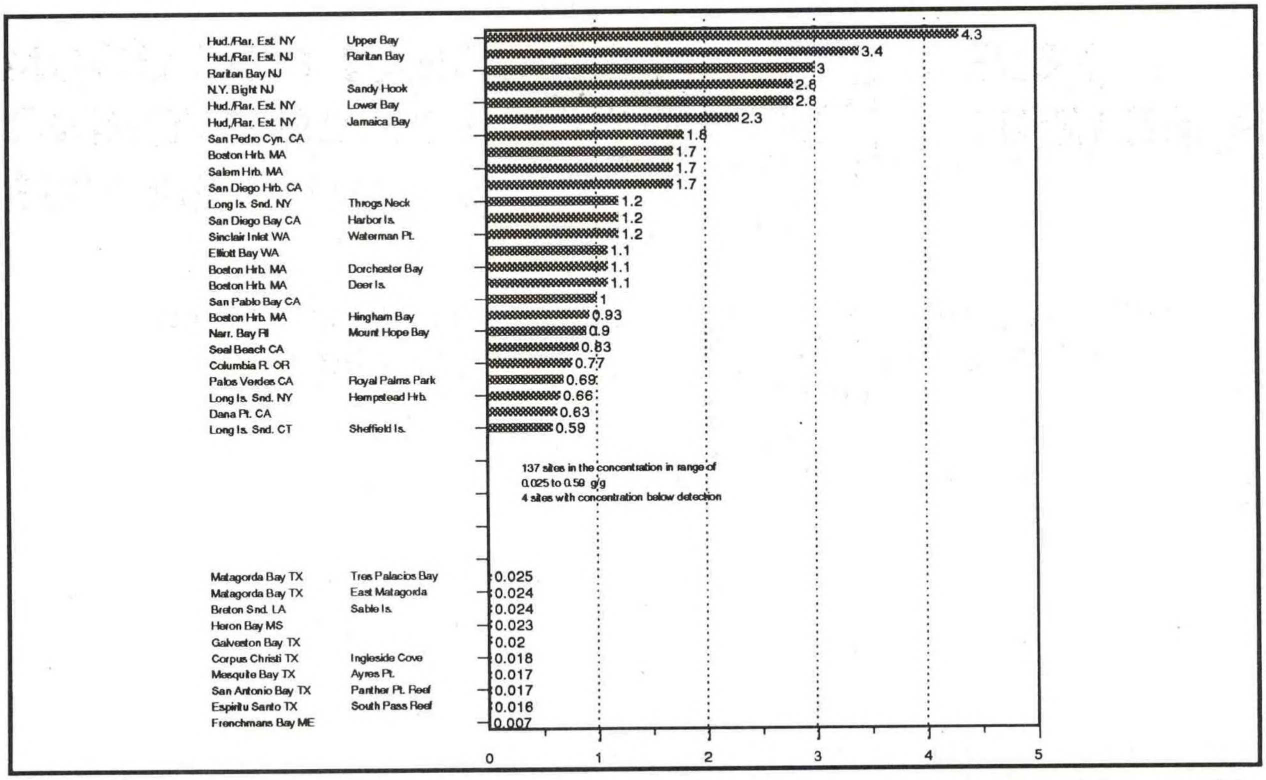


Figure 2.1. Concentrations of mercury in sediments from National Status and Trends sites around the coast of the United States (µg/g dry weight normalized for % lines). (Robertson and O'Connor, 1989.)

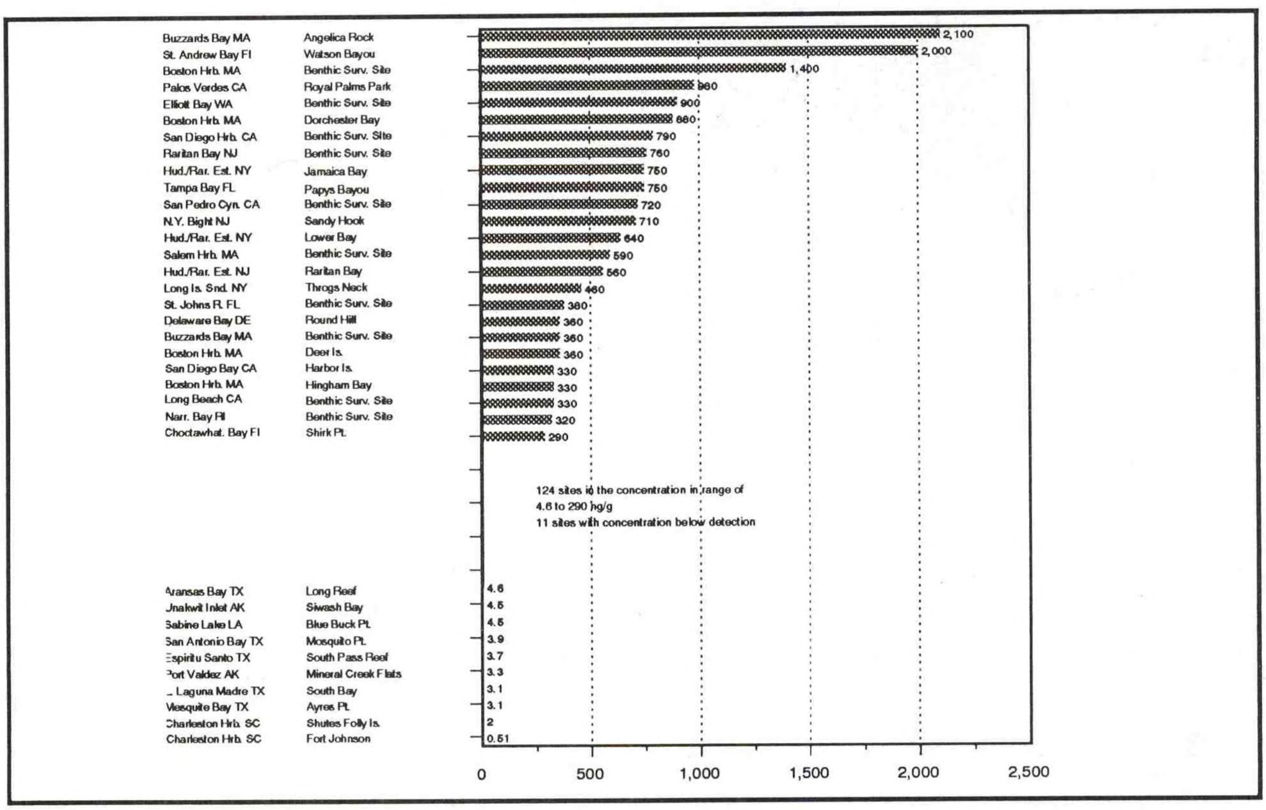


Figure 2.2. Concentrations of total PCB in sediments from National Status and Trends sites around the coast of the United States (µg/g dry weight normalized for % lines). (Roberston and O'Connor, 1989.)

resulting from exposure to and bioaccumulation of toxic substances include liver lesions, reproductive impairment, developmental abnormalities, various diseases, and mortality. It is these types of effects on marine organisms that motivate our need to understand such processes as fluxes and transformations. In addition, there is much concern about the risk posed to human health by consumption of toxicant-contaminated seafoods, as well as community and ecosystem level impacts resulting from toxic substances.

Much research has been conducted to understand the risks and impacts of toxic substances in the marine environment. The complexity of the marine environment, coupled with the continued generation of large amounts of conventional pollutants and new toxic substances, however, has made the accurate assessment of risks and impacts a difficult task. Numerous information gaps about the sources, transport, bioavailability, bioaccumulation, fate, and effects of many toxic substances still exist. These information gaps need to be filled to facilitate better pollution management and to more accurately predict risks and impacts of toxic substances in the marine environment.

The National Ocean Pollution Program Office, in association with the Federal and Scientific Work Groups, has identified three research priority issues reflecting information gaps that need to be filled:

- Quantification of source routes, and transformations of toxic contaminants released to the marine environment;
- Factors influencing bioavailability and bioaccumulation of toxic contaminants; and
- Relationship between exposure and effects on the most sensitive life stages of aquatic organisms.

Priority Issues and Information Needs

The priority issues and information needs discussed in this section focus on the most important aspects of toxic substances in the marine environment. The three priority issues discussed include management information needs related to the goal of understanding the sources, fates, and effects of toxic materials entering the marine environment as a result of human activities.

Priority Issue: Quantification of Sources, Routes, and Transformations of Toxic Contaminants Released to the Marine Environment

Information Need: Relative Contribution of Toxic Substances from the Atmosphere, Sediments, Other Nonpoint Sources, and Rivers to the Marine Environment. It has become increasingly apparent that rivers and nonpoint sources such as surface runoff, contaminated sediments, and atmospheric deposition play a major role in the contribution of toxic substances to the marine environment. Implementing effective pollution reduction strategies requires some knowledge of the relative contribution of toxic materials to the marine environment.

The primary sources of anthropogenic metals to the marine environment are rivers and atmospheric deposition (Chester and Murphy, 1990). Accurate estimation of the relative contributions of these sources is generally difficult because of variable influences such as seasonal and climatic factors. Nevertheless, several estimates on a regional and/or metal-specific basis have been attempted. It is well documented, for example, that the atmosphere is the major contributor of lead and vanadium to the marine environment (Nriagu and Pacyna, 1988). Estimations of the ratios of atmospheric to riverine trace metal fluxes into the ocean show considerable variability depending on metal species and geographic region examined, and whether coastal or open ocean areas are considered. Calculations of trace metal fluxes for the North Atlantic and North Pacific open ocean regions suggest that lead and zinc are deposited primarily from the atmosphere, whereas aluminum, manganese, nickel, copper, chromium, and cobalt are obtained mostly from riverine inputs (Chester and Murphy, 1990). In coastal areas, atmospheric deposition generally plays nearly as significant a role as riverine inputs as a source for many trace metals. Atmospheric fluxes of some metals such as lead, zinc, and cadmium, however, clearly exceed their riverine fluxes (Chester and Murphy, 1990).

The introduction of anthropogenic organic and chlorinated chemicals into the marine environment has caused much concern because of their ubiquity, persistence, toxicity, and carcinogenicity. Atmospheric deposition, rivers, and nonpoint sources such as surface runoff are all significant sources of synthetic organics in the marine environment. In general, the highest concentrations of these chemicals are found near the most densely populated and industrialized regions (Fowler, 1990). As in the case of trace metals, however, the relative contributions from the various sources are difficult to quantify and are strongly influenced by regional factors such as the extent of industrial and agricultural practices and climate. Although riverine inputs of synthetic chemicals can be significant in some coastal regions (e.g., the Hudson Estuary, the Mississippi Delta), atmospheric deposition and surface runoff are likely to play a more significant role in regions like the Southern California Bight, which have no major riverine inputs (NRC, 1990b). Synthetic chemicals such as pesticides and PCBs have also been found in arctic air, snow, and seawater, far removed from any major population or industrialized regions. Atmospheric transport from North American and Asian agricultural and urban areas appears to be the most likely source of these chemicals (Welch et al., 1991).

Many of the toxic substances entering the marine environment arrive as forms already bound to particles settled in the sediments (i.e., derived from riverine inputs, soil erosion, surface runoff, etc.) or as dissolved forms that subsequently bind to marine sediments as a result of physicochemical interactions. The widespread occurrence of toxic sediment contamination in U.S. waters has generated considerable concern about the potential impacts of these substances on marine resources (NOAA, 1990a). The threat posed by sediment-bound toxic substances depends on the availability of these toxics to marine organisms. Organisms can accumulate toxic substances from solution via diffusion across gill membranes and/or by ingestion of contaminated food and sediment. The extent to which bound toxics are released from sediments into interstitial and surface water, therefore, affects the route of exposure.

Factors influencing the release of toxic substances from sediments include sorption/desorption kinetics, which in turn are affected by numerous factors such as pH, organic carbon content of sediment particles, dissolved oxygen levels, salinities, type of toxic substance, sediment characteristics, and redox potentials (Jenne and Zachara, 1987; Fisher, 1990; Luoma, 1990). The rates of contaminant release are also influenced by physical factors such as resuspension of sediments caused by wave and current action, perturbation of sediments caused by organisms, and relative rates of sediment deposition versus erosion. Such activities can result in transport of interstitial waters (usually containing higher concentrations of toxic contaminants) to the surface, and exposure of deeper contaminated sediments to the water column. Even though the importance of physicochemical and environmental influences on sorption/desorption kinetics of sediment-bound toxic contaminants is well recognized (NOAA, 1988), the large number of factors involved and their interaction make deciphering and modeling these processes extremely complex.

Techniques and instrumentation for sampling and measuring toxic substances in the marine environment and in biological tissues continue to be improved. Newer, more sensitive techniques such as MS/MS, GC/AES, ICP/MS, electrophoretic measurements, and immunoassays are being evaluated and implemented for more accurate detection and quantification of a broader range of toxic substances and their metabolic transformation products.

The boundary between the sea surface and air comprises a microlayer that is enriched with organic compounds derived from natural processes and anthropogenic inputs. A large community of microorganisms and fish and invertebrate eggs and larvae come into contact with this layer (Hardy et al., 1988). Many of the anthropogenically derived toxic substances entering the marine environment concentrate in the microlayer by adhering to the organic material. Consequently, the toxics pose a potential hazard to the sensitive life stages in the microlayer. The sediment/water interface and interstitial waters also provide a habitat for a large diversity of organisms and are the primary sites of biological and physicochemical processes responsible for fluxes of toxics from contaminated sediments. Understanding and predicting toxic substance fluxes and impacts in these important microenvironments will require proper sampling techniques and accurate measurement of pollutants.

Several Federal agencies are conducting research activities aimed at determining the contribution of rivers, sediments, atmospheric deposition, and other nonpoint sources to toxic substances in the marine environment. The U.S. Geological Survey's programs addressing this information need include the National Stream Quality Accounting Network (NASQAN), which involves sampling moderate- to large-sized rivers around the Nation to obtain estimates of sediments and trace metal loads delivered to the coastal zone, and the newly begun Toxic Substances Hydrology Program (TOXICS), which will study transport of trace organic chemicals originating from rice-farming activities to San Francisco Bay. Extensive studies of contaminated sediments and the environments and processes of Boston Harbor and Massachusetts Bay are being performed by the USGS Office of Energy and Marine Geology, Branch of Atlantic Marine Geology (Geological Division). A development of potential importance to cooperative inventorying of the Nation's coastal sediments is the forthcoming release by the USGS of an updated and fully computer-interactive data base of sediment and associated information (>7000 stations) for the Atlantic continental margin.

The U.S. Department of Energy (DOE) supports substantial interdisciplinary research directed toward understanding air-sea exchange processes, including quantification of toxic substance deposition from the atmosphere. DOE's Environmental Sciences Division has funded multidisciplinary projects in the California Basin to study transport and cycling of energy-related materials. Projects related to this information need center on determining fluxes of energy-related anthropogenic compounds into and out of sediments.

The U.S. Environmental Protection Agency (EPA) has programs directed at evaluating the contribution of toxic substances from the atmosphere and from surface runoff, stream-induced discharges, and combined sewer overflows. Research efforts are also directed at identifying sources and controlling release of toxic substances in urban runoff and investigating the effectiveness of several general pollution control practices (Field and Pitt, 1990). The EPA Office of Research and Development has established a Sediment Quality Research Initiative program, the purpose of which is to integrate and expand current research efforts on sediment quality. Programs investigating the fate and transport of sediment contaminants include research on contaminant partitioning between sediment and water, modeling deposition and resuspension of sediments in relation to physical and biogeochemical factors, and evaluating the importance of different routes of exposure in relation to sediment characteristics and biological and chemical variables.

The National Oceanic and Atmospheric Administration (NOAA) administers the Great Lakes Environmental Research Laboratory (GLERL). GLERL conducts studies focused primarily on the issues associated with contaminated sediments. Most of the work deals with the issues of bioavailability and bioaccumulation of sediment-associated contaminants. GLERL is also conducting studies examining the role of bioturbation in the transport, resuspension, and burial of sediment-associated contaminants in both fresh and marine waters. NOAA's National Status and Trends Program (NS&T) has a major initiative to measure and identify the distribution of contaminants in sediments in coastal U.S. waters.

Also within NOAA, the National Geophysical Data Center (NGDC, Marine Geology and Geophysics Division) acts as the U.S. national repository for marine geological and geophysical data, including all types of descriptive and analytical data for marine sediments, and geophysical data including bathymetry. NGDC maintains a data base of trace element geochemistry for marine pollution and baseline environmental studies, and related data including sediment size and description. NGDC plans increased activities in bathymetric and sediment studies in the Great Lakes and in the offshore continental margins of the United States in the near future.

NOAA's National Sea Grant College Program conducts research on the transport, fate, and effects of toxics in the Nation's estuaries and coastal waters and in the Great Lakes. Sea Grant conducts a major program in Chesapeake Bay in cooperation with EPA.

The Environmental Studies Program of the U.S. Department of the Interior's Minerals Management Service (MMS) has established cooperative agreements with the University of California to study the resuspension, flocculation, and transport of drilling muds and associated toxic contaminants, and with the Louisiana Universities Marine Consortium to research both the fate and transport of particle-reactive aromatic and heterocyclic hydrocarbons in a sediment-water-colloid system and the bioavailability and genotoxicity of petroleum and produced water discharges.

Although several Federal agencies have initiated programs to address the above information need, the magnitude and evolving complexity of the problem require that the effort not only be continued, but also be redirected in some cases to take new information into account. The following recommendations for addressing this information need are suggested.

Any assessment of the relative importance of the above sources to marine (including the Great Lakes) pollution will require estimates of the gross fluxes of toxic substances from these sources. Fluxes are generally difficult to estimate, however, because of insufficient or inappropriate monitoring data. Monitoring design must take into account the significant variability in fluxes resulting from seasonal and climatic factors, different geological and hydrological processes characteristic of each river, and the influence of episodic events such as storms. Nonpoint sources such as urban and agricultural runoff and combined sewer overflows are thought to be significant contributors of toxic substances to the marine environment (OTA, 1987). The loading rates of nonpoint source toxics are affected by several variables and are likely to be site-specific. Consequently, it becomes necessary to evaluate these loading rates for different situations where water quality remediation is being attempted.

> *Recommendation: Collect additional monitoring data in order to more accurately quantify fluxes and loading rates of toxic substances from the atmosphere, rivers, and nonpoint sources.*

In view of the potential significance of contaminated sediments as a source of toxics (NRC, 1989), it is important to characterize the basic processes controlling sorption/desorption phenomena. Basic research on the processes controlling sorption/desorption kinetics of toxic substances to and from sediments should continue to be addressed in order to more accurately model and predict toxic substance partitioning, transport, and availability to marine organisms.

> *Recommendation: Continue research to determine the role of contaminated sediments as a source of toxic substances released to the marine environment.*

Proper sampling techniques and accurate measurement of pollutants are necessary to understand and predict toxic substance fluxes and impacts in important marine microenvironments. These microenvironments include the sea surface/air microlayer and the sediment/water interface and interstitial waters, which provide habitat for many communities of sensitive marine organisms. The sediment/water interface and interstitial waters are also the primary sites of biological and physicochemical processes responsible for fluxes of toxic material from contaminated sediments.

Recommendation: Continue to develop new and improved techniques for sampling and measuring toxic substances in marine microenvironments, particularly the sea-surface microlayer, the sediment/water interface, and interstitial waters.

Priority Issue: Mechanisms That Influence Bioavailability and Bioaccumulation of Toxic Substances

Information Need: Effects of Physicochemical and Speciation Processes on Bioavailability and Bioaccumulation of Toxic Substances. There is increasing evidence that sediment-associated toxic substances enter and adversely impact biological systems (NRC, 1989). The processes controlling availability of these toxic substances to the biota and the influence of physicochemical and environmental factors on these processes remain poorly understood. Because bioaccumulation of toxic substances is directly dependent on the bioavailability of these substances, an understanding of the basic factors and processes affecting bioavailability is necessary to assess impacts of contaminated sediments on marine biota. The simple measurement of toxic chemicals associated with bulk sediments by itself, however, is not an accurate or reliable indicator of the potential bioavailability of these contaminants.

Among the physicochemical factors influencing bioavailability are geochemical characteristics of the sediments and characteristics of the toxic substances (Luoma, 1989; Landrum and Robbins, 1990). For example, in clams, bioaccumulation of silver bound to manganese oxide particulates was found to be considerably higher than bioaccumulation from iron oxide particulates (Harvey and Luoma, 1985). Similarly, uptake of cadmium from ingested sediments containing low levels (<4 percent) of iron oxides was much higher than from sediments dominated by iron oxides (Luoma, 1989). Geochemical characteristics of the contaminated sediment appear to strongly influence the relative importance of sediments as a source of bioavailable toxic metals.

Although toxic metals can enter marine biota directly from solution as well as by ingestion of contaminated particulates, uptake from solution is generally more efficient (Forstner, 1990). Sediment characteristics that increase rates of toxic substance release into the water column, therefore, can affect bioavailability. The importance of understanding sorption/desorption kinetics of sediment-bound toxics has been addressed earlier in this chapter. Additional physicochemical factors influencing the partitioning of toxic metals between sediment and solution include the metal binding intensity at the surface of sediment particles (Luoma, 1989). Binding intensities can vary depending on sediment composition and particle type and therefore can influence the sediment-water distribution and bioavailability of certain metals (Luoma, 1989).

The partitioning of toxic metals between sediments and solution is also influenced by the chemical form of the metals (Forstner, 1990). In solution, metals exist as a variety of forms (species) complexed to dissolved ligands (Luoma, 1989). This complexation to ligands is a major factor influencing bioavailability. For example, complexation with inorganic ligands generally decreases adsorption of the metals to particulates, making them more bioavailable. In contrast, complexation to organic ligands generally increases adsorption of the complexed metals to solids (Jenne and Zachara, 1987).

In sediments, the different metal species also partition between the different ligands associated with the various particulate types. In oxidized sediments, metals are distributed primarily among sites on iron and manganese oxides and organic substances (Jenne and Zachara, 1987). In reduced sediments, in contrast, the metals often precipitate as metal sulphides, thus affecting the form of the metal and its availability (Luoma, 1989). The speciation and concentration of soluble metals in interstitial sediment waters is usually different from that in the overlying water column, resulting in different bioavailabilities to infaunal and epifaunal organisms.

The physicochemical and metal species-specific reactions occurring in contaminated sediments remain ill-defined, and considerable uncertainty exists in the modeling approaches aimed at describing these reactions (Luoma, 1989). Realistic predictions of the bioavailability of sediment-bound toxic metals, therefore, will require continued effort on characterization of physicochemical and metal speciation processes in sediments.

In the case of nonpolar organic compounds, the primary physicochemical factors controlling bioavailability from contaminated sediments are the organic carbon content of the sediments and hydrophobicity (as represented by the octanol-water partitioning coefficient-K_{ow}) of the compound (Adams, 1987; Landrum and Robbins, 1990). Other physicochemical factors that increase or decrease sorption and complexation of toxic organic compounds to sediments include hydrogen bonding, compound ionization, sediment particle size distribution, clay content, cation exchange capacity of the sediment, and pH (Rogers et al., 1987; Servos et al., 1989; Landrum and Robbins, 1990).

The complex interactions of the above factors make modeling and predicting behaviors of toxic organic compounds a difficult but important task. Considerably more research is needed, therefore, on physicochemical processes regulating partitioning of organic chemicals from the sediments in order to develop predictive models on bioavailability of organic compounds.

The most commonly used parameter for estimating bioaccumulation potential of toxic organic compounds from solution is the hydrophobicity of the compound. Although hydrophobicity models have some predictive value in the case of certain compounds, they are not useful for all classes of chemicals. Moreover, they do not take into account several factors that can affect uptake (and therefore bioaccumulation) of the compounds. Factors influencing the rate of uptake and elimination of organic compounds and metals include physiological characteristics of the organisms, stearic properties of the compound, size of the animal, form and distribution of the compound in different tissues, and environmental conditions such as temperature, ionic composition of the water, and pH (Barron et al., 1987; Luoma, 1989; Hayton and Barron, 1990; Barron, 1990).

Federal agencies addressing this information need include the EPA, U.S. Fish and Wildlife Service (FWS), U.S. Navy, and NOAA. The EPA has several research programs aimed at developing laboratory procedures and computer models to predict bioavailability and bioaccumulation of toxic substances associated with sediments, dredged materials, and complex effluents. Specific examples of these programs include research on development of equilibrium partitioning models to predict bioavailability, and uptake and depuration models to predict bioaccumulation. The FWS has programs aimed at identifying and quantifying toxic contaminant burdens in aquatic organisms and water birds. FWS is also conducting research on alternative techniques for assessing availability of contaminants from sediment. The U.S. Navy is investigating effects of the physicochemical form of copper and tin on toxicity to marine organisms. NOAA's National Status and Trends (NS&T) Program is conducting studies to identify and quantify accumulation of toxic substances in fish and shellfish tissues. NOAA's NS&T determines the level and detects changes of toxic contaminants in coastal and estuarine waters at over 300 sites nationwide. NOAA's Coastal Ocean Program is enhancing NOAA's ability to define effects of toxic chemical contamination. Ongoing efforts include contaminant studies in Tampa Bay, the Hudson-Raritan Estuary, and Southern California and development of improved indicators of stress in living organisms. In FY92, NOAA will begin more generic studies of contaminant effects on organisms, populations, and ecosystems. NOAA's Great Lakes Environmental Research Laboratory is investigating the factors affecting bioavailability of sediment- associated toxic substances. NOAA's Sea Grant Program is studying the bioavailability of toxics to the organisms of Chesapeake Bay.

To better understand the processes that affect the bioavailability and bioaccumulation of toxic substances in marine organisms, additional information is needed on the environmental processes influencing bioavailability, uptake, and bioaccumulation of toxic substances.

> *Recommendation: Conduct basic research elucidating the interrelationships between physicochemical, physiological, and environmental processes and chemical speciation that influence bioavailability, uptake, and bioaccumulation of toxic substances.*

The development of accurate bioaccumulation models for environmental risk assessment studies will require that basic mechanisms influencing uptake, bioaccumulation, and elimination of toxic substances be elucidated. Both the biotic and abiotic factors described above will need to be incorporated into these models to improve their predictive powers (Barron, 1990; Van Hattum et al., 1991).

> *Recommendation: Continue research to develop, refine, and validate models for predicting uptake and bioaccumulation of toxic substances, particularly for sediment-associated contaminants.*

Information Need: Biochemical and Physiological Processes That Control Bioaccumulation of Toxic Substances. For many toxic substances, bioaccumulation in tissues of aquatic organisms cannot be explained solely on the basis of the substance's physicochemical properties. Metabolism (i.e., biochemical and physiological processes) often has considerable influence on the extent of bioaccumulation. Biotransformation processes are increasingly recognized as a major factor controlling bioaccumulation of some xenobiotics in aquatic species (Sijm and Opperhuizen, 1988; Barron et al., 1989; Opperhuizen and Sijm, 1990). For example, inhibition of biotransformation enzymes in goldfish resulted in reduced elimination-rate constants and correspondingly higher bioaccumulation of 2,8-dichlorodibenzo-*p*-dioxin (Sijm and Opperhuizen, 1988; Opperhuizen and Sijm, 1990). Inhibition of metabolism has been shown to increase bioaccumulation of a variety of organic chemicals (Barron, 1990), implicating the role of biochemical and physiological processes in controlling bioaccumulation of at least some xenobiotics.

The liver is generally believed to be the main site of biotransformation reactions in organisms. Extrahepatic regions, however, may also play an important role in metabolizing xenobiotics. In fish, for example, the gills have been shown to transform highly lipophilic organic compounds to metabolites that could not easily be taken up into the bloodstream (Barron et al., 1989). In view of the fact that the gills are an important site of pollutant uptake, their role in controlling bioaccumulation by metabolic transformation of xenobiotics may be potentially significant. Further studies are needed to classify the role of extrahepatic tissues in controlling uptake and bioaccumulation in aquatic organisms.

Although biotransformation processes normally result in metabolic intermediates that are less toxic and more easily excretable, biotransformation processes can also result in the enzymatic conversion of some xenobiotics to more reactive and toxic metabolites (Buhler and Williams, 1988). In aquatic organisms, the specific identity, chemical structure, and rate of formation of many of these activated metabolites are poorly understood.

In view of the significance of biotransformation processes in controlling bioaccumulation and toxicity of xenobiotics, more research elucidating these processes will be necessary to derive better predictive models for estimating the bioaccumulation and toxicity potential of various chemicals.

> *Recommendation: Conduct research on the role of biotransformation and other metabolic activities on uptake, bioaccumulation, and toxicity of chemical contaminants in the marine environment.*

Priority Issue: Relationship Between Exposure and Effects of Toxic Material (Including Complex Mixtures) on the Most Sensitive Life-Stages and Population Dynamics of Aquatic Organisms

Information Need: Sublethal Effects of Toxic Substances, Especially with Regard to the Relationship Between Effects on Individuals and Integrity of Populations. The description and prediction of adverse health and environmental effects caused by toxic substances are a generally complicated and difficult endeavor. The type and extent of adverse effects are dependent on a number of factors, including the nature of the toxicant(s), susceptibility of individual organisms and species, duration of exposure, availability of the toxicant, and species-specific factors such as age, body size, and physiological characteristics of the organisms. These multiple factors and their interactions result in confounding responses by the organisms, making predictions of adverse effects based on controlled laboratory studies very uncertain.

In view of the complications described above, an interest in the use of biological markers to assess exposure and effects of toxic substances on aquatic organisms has developed (Bayne et al., 1988; McCarthy and Shugart, 1990). Biological markers can provide a sensitive indication of the sublethal effects of toxic substances at the cellular and tissue levels of organisms, often serving as "early warning" signals of adverse effects that may ultimately manifest themselves at the population and community levels.

Perhaps the most well-characterized biological marker for assessing sublethal biochemical changes is the induction of the cytochrome P-450 mixed function oxidase (MFO) system in response to a wide range of organic xenobiotics (Stegeman, 1990; McCarthy and Shugart, 1990). Induction of MFO enzymes by xenobiotics has been validated in many field studies and is useful as a sensitive indicator of pollutant exposure and the geographic range of pollution impact (Payne et al., 1987; Sulaiman et al., 1991). Other biological markers for assessing sublethal impacts include induction of stress proteins; expression of metal-induced metallothionein proteins; genotoxic markers (e.g., formation of DNA adducts, detection of DNA strand breakage, measurements of aberrant nucleotide composition in DNA); and changes in immune function, as measured by activity of kidney macrophages in fish (Sanders, 1990; Weeks et al., 1990; Maccubbin and Black, 1990; Benson et al., 1990; Shugart, 1990; Varnasi et al., 1989). Recently explored and potentially powerful biomarkers detected by molecular techniques include alterations in *ras*-gene expression in sponges (Ugarkovic et al., 1990), detection of mutations in c-Ki-*ras* oncogenes in winter flounder (McMahon et al., 1990), and quantification of changes in P-450 messenger RNA after exposure of fishes to pollutants (Haasch et al., 1989; Wirgin et al., 1990).

The ultimate effects of such genetic and biochemical alterations due to pollutant exposure have been examined by numerous studies on the physiology, behavior, and histopathology of aquatic organisms. In particular, histopathology studies have validated the development of neoplasms on fish exposed to toxic compounds from a variety of estuaries including Boston Harbor, Massachusetts; the Hudson River estuary, New York; Southern California; and Puget Sound, Washington (Mix, 1986). Harshbarger and Clark (1990) noted the case for pollutant-associated neoplasia was strongest for those hepatic lesions found in fish, while neoplastic diseases in bivalve mollusks did not seem to be correlated with environmental pollution (Mix, 1986). In all cases, there are a variety of pollutants in the system and identification of the cause(s) of the sublethal effects seen is difficult. However, some of these same abnormalities have been reproduced in the laboratory with exposure to specific chemicals (e.g., PAHs) found in the contaminated areas. Gardner et al. (1991) induced gill and gastrointestinal neoplasms in oysters exposed in situ to chemically contaminated sediments from Black Rock Harbor, Bridgeport, Connecticut, and Quincy Bay, Boston Harbor. These and other neoplastic lesions were also found in laboratory exposures of oysters. Mussels exposed to Black Rock Harbor sediments did not develop neoplasms, but winter flounder fed the contaminated mussels developed renal and pancreatic neoplasms as well as hepatotoxic neoplastic precursor lesions. Chemical analyses demonstrated trophic transfer of sediment-bound carcinogens through this food chain.

Although the use of biological markers at the cellular and tissue levels provides a good indication of early pollution effects on individual organisms, the significance of such markers as predictors of the impacts on structure and function of whole populations and communities is unknown. It seems reasonable, however, that adverse impacts on individuals are likely to be propagated at higher organizational levels over time. Biochemical or molecular level impacts that affect reproductive success of individuals are likely to be translated into adverse effects on populations, such as the findings of epizootic neoplastic diseases in livers of pollutant-exposed fish. Malignant neoplasia may reduce the numbers of older fish in some areas (Harshbarger and Clark, 1990). There is also evidence, for example, that induction of MFO enzymes due to pollutant exposure can affect metabolism of sex steroids and reproduction in some fishes (Spies et al., 1990). Histopathological examinations of fish and invertebrates from contaminated sites, as well as in laboratory exposures, have documented reproductive impairment, including anomalous development of gonads and gametes and deformed or nonviable larvae have been found in other studies (Mix, 1986; Turgeon et al., in press). The lack of young animals in some population survey may be related to such changes.

Several Federal agencies are addressing the issues of sublethal effects on individual organisms and populations. EPA has a program to assess the expression of stress proteins in sediment-dwelling clams exposed to pollutants. NOAA has long-standing programs to develop and assess biological markers as indicators of pollution impact. The NOAA National Status and Trends Program monitors biological response to contamination by examining indigenous organisms and subjecting them to bioassay analysis. NOAA's Coastal Ocean Program is involved in the development and testing of bioindicators (also called biomarkers) that measure contaminant exposure and responses at the biochemical physiological, and organismal levels. The U.S. Navy has a program aimed at the development of biological markers for assessing pollution stress. The U.S. Navy also has a program to develop and use portable marine microcosms to evaluate effects of toxic contaminants on organisms and populations. The FWS has implemented programs to develop toxicity tests aimed at detecting sublethal carcinogenic and teratogenic responses of fish and invertebrates to sediment pollutants. FWS is also conducting research on the effects of contaminants on wildlife in the Great Lakes and in coastal areas such as San Francisco Bay and the Gulf coast.

The use of biological markers shows great promise for providing early warning signals of pollutant impacts (McCarthy and Shugart, 1990). It must be recognized, however, that research on the biological markers described above exists in various stages of development, and much more research will be necessary in some cases (e.g., detecting changes in gene expression, detection of genetic mutations) before the feasibility of using these markers in biomonitoring programs can be assesed. The more developed biomarkers (e.g., induction of MFO enzymes, detection of DNA adducts) are ready to be used at the present time. However, the widespread implementation of such markers in applied monitoring programs has not yet occurred.

> *Recommendation: Conduct additional research to develop markers that indicate sublethal toxicological effects of pollutants on organisms in laboratory and field studies.*

In general, it appears that long-term biomonitoring studies incorporating both the use of biomarkers at the cellular and tissue levels in individual organisms and measures of population changes (in terms of abundance and diversity) will be required to establish the relationships between these measures (McCarthy, 1990).

Recommendation: Conduct addiitonal research to determine the relationship between sublethal effects in individuals and population responses to toxic contaminants.

Bioaccumulation of toxic substances in marine organisms has been shown to result in such effects as lesions, problems during the reproductive cycle (including larval viability), developmental abnormalities, disease, and mortality. Findings from research addressing the relationship between exposure to toxic contaminants and observed effects in marine organisms would provide managers and researchers with information necessary to give scientifically-based priorities to those suites of contaminants that should be investigated to determine their routes, transformations, sources, bioavailability, and bioaccumulation.

Recommendation: Continue research addressing the links between toxic contaminants and known effects.

Information Need: Interactive Effects of Different Classes of Toxic Substances. Coastal areas in close proximity to major urban, industrial, and agricultural centers are usually contaminated with several different types of toxic substances. The toxicity of these substances to aquatic organisms can be influenced by additive, synergistic, potentiating, and antagonistic interactions between these substances and environmental variables. For example, selenium has been shown to have an antagonistic effect on the bioaccumulation of mercury (Pelletier, 1985). Antagonistic effects on bioaccumulation in oysters have also been observed for several organic substances (Fortner and Sick, 1985). Environmental variables such as high temperature and low salinity act synergistically with metals to increase toxicity to marine invertebrates (McLusky et al., 1986).

The use of biological markers for detection of impacts is particularly advantageous in situations where the pollutants consist of complex mixtures. Interactive effects of the multiple pollutants are all integrated in the response of the organism. Biological markers, therefore, are a response to the combined effects of pollutant interactions at the molecular and cellular levels (McCarthy and Shugart, 1990).

The extremely large number of toxic substances in the marine environment, coupled with numerous environmental influences, makes predicting interactive effects very complicated. Much more research is necessary before predictions can be made based on empirical data.

Recommendation: Continue to conduct research on combinations of toxic substances to identify interactive effects on marine organisms.

Conclusions

The magnitude of anthropogenically derived toxic substances entering the marine environment has caused much concern over the potential impacts on marine ecosystems and human health. (see Chapter VII). The Federal Government has supported substantial research and monitoring activities aimed at elucidating and predicting the adverse impacts caused by these substances. These efforts have also identified a much wider range of sources, processes, and pathways involving toxic substances in the marine environment. However, the large scale of the problem, the complexity and diversity of the marine environment and biota, and the continued generation of more and new types of toxic substances have made assessing impacts an extremely complex endeavor, and much additional research is necessary to address the remaining unanswered questions. The main challenge is understanding the thermodynamic, kinetic, and biological properties for each specific compound entering the marine environment. Methods that will be an asset to the identification of specific chemical properties include biomarkers (i.e., cytochrome P-450 MFO); newer and more sensitive techniques such as MS/MS, GC/AES, and immunoassay; and measures of population changes (abundance and diversity).

Research should be focused on filling the knowledge gaps for the sources, kinetics, complex formation, and factors controlling sorption/desorption for the multitude of chemical species and metal ions entering the marine environment. Information on the interaction of toxic substances and biological processes as they relate to bioavailability and bioaccumulation for specific compounds is also needed, as are highly accurate measurements of the flux of contaminants through the marine environment, especially the boundary layers of the air/sea interface and the water/sediment interface. By understanding the sources, fates, and effects of specific chemicals, a prediction of the net effects of combinations of chemicals can be derived. Most polluted waterways contain such combinations, the effect of which is poorly understood at present but must be known to accurately assess the health of the biota in marine systems and, indirectly, human health.

Based on these conclusions, the following recommendations are made to improve our understanding of the sources, fates, and effects of toxic materials in the marine environment.

Recommendations

Routes, Transformations, and Sources

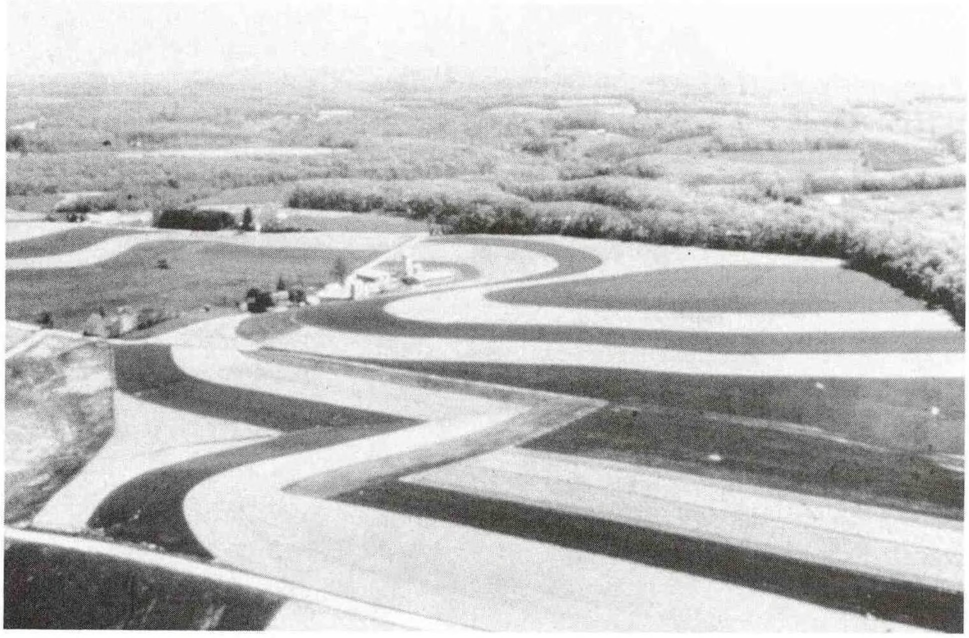
- Collect additional monitoring data in order to more accurately quantify fluxes and loading rates of toxic substances from the atmosphere, rivers, and nonpoint sources.
- Continue research to determine the role of contaminated sediments as a source of toxic substances released to the marine environment.
- Continue to develop new and improved techniques for sampling and measuring toxic substances in marine microenvironments particularly the sea-surface microlayer, the sediment/water interface, and interstitial waters.

Bioavailability and Bioaccumulation

- Conduct basic research elucidating the interrelationships between physicochemical, physiological, and environmental processes and chemical speciation that influence bioavailability, uptake, and bioaccumulation of toxic substances.
- Continue research to develop, refine, and validate models for predicting uptake and bioaccumulation of toxic substances, particularly for sediment-associated contaminants.
- Conduct research on the role of biotransformation and other metabolic activities on uptake, bioaccumulation, and toxicity of chemical contaminants in the marine environment.

Exposure and Effects

- Conduct additional research to develop markers that indicate sublethal toxicological effects of pollutants on organisms in laboratory and field studies.
- Conduct additional research to determine the relationship between sublethal effects in individuals and population responses to toxic contaminants.
- Continue research addressing the links between toxic contaminants and known effects.
- Continue to conduct research on combinations of toxic substances to identify interactive effects on marine organisms.



Chapter III

Understand the Sources, Fates, and Effects of Nutrients Entering the Marine Environment as a Result of Human Activities

Nutrients are usually defined as those substances that are required for the growth of primary producers such as benthic algae, aquatic vascular plants, and phytoplankton (GESAMP, 1990b). Nitrogen, phosphorus, and silicon are the major nutrients (macronutrients) in marine and fresh waters. However, a wide variety of elements (e.g., iron, manganese, zinc, copper, and cobalt) and trace organic compounds (e.g., vitamin B_{12}, thiamine, and biotin) are also required for the growth of primary producers (Aubert, 1990; Bonin et al., 1981; Hecky and Kilham, 1988).

Human activities contribute large quantities of nutrients to the marine environment. These inputs in many cases equal or exceed nutrient inputs from natural processes (GESAMP, 1990b). Publicly owned treatment works and industrial dischargers are the main point sources of nutrient loadings. Urban and agricultural runoff and emissions from automobiles and industry are the major nonpoint sources of nutrient inputs to estuaries and coastal waters. The degree of nutrient loading has been identified as a serious problem in many national estuaries and bays, such as Boston Harbor, Buzzards Bay, Chesapeake Bay, Long Island Sound, New York Harbor, and Kaneohe Bay (Hawaii). Therefore, understanding the sources, fates, and effects of nutrients entering the marine environment as a result of human activities is one of the six goals of the National Ocean Pollution Program.

Goal Definition

Effective management of nutrient loading requires knowledge of the quantities and timing of inputs from the pollution sources, as well as knowledge of the capacity of particular ecosystems to assimilate nutrient loads. The relative contribution of nutrients from these sources varies considerably, depending on factors such as location, degree, and type of industrialization; land practices; and climatic factors. Over the past two decades, Federal and State regulation and monitoring of point source dischargers have resulted in the collection of substantial amounts of data on nutrient loading from point sources. Much less information, however, is available on nutrient loading from nonpoint sources.

The ability of coastal systems to assimilate nutrient loads depends on the quantity and timing of inputs relative to their rates of removal from and recycling within these systems. The primary production supported by uptake of nutrients can theoretically be partitioned into new and regenerated production, depending on whether the nutrients supporting growth are derived from external (new) sources (i.e., atmospheric deposition, advection, vertical flux from below the photic zone, and anthropogenic sources) or are regenerated from organisms within the euphotic zone (Platt et al., 1989). When regenerated production is high relative to new production, 1) primary production is typically low and nutrient limited and 2) the processes of production, heterotrophic consumption, and nutrient regeneration tend to be closely coupled in time and space. As the proportion of new production increases in response to nutrient loading (e.g., from anthropogenic inputs), the capacity of the food web to assimilate added nutrients is exceeded and the magnitude and variance of phytoplankton production increase, resulting in increased potential for phytoplankton blooms and the occurrence of anoxic or hypoxic events. While these general concepts have been known for some time, the ecological changes that will occur in any particular coastal area with a qualitative or quantitative change in nutrient input are still not clearly understood.

Excessive nutrient enrichment of coastal waters can result in degradation of water quality, adverse impacts to aquatic and marine biota, and alterations in species composition. In recent years, the apparent increased occurrence of nuisance and toxic blooms in coastal waters has attracted considerable attention because of their tremendous impact on fisheries, aquaculture, and human health. The causes and mechanisms responsible for such blooms are at present unclear; however, the general eutrophication of coastal waters by human activities has been suggested by several authors (e.g., Cherfas, 1990; Legendre, 1990; Prakash, 1987; Paerl, 1988; Smayda, 1990).

In many regions there is concern that unless mitigation measures are implemented, the fluxes of nutrients (especially nitrogen) into coastal waters will continue to increase, resulting in degradation of coastal resources. The growth of human populations along the coasts, the pressure to increase agricultural production through fertilization, the conversion of forest and wetlands into fields and urban areas, and the release of nitrogen oxides into the atmosphere will all contribute to the nutrient loading of coastal waters (Nixon, 1990).

This goal section will discuss priority issues identified by the National Ocean Pollution Program and the Scientific and Federal Working Groups that need to be addressed by the Federal government in the next 5 years in order to increase our understanding of the effects of nutrients entering the marine environment and the Great Lakes as a result of human activities. These priority issues are as follows:

- Quantification of amounts, rates, and sources of anthropogenic and natural nutrient inputs and

- Effects of nutrient inputs on marine ecosystems.

The discussion that follows identifies the information needs associated with each of these priority issues, discusses current Federal activities to address these information needs, and recommends future Federal research and monitoring activities.

Priority Issues and Information Needs

Priority Issue: Quantification of Amounts, Rates, and Sources of Anthropogenic and Natural Nutrient Inputs

Information Need: The Relative Contribution of Nutrients from the Atmosphere, Groundwater, Surface Runoff, Sediments, and Offshore Sources. Over the past two decades, Federal and State regulation and monitoring of point source dischargers have resulted in the collection of substantial amounts of data on nutrient loadings from point sources. As the effluent quality of point source discharges has improved, the relative importance of nonpoint sources has increased and emphasis has been placed on developing approaches to monitor and control nonpoint sources (e.g., Moore, 1991).

Atmospheric deposition of phosphorus and nitrogen can supply significant quantities of these nutrients to marine and freshwater systems. Atmospheric deposition of phosphorus to marine coastal waters may represent up to 10 percent of the total phosphorus contribution from rivers (Graham and Duce, 1981, 1982) and up to 26 percent of the particulate phosphate flux from surface waters of freshwater lakes (Cole et al., 1990). Atmospheric deposition of nitrogen is estimated to account for 20 to 30 percent of the total annual loading of this nutrient in Chesapeake Bay (Fischer et al., 1988), and similar levels of nitrogen loading have been calculated for North Carolina's Albemarle-Pamlico Sound Estuary (Copeland and Gray, 1989). Paerl et al. (1990) suggest that based on projected increases in atmospheric nitrogen emissions from automobiles alone, the importance of atmospheric nitrogen deposition may increase substantially in the future and may accelerate eutrophication in coastal waters.

Little information is available regarding the quantity of nutrients supplied to marine waters from nonpoint groundwater sources. It is known that groundwaters can be contaminated with anthropogenic nutrient loads from agricultural and urban fertilizer applications, and leaching from septic systems and landfills. Quantification of the nutrient loads in groundwater is problematic because of a lack of understanding concerning transport and/or transformation processes occurring in the vadose zone (the area between the land surface and the water table) and the groundwater system. Increases in groundwater concentration of nitrogen have been linked to the use of fertilizers in urban areas. Models based on site-specific soil and land use characteristics have been used to estimate nitrogen contamination of groundwater (Flipse et al., 1984; Lau et al., 1991).

Nonpoint nutrient loading from agricultural sources and urban runoff can contribute substantial quantities of nutrients to coastal waters. Agricultural runoff impacts approximately 18 percent of the estuarine areas that do not meet water quality standards (USEPA, 1990d). Reducing nutrient loading from agricultural runoff is a key objective for the restoration and protection of Chesapeake Bay (Dunn and Shortle, 1988). Urban runoff of nutrients, derived primarily from urban lawn fertilization, also can supply substantial amounts of nutrients to coastal waters. High concentrations of nitrate in runoff have been implicated in blooms of nuisance algae in Newport Bay, California (NRC, 1990b).

The sediments are an important internal source of recycled nutrients, particularly in shallow waters, and quantification of sediment nutrient fluxes is essential to the development of mass balance approaches to nutrient management. Recent applications of eutrophication models have shown that mass balances of nitrogen and phosphorus are unsuccessful unless sediment sources and sinks are taken into account (Cerco, 1988). For example, phosphate concentrations in the water column of Narragansett Bay indicate a very regular annual pattern that has been shown to be primarily controlled by the changing balance between sediment uptake and release of phosphate (Hinga, 1989).

Information on nutrient loading from benthic processes, such as sediment-water exchanges, and physical transport of water masses is needed to assess the potential significance of anthropogenic inputs of point and nonpoint sources of nutrients. For example, in the Southern California Bight, Eppley (1986) compared the rate of input of ammonia and particulate organic nitrogen in municipal wastewater to the rate at which these compounds are generated by natural processes. Wastewater discharge was determined to be equivalent to the natural flux of ammonia and particulate organic nitrogen taking place under 772 mi^2 and 127 mi^2 of sea surface, respectively.

Several Federal agencies are currently conducting research programs designed to assess the relative inputs of different sources of nutrients to marine waters. The U.S. Department of Agriculture (USDA) is undertaking several projects involving the characterization of nutrient releases from aquaculture facilities.

The Environmental Sciences Division of the U.S. Department of Energy (DOE) Office of Health and Environmental Research is continuing studies on nutrient cycling within continental shelf ecosystems. In June 1990, a workshop was held to assess the current state of knowledge and propose research goals to quantify the fluxes of materials between coastal areas and the open ocean. Among the proposed research activities to be conducted along the continental shelf are experiments and analyses designed to measure 1) the exchange of nutrients between the shelf and interior ocean, 2) biogeochemical cycling of nutrients within ocean margin ecosystems, and 3) the role of ocean margins as potential sources and sinks for nutrients in global biogeochemical cycles.

The U.S. Geological Survey (USGS) has several ongoing and new programs related to nutrient input. The National Stream Quality Accounting Network (NASQAN) currently consists of a national river sampling network of 410 sites, 140 of which are in or near the coastal zone. The measurement of nutrient loads is planned for a subset of those rivers located at coastal sites. The National Water Quality Assessment Program (NAWQA) is scheduled for full implementation in 1994. This program will include a number of large-scale monitoring and assessment studies and will be designed to examine sources, fates, and effects of several parameters, including nutrients along coastal areas. USGS is also participating in the development of the Coastal America program. This program is designed to develop management strategies for coastal areas that will be useful in the prevention or remediation of pollution problems, including nonpoint sources of pollution.

To better assess any adverse effects of anthropogenic nutrient loading on the environment, it is necessary to continue to characterize and quantify sources of nutrient inputs and their variability.

> *Recommendation:* *Conduct research to determine the relative importance of nutrient sources to nutrient budgets in marine ecosystems and characterize the spatial and temporal variability of nonpoint sources of nutrients.*

Information Need: Quantification of Those Aspects of Nutrient Cycling Within and Export from Coastal Water Bodies That Are Perturbed by Anthropogenic Activities. Prediction of the effects of nutrient loading to coastal waters is dependent upon the ability to understand several complex processes, including the mechanisms and rates of internal cycling of key nutrients (primarily ammonium and urea) and the extent of nutrient export from coastal to offshore areas. Anthropogenic nutrient loading may occur from both point and nonpoint sources. The characterization and quantification of nutrient loading from point sources is less problematic than from nonpoint sources because of the inherent differences in the discharges. As opposed to point source pollution, nonpoint pollution originates over broad areas, fluxes of pollutants are intermittent, and the mode of transfer to coastal waters is often difficult to analyze. Therefore, assessment of the role of nonpoint nutrients in cycling and fluxes will require considerable effort.

NOAA's Coastal Ocean Program (COP) has several programs assessing the impact of nutrient inputs on estuarine and coastal waters. The Atmospheric Nutrient Input to Coastal Areas (ANICA) component of the COP is measuring the flux of atmospheric nitrogen to Chesapeake Bay and its watershed. The COP Nutrient Enhanced Coastal Ocean Productivity

(NECOP) program is a major study of the impact of anthropogenic nutrients from the Mississippi and Atchafalaya Rivers on the Louisiana shelf.

Nutrient cycling involves complex couplings among the water column, sediments, atmosphere, and surrounding land masses. Nutrient fluxes among these reservoirs involve transformations between both dissolved and particulate fractions and inorganic and organic nutrients. Nutrient cycling determines the availability of nutrients for uptake by primary producers and, therefore, impacts all biological communities. Accurate characterization of nutrient cycling is necessary for prediction of impacts from nutrient loading.

Classical descriptions of nutrient flux between dissolved and particulate pools consider nutrient uptake by phytoplankton, phytoplankton-zooplankton trophic interactions, transport of nutrients to the benthos via sedimentation of particulates, remineralization of nutrients by planktonic and benthic microorganisms, and subsequent upwelling of the nutrients to surface waters. In these models, transitions from particulate to dissolved fractions occur primarily during uptake of nutrients by phytoplankton and during benthic remineralization.

The concept of a microbial loop in the water column was first proposed by Azam et al. (1983) and has drastically changed ideas concerning nutrient cycling; many studies have illustrated the importance of bacteria, heterotrophic flagellates, and microzooplankton on the cycling of nutrients in the water column. Recognition of the tightly coupled cycling between inorganic and organic nutrients and the particulate and dissolved fractions has revealed additional levels of complexity in aquatic environments.

Sediment processes are also an important factor in nutrient cycling. For example, it has been demonstrated that the coupled process of nitrification-denitrification is quantitatively important in the nitrogen budgets of continental shelf sediments (Christensen et al., 1987) and of estuaries, where nitrogen losses via denitrification may account for half of the terrestrial impacts (Seitzinger, 1988). The coupled process of nitrification-denitrification in sediments, therefore, represents a sink that shunts nitrogen away from recycled pathways (Jenkins and Kemp, 1984). Kemp et al. (1990), however, have demonstrated that for some estuaries such as the Chesapeake Bay, the increased production and consumption of organic matter associated with eutrophication may lead to a marked reduction in rates of nitrification and denitrification in sediments. Thus, this natural process that might help keep eutrophication in check is itself inhibited in such organic-rich environments (Kemp et al., 1990). A conceptual model of nitrogen pools, transformations, and sediment-water fluxes for the coastal sediments examined by Kemp et al. (1990) is illustrated in Figure 3.1.

Recent research has not only revealed previously unknown sources of variability in the environment, but has also indicated the need for improved sampling methods. For example, physiologically-based approaches (i.e., measurements of the amounts of biologically active nutrient pools in cells) to determine phytoplankton nutrient requirements may be more useful than existing methods involving bulk chemical measurements of collected waters (Hecky and Kilham, 1988). Water column nutrients may be more adequately analyzed by measuring dissolved nutrient concentrations because they are more useful than nutrient concentrations derived from particulate sources in determining nutrient loading rates of aquatic ecosystems (Hecky and Kilham, 1988; Jackson and Williams, 1985). Large-scale spatial and temporal variability may best be examined through the use of satellite mapping technology and other remote sensing devices (e.g., Mortimer, 1988; Yentsch, 1989; Balch et al., 1989; Uno and Yokota, 1989; Bagheri and Dios, 1990).

A number of Federal research and monitoring programs designed to characterize nutrient cycling currently exist or are proposed. The DOE Ocean Margins Program is designed to measure the nutrient fluxes along the continental shelf. EPA's National Estuary Program supports monitoring of nutrient levels that may be used to characterize nutrient cycling in estuaries. The USGS has proposed two programs devoted in part to the assessment of anthropogenic nutrient inputs. The National Water Quality Assessment Program (NAWQA)

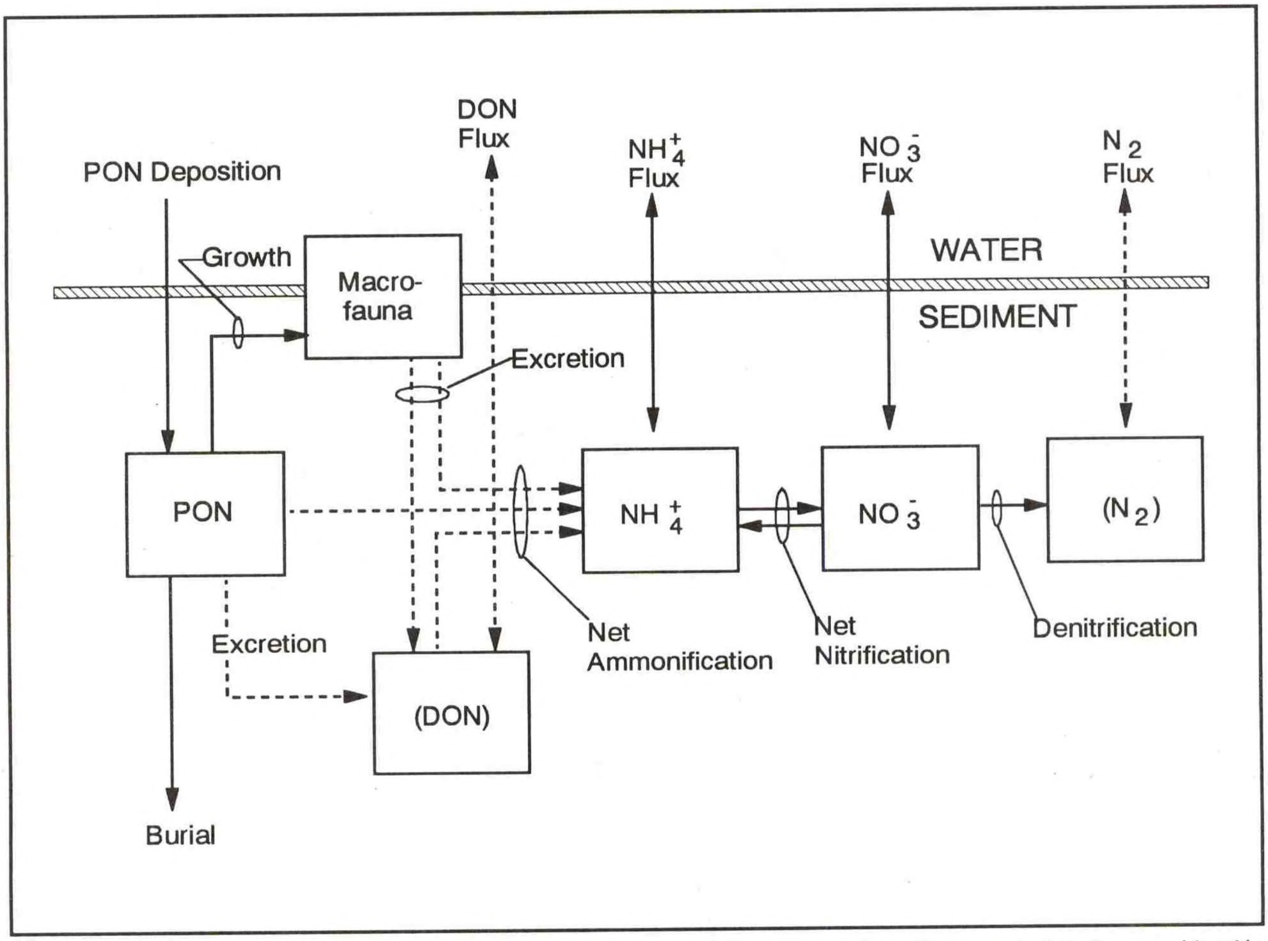


Figure 3.1. Conceptual diagram depicting N pools, transformations, and fluxes across the sediment-water interface considered in Kemp et al. (1990) study. Processes and fluxes for which direct measurements are available are shown as solid lines, whereas broken lines are used for those rates estimated by subtraction. Pools not measured are indicated in parentheses.

is designed to examine sources, fates, and effects of several parameters, including nutrients, on coastal areas. The Federal multi-agency Coastal America Program is designed to develop coastal management strategies for the prevention or remediation of problems such as nonpoint sources of pollution (e.g., nutrient loading from runoff).

NOAA has several new and ongoing programs to monitor nutrients and to study their effects on ecosystems. The NOAA Strategic Assessment Program is conducting an ongoing assessment of eutrophication in approximately 120 estuaries. NOAA's Great Lakes Environmental Research Laboratory has an ecological monitoring program in Lake Michigan to provide time-series data for a number of parameters including nutrients. NOAA's Coastal Ocean Program has initiated a 5-year project, Nutrient Enhanced Coastal Ocean Productivity (NECOP), to conduct process-oriented research on the quantitative impacts of nutrient overenrichment in the Mississippi/Atchafalaya Rivers outflow. The dramatic increase of nutrients may have altered the natural cycling of nutrients in the region of the Louisiana shelf, perhaps affecting productivity, seasonal hypoxia, carbon transport, and yield of living marine resources. NOAA's National Sea Grant College Program conducts research on the cycles of nutrients and carbon in coastal waters and coastal wetlands in order to understand the pathways and transformations of key nutrients.

Further research and monitoring to quantify nutrient cycling and allow predictions of the effects of anthropogenic nutrient inputs from point and nonpoint sources on the coastal environment are recommended.

Recommendations: 1) Conduct research to characterize nutrient cycling between organic and inorganic pools and the role of dissolved and particulate nutrient fractions in marine ecosystems, and 2) develop improved techniques for synoptic areal coverage of nutrients and/or their indicators (e.g., algal blooms).

Priority Issue: Effects of Nutrient Inputs on Marine Ecosystems

Nutrient loading can cause adverse effects on the receiving environment. To effectively manage anthropogenic nutrient inputs, it is necessary to understand the changes that may occur in marine coastal waters if nutrient loading levels are too high.

Information Need: The Effects of Nutrient Variability and Availability on Trophic Structure, Water Quality, and Occurrence of Nuisance and Toxic Blooms. At present, insufficient information is available to allow prediction of the response of marine ecosystems to nutrient loading. In particular, additional data are needed to determine the conditions under which macronutrients (nitrogen, phosphorus, and silicon) and/or micronutrients may limit primary productivity and the nature and degree of trophic structure changes resulting from excessive nutrient inputs.

The response of an ecosystem to nutrient inputs depends on many factors, including the timing, amounts, and kinds of nutrient loadings, and the physical and biological characteristics of the system. Excessive nutrient inputs accelerate eutrophication, resulting in increased abundances of phytoplankton. In recent years, considerable attention has been devoted to the apparent increased frequency of occurrence of exceptional phytoplankton blooms (e.g., Anderson, 1989; Cherfas, 1990; Cosper et al., 1990; GESAMP, 1990a; Smayda, 1990). Several coastal embayments along the northeast coast (e.g., Narragansett Bay, Long Island Sound, and Barnegat Bay in New Jersey) have in recent years experienced exceptional blooms of previously unidentified microalgae (Cosper et al., 1990). Exceptional blooms of phytoplankton have also occurred in recent years in the coastal and estuarine waters off Texas, Louisiana, California, and Washington (Beers, 1986; Harper and Guillen, 1989; Horner et al., 1990).

The increased frequency of nuisance and toxic phytoplankton blooms has accompanied nutrient enrichment of coastal waters; however, there is insufficient information as to the mechanisms, the identity of nutrients, and the physical conditions that trigger such events. In some cases, exceptional blooms appear to be unrelated to the loading of macronutrients and may instead be dependent on the quantities and timing of micronutrient availability (Aubert, 1990; Cosper et al., 1990). Trace organic substances such as biotin, thiamin, vitamin B_{12}, and chelating agents can stimulate the productivity of some algal species. These materials can be detected in anthropogenic discharges such as sewage and may alter the competitive abilities of phytoplankton species.

Increases in the level of nutrients, as well as alterations in the relative abundance of key nutrients, can alter the species composition and size structure of primary producers (Hecky and Kilham, 1988; GESAMP, 1989; Thingstad and Sakshaug, 1990) and impact organisms at higher trophic levels. The optimal nutrient requirements of most algal species are not sufficiently known to permit detailed predictions of how changes in nutrient ratios will impact species composition. Historical shifts from a diatom- to flagellate-dominated community in Chesapeake Bay have been attributed to nutrient loading (Officer et al., 1987). The anthropogenic enrichment of nitrogen and phosphorus in many areas has led to long-term declines in Si:N and Si:P ratios (Smayda, 1990). These changes may tend to favor species other than diatoms which have a requirement for silicon. Of particular uncertainty is our ability to measure or predict effects on marine resources. This will require substantially more quantitative understanding of the dissolved oxygen and nutrient concentrations and nutrient ratios that cause population-level effects of consequence.

In eutrophic water bodies, the large planktonic biomass decreases the distance that light can penetrate through the water column, thereby providing insufficient light for submerged aquatic vegetation (SAV) growth at the sediment surface during blooms (Twilley et al., 1985; Kemp et al., 1983). In addition, Twilley et al. (1985) found that in nutrient-treated experimental ponds an extensive epiphytic community developed on the leaves of submerged vascular plants, reducing net production of these plants through several mechanisms, including light attenuation and reduction of diffusive transport of inorganic carbon, nitrogen, and phosphorus. The resulting declines in SAV result in the loss of valuable habitats for finfish and shellfish as well as decreased oxygen production.

Several Federal programs, either ongoing or proposed, address the effects of nutrients on marine ecosystems. CoastWatch is a NOAA program designed to intensely monitor coastal areas. Two prototype CoastWatch programs currently exist: Southeast CoastWatch and Chesapeake Bay CoastWatch. The Southeast CoastWatch program is using advanced very high resolution radar (AVHRR) satellite imagery to detect warm-water Gulf Stream intrusions into southeast coastal waters; such intrusions have been linked to outbreaks of red tides. The Chesapeake Bay CoastWatch program, in cooperation with the Maryland Sea Grant program, is using aircraft-derived ocean color measurements to monitor the extent, location, and timing of algal blooms in the Bay. The CoastWatch program plans to expand its AVHRR and ocean color coverage to all the Nation's coasts in future years. NOAA's Coastal Ocean Program will contribute to an assessment of the severity of nutrient over-enrichment problems in U.S. coastal waters and will conduct studies to understand and predict occurrences of toxic algal blooms. NOAA's National Sea Grant College Program conducts research into the control of nutrients on coastal and estuarine ecosystem composition and function.

Identification of limiting nutrients in marine and freshwater systems is a central management concern. Mitigation policy can be formulated and implemented only when environmental responses to changes in nutrient loadings can be predicted accurately.

> *Recommendations: 1) Continue research to determine conditions under which macronutrients and/or micronutrients control primary productivity; 2) conduct additional research to determine the trophic structure changes resulting from changes in nutrient inputs; and 3) develop protocols and indicators that can provide advanced warning of, or document existing effects of, hypoxia at the population level.*

Information Need: The Role of Climatic Effects, Basin Physiography, and Nutrients in Causing Hypoxia and Anoxia in Marine Ecosystems. Excessive nutrient loading to marine ecosystems can result in elevated phytoplankton standing stocks and lead to hypoxia (low oxygen levels) or anoxia (lack of oxygen) in subsurface waters due to microbial oxygen consumption from degradation of phytodetritus and other sources of organic matter. The environmental consequences of hypoxic and anoxic events can be severe, including fish kills (Harper and Guillen, 1989) and widespread destruction of benthic populations (Harper and Guillen, 1989; Seliger et al., 1985; Swanson and Parker, 1988; Murrell and Fleeger, 1989; Officer et al., 1987).

Both biological and physical factors are responsible for the onset and duration of hypoxic and anoxic events. The importance of physical factors in the development of hypoxic and anoxic events has been studied in Chesapeake Bay and New York Bight and in waters off Galveston, Texas.

In Chesapeake Bay, the development of anoxia was found to be dependent upon the vertical flux of plankton-derived organic matter and the formation of a strong halocline (Officer et al., 1987; Seliger et al., 1985). Seliger et al. (1985) determined that the area exposed to anoxic conditions in the Bay appeared to be increasing and suggested that this may be the result of anthropogenic nutrient loading.

A recently completed major research program in Chesapeake Bay, undertaken by NOAA's Sea Grant Program, has found that nutrient remineralization processes play a major role in determining the extent and duration of hypoxic events.

Seasonal development of hypoxia in the New York Bight has been attributed to increased anthropogenic carbon loading from adjacent urban areas, an unusual climatic regime that restricts renewal of oxygen to bottom waters, and elevated abundances of dinoflagellates (Falkowski et al., 1980; Swanson and Parker, 1988). Hypoxia in the northern Gulf of Mexico is usually associated with high river discharge, a phytoplankton bloom, and stratification of the water column due to calm weather and/or temperature-salinity gradients (Harper and Guillen, 1989).

The Nutrient-Enhanced Coastal Ocean Productivity (NECOP) program, part of the NOAA Coastal Ocean Program, is designed to assess the impact of terrestrial nutrient inputs on coastal primary productivity. Part of this program includes a study of hypoxia on shelf areas near the Mississippi and Atchafalaya Rivers. In addition, EPA's National Estuary Program supports monitoring of nutrients and potential assessment of their relationship to hypoxia and anoxia in several estuaries.

Although the main factors that result in hypoxia or anoxia appear to have been identified, it is still not possible to predict the degree of hypoxia adequately. Because of the potential serious impacts to coastal fisheries and aquaculture, further study is warranted.

> Recommendation: *Conduct further research on the role of freshwater input, basin physiography, and nutrients in causing hypoxia and anoxia in marine ecosystems to support the development of models of eutrophication, prediction of hypoxia and anoxia, and quantification of the effects of hypoxia and anoxia on aquatic and marine organisms.*

Conclusions

Excessive human-induced nutrient loading into estuaries, from nonpoint sources such as runoff from agricultural and urban areas and point sources such as publicly owned treatment works (POTWs) and industrial dischargers, has resulted in degraded water quality leading to hypoxia and anoxia. Estuaries have the ability to remove and retain nutrients in suspension or in solution, leading to pollution and management problems that are difficult to control. Successful understanding of the estuary as a geochemical filter requires knowledge of not only the distributions of dissolved and particulate species but also their rate of introduction, discharge, and accumulation.

Over the past several years, nutrient loading has exceeded flushing capacity in estuaries that have experienced large amounts of human and agricultural growth. The excess nutrients create eutrophic conditions, resulting in the formation of a large nutrient pool in the benthic sediments. The regeneration of this nutrient pool into primary production, along with the high levels of new nutrient loadings, leads to alteration in species composition and productivity. These changes in primary production lead to altered trophic relationships within the ecosystem, degraded water quality, and the occurrence of nuisance and toxic blooms—all of which are not fully understood. Nutrients can be flushed from the estuarine system in the form of particulate organic matter by tidal action with the rate being correlated with loadings and seasonal factors. Assimilation of sewerage nitrogen within estuaries is low in the winter and thus most is exported offshore; in the summer, assimilation is high and export is low (Schubel and Kennedy, 1984).

The following conclusions relating to the state of our knowledge concerning sources, fates, and effects of nutrients in aquatic environments are based on the discussion of priority issues and information needs presented in this chapter:

1) Although there is substantial information concerning point source nutrient loadings rates from decades of Federal and State regulation and monitoring, a data gap still

exists concerning nutrient loading rates from nonpoint sources, especially from the atmosphere, surface runoff, sediments, groundwater, and offshore.

2) While the concept of the distinction between new and regenerated production has been known for some time, the changes that occur in any particular coastal area with a qualitative or quantitative change in nutrient input are still not clearly understood.

3) Nuisance and toxic blooms have become an increasing concern for the past few years since they impact fisheries, aquaculture, and human health and recreation. The conditions causing these blooms are not well understood, and the present level of knowledge only suggests eutrophication of the coastal waters as a potential cause.

4) Although the role that nutrients play in estuarine productivity is well understood, the conditions under which macronutrients and micronutrients degrade productivity and the changes in trophic structure resulting from excessive nutrient inputs are not clear. The identification of limiting nutrients in marine and freshwater systems is also an important management concern.

5) Estuaries with high anthropogenic nutrient loadings exhibit an alteration in phytoplankton population composition. Changes from diatom- to dinoflagellate- dominated communities can negatively impact the productivity of the estuary, but the factors involved in the decrease in productivity and the species conversion are not well understood.

6) The coupling of increased nutrient levels and stratification leads to hypoxic or anoxic conditions affecting estuarine fisheries and aquaculture. At present, it is not possible to predict the intensity, the ranges and the duration of these events.

Based on these conclusions, the following recommendations are made to improve our understanding of the sources, fates, and effects of nutrients entering the marine environment as a result of human activities. The information generated will supplement our knowledge of nutrient sources and the biogeochemical relationships within the marine environment.

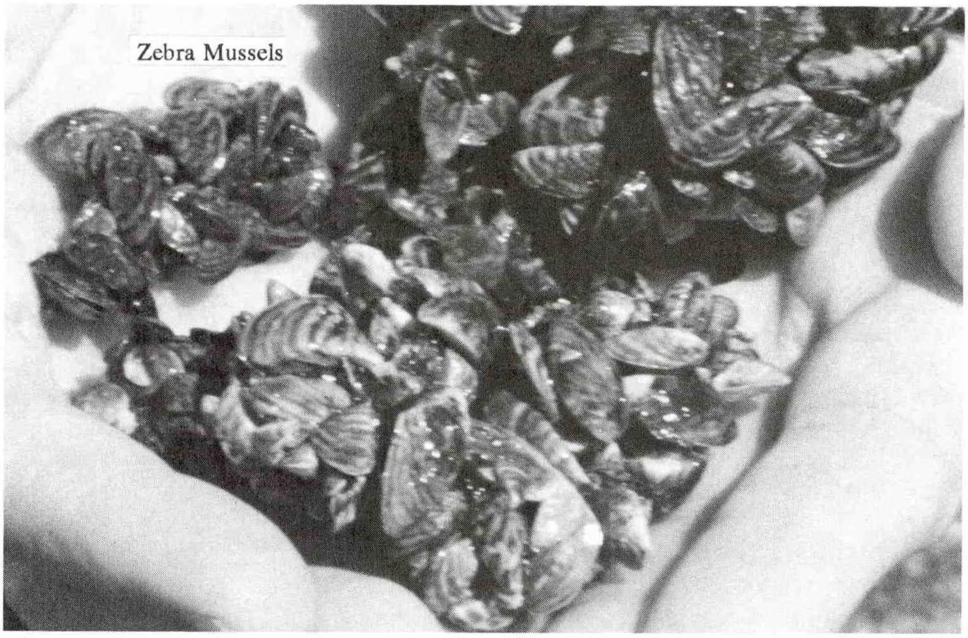
Recommendations

Nutrient Inputs

- Conduct research to determine the relative importance of nutrient sources to nutrient budgets in marine ecosystems and to characterize the spatial and temporal variability of nonpoint sources of nutrients.
- Conduct research to characterize nutrient cycling between organic and inorganic pools and the role of dissolved and particulate nutrient fractions in marine ecosystems.
- Develop improved techniques for synoptic areal coverage of nutrients and/or their indicators (e.g., algal blooms).

Effects

- Conduct further research to determine conditions under which macronutrients and/or micronutrients control primary productivity.
- Conduct additional research to determine the trophic structure changes resulting from changing nutrient inputs.
- Develop protocols and indicators that can provide advanced warning of, or document existing effects of, hypoxia at the population level.
- Conduct further research to determine the role of freshwater input, basin physiography, and nutrients in causing hypoxia and anoxia in marine ecosystems to support the development of models of eutrophication, prediction of hypoxia and anoxia, and quantification of the effects of hypoxia and anoxia on aquatic and marine organisms.



Chapter IV

Understand the Sources, Fates, and Effects on Aquatic Organisms of Pathogens and Nuisance Species That Are Introduced or Influenced by Human Activities

In the 1988 Federal Plan, a biological agent was defined as a living organism, whether introduced or indigenous, that, through human influence and under the proper conditions, will have an adverse impact on the ecosystem or organisms in the ecosystem. Such agents included pathogens, toxic algae, and introduced microorganisms. Because of increased recognition of biological agents, this goal in the 1992 Plan specifically addresses only pathogens and nuisance species (both micro- and macroorganisms). Other organisms such as toxic algae, which release their toxic products to the aquatic environment or are toxic by ingestion, are discussed in Chapter III, on nutrients, and in Chapter VII, on human health. All human health effects are discussed in Chapter VII.

The presence of pathogens or nuisance species in marine, estuarine, or Great Lakes environments can cause decreases in the population size and/or in the economic value of the affected species. Pathogens may increase the incidence of various diseases among aquatic organisms, causing epizootics (disease outbreaks) and/or mass mortalities. Nuisance species are nonindigenous species (i.e., species non-native to the United States, species native to the United States but not to the particular localized area, or native species that have been altered genetically), including both pathogenic microorganisms and introduced macroorganisms. Nuisance species may affect abundances of indigenous species by outcompeting or preying on them. Indigenous species whose populations have undergone rapid growth may also become a nuisance. Susceptibility of aquatic organisms to pathogens and nuisance species may be increased as a result of pollution: human activities may introduce or induce the proliferation of such agents.

The resources of concern are individual species or communities including marine mammals, fish and shellfish stocks and their supporting communities, and populations of endangered species. Therefore, understanding the sources, fates, and effects of pathogens and nuisance species that are introduced or influenced by human activities is one of the six goals of the National Ocean Pollution Program.

Pathogens act within tissues of affected organisms and can cause adverse impacts to individuals and populations. Known pathogens include viruses, bacteria, fungi, and protozoans. Pathogens may cause various diseases among aquatic organisms, depending on the resistance of the host. Some effects of disease on marine fish populations are illustrated in Figure 4.1. Introduced species, or the water that is discarded into the habitat with them, can also contain pathogens or microorganisms that were nonpathogenic to their native hosts but can be pathogenic to indigenous species.

The majority of introduced organisms are exotic species introduced into the aquatic environment through human activities. These organisms include nonindigenous macro- and microorganisms and genetically engineered organisms. Releases of genetically engineered organisms have not yet been permitted in aquatic environments. However, a number of naturally-occurring species have been transferred to new habitats, where they may compete with indigenous species for resources such as space or nutrients or may have more direct impacts through predation. It is evident that serious economic impacts on humans can result from these introductions, including the loss of commercial indigenous species (e.g., due to the lamprey) or adverse physical modification of submerged structures and equipment by sessile aquatic macroorganisms (e.g., by the zebra mussel).

While the occurrence and action of some pathogens and introduced species in aquatic environments are known to be pollution-related, for others the link to pollution is only suspected, and all are clearly influenced by natural phenomena. Interactions among pathogens, introduced species, and native species can also be altered by environmental conditions such that native species may have adverse impacts on ecosystems. Once established, pathogens and/or nuisance species are difficult to eradicate.

The issues targeted by the National Ocean Pollution Program and the Scientific and Federal Working Groups focus on determining how acute and chronic problems associated with both pathogens and nuisance species can be identified, controlled, treated, and predicted. The discussion below addresses pathogens and nuisance species separately.

Goal Definition: Pathogens

Pathogens may be introduced or endemic. The presence of some pathogens increases the occurrence of disease and threatens the existence of sensitive living resources (e.g., endangered species). Pathogens also may threaten the economic well-being of commercially important fish and shellfish industries. Table 4.1 lists some pathogens of aquatic organisms, their sources, human influence, resources affected, and impact. Examples within these groups of pathogens are discussed below, as well as diseases of unknown etiology and sources of pathogens.

Viral Pathogens

Viruses affect a variety of aquatic shellfish and other invertebrates (Farley, 1978; Johnson, 1984) and fish (Wolf, 1988), with new ones being recognized each year. Many fish viruses appear to exist as latent infections, particularly in adult fish, but when contracted by fry or fingerlings, or with exposure of infected adults to environmental stresses, these viruses become pathogenic and can cause substantial mortalities (Sindermann, 1990). Although many viral diseases in fish appear to have a restricted geographic range, a few are quite widespread, including lymphocystis, viral erythrocytic necrosis (VEN), infectious pancreatic necrosis (IPN), infectious hematopoietic necrosis (IHN), and viral hemorrhagic septicemia (VHS).

In addition to causing debilitating diseases or death in aquatic organisms, viruses are also suspected of contributing to the development

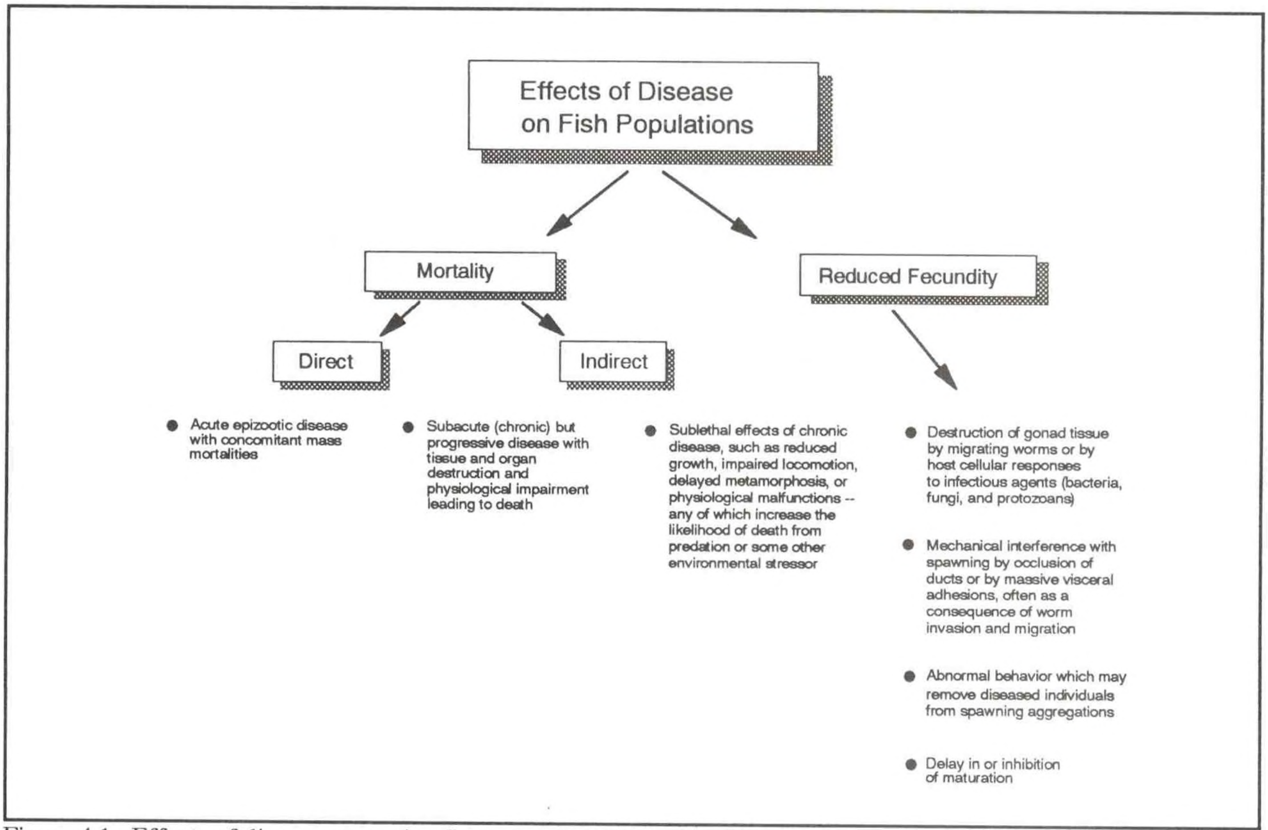


Figure 4.1. Effects of disease on marine fish populations (Source: Sindermann, 1990)

of cellular proliferative disorders. For example, neoplasms of hematopoietic origin (suspected of developing from blood cell precursors, leukemia-like) have been found in epizootics of softshell clams (*Mya arenaria*) on the east coast of the United States and in mussels (*Mytilus* spp.) on the west coast (Brown et al., 1977; Elston et al., 1988). The occurrence of these sarcomas is enhanced when the animals face natural environmental stresses such as changes in temperature and salinity, but no correlation with pollution has yet been established (see review by Peters, 1988). A virus is the suspected agent, and this is actively being investigated on both coasts.

Type A influenza virus is an example of a human pathogen that has been implicated in mortalities of harbor seals and pilot whales (Murphy et al., 1983; Geraci et al., 1982, 1983; Hinshaw et al., 1986). Influenza A viruses found in whales in one study were believed to have been dispersed in seagull feces (Geraci et al., 1983).

Recent work has also identified large numbers of viruses in marine waters—many more than were previously suspected. Some have been identified as bacteriophages (Proctor and Fuhrman, 1990); others have been shown to infect a wide variety of marine phytoplankton, including diatoms, cryptophytes, prasinophytes, and chorococcoid cyanobacteria (Suttle et al., 1990). These phages may have profound effects on the productivity of aquatic microorganisms and microalgae, as well as other serious consequences (see below).

Bacterial Pathogens

Bacteria of the genus *Vibrio* are ubiquitous in the marine environment. Superficial characteristics of fish disease caused by *Vibrio* spp. include skin lesions and ulcers. Although infections are usually disseminated, outbreaks of vibriosis are generally attributed to some form of environmental stress or exposure to metal contamination, which increases the susceptibility of the fish to the disease (Colwell and Grimes, 1984). Recently, however, the occurrence of obligate pathogenic genotypes has been proposed (Toranzo and Barja, 1990). A high correlation between the occurrence of *V. anguillarum* in fish and contamination by

Table 4.1
Examples of Pathogens, Their Sources, Human Influences, and Impact on Living Marine Resources

Category and Agent	Source	Human Influence	Resource Affected	Impact
Viruses				
Adenoviridae	Unknown	Effects enhanced by environmental stress	Fish	Epithelial hyperplasias (Bloch et al., 1986).
Baculoviridae	Unknown	Environmental enhancement	Crustaceans	Mortalities in natural and cultured populations of penaeid shrimp and crabs (Sindermann, 1990).
Caliciviridae	Indigenous	Unknown	Pinnipeds	Premature parturition (Howard, 1984).
Herpesviridae	Unknown	Environmental enhancement	Fish, crustaceans, molluscs	Mortalities from systemic infections and associated with hyperplastic and neoplastic diseases (Sindermann, 1990).
Iridoviridae	Mammalian	Unknown	Fish, molluscs	Lymphocystis, mortalities from viral erythrocytic necrosis in fish, gill lesions and mortalities in molluscs (Sindermann, 1990).
Papovaviridae	Unknown	Unknown	Molluscs	"Ovacystis" disease of gametocytes and eggs (Sindermann, 1990).
Influenza A	Human	Unknown	Marine mammals	Strandings, mortalities (Hinshaw et al., 1986; Geraci et al., 1982).
Bacteria				
Aeromonas salmonicida	Indigenous	Unknown	Fish	Furunculosis, mortalities (Sanders and Fryer, 1988).
Edwardsiella tarda	Unknown	Unknown	Fish, marine mammals	Hemorrhagic disease in fish, peritonitis, opportunistic invader of sick and injured mammals (Coles et al., 1978).
Aerococcus viridians variety *homari*	Indigenous	Unknown	Lobster	Septicemia: gaffkaemia, mortalities (Sindermann, 1990).

Table 4.1 (continued)

Category and Agent	Source	Human Influence	Resource Affected	Impact
Leptospira spp.	Indigenous	Unknown	Pinnipeds	Leptospirosis, multiple hemorrhage syndrome, strandings, mortalities (Vedros et al., 1971; Smith et al., 1977).
Pasteurellapiscida	Unknown	Unknown	Fish (striped bass, white perch)	Pasteurellosis, mortalities (Sanders and Fryer, 1988).
Phormidium corallyticum	Indigenous	Environmental stress, nutrient loading?	Scleractinian corals	Loss of living coral tissue from reef areas (Rutzler et al., 1983).
Pseudomonas spp.	Indigenous	Unknown	Crustaceans	Shell disease, black spot disease. Disease enhanced by temperature and overcrowding (Sindermann, 1990).
Renibacterium salmoninarum	Indigenous	Unknown	Fish	Bacterial kidney disease (Sanders and Fryer, 1988).
Salmonella spp.	Unknown	Unknown	Marine mammals	Juvenile mortality. Gulls aid in spreading the disease (Gilmartin et al., 1979)
Staphylococcus aureus *Staphylococcus equi*	Unknown Equine	Unknown	Dolphins, pilot whales, other marine mammals	Cerebral abscesses resulting in strandings (Colgrove and Migaki, 1976). Broncho-pneumonia-induced mortalities (Higgins et al., 1980).
Streptococcus spp.	Unknown	Unknown	Fish	Streptococcal septicemia, mortalities (Sanders and Fryer, 1988).
Vibrio spp.	Indigenous	Pollution stress enhances disease	Fish, arthropods, molluscs	Red sore disease, ulcers, skin lesions, hemorrhages. Vibriosis generally affects stressed organisms (Colwell and Grimes, 1984).
Fungi				
Blastomyces spp.	Unknown	Resuspension, environmental stress	Marine mammals	Dermatitis, systemic infections (Howard, 1984).
Fusarium spp.	Unknown	Enhancement	Crustaceans, sharks	Mortality (Sindermann, 1990).
Ichthyophonus spp.	Indigenous	Dredging	Fish	Mortality (Sindermann, 1990).
Laegenidium spp.	Indigenous	Enhancement	Crustaceans	Mortality (Sindermann, 1990).

Table 4.1 (continued)

Category and Agent	Source	Human Influence	Resource Affected	Impact
Protozoa				
Haplosporidium nelsoni	Unknown	Incidence spread on East Coast due to contaminated shipments	Oysters	Causative agent of MSX; destruction of many oyster beds (Ford and Haskins, 1982).
Hematodinium spp.	Indigenous	Unknown	Blue crab, Alaskan tanner crab	Mortality; meat can not be used commercially (Meyers et al., 1990).
Labyrinthula spp.	Indigenous	Unknown	Seagrasses	Mortality, loss of beds on East Coast and in Florida (Muehlstein, 1989).
Perkinsus marinus	Introduced	Enhanced by environmental stress	Oysters	Significant mortalities (Sindermann, 1990).

wastewater discharges has been observed in some outbreaks (Larsen et al., 1978). In addition, significantly higher concentrations of antibodies to *V. anguillarum* were observed in flounder collected from the New York Bight apex than in flounder from unpolluted coastal waters (Robohm et al., 1979).

A cyanobacterium, *Phormidium corallyticum*, causes black band disease in scleractinian or stony corals (Rutzler et al., 1983). Nutrient loading has been proposed recently as a possible contributor to the extensive outbreaks of black band disease that began in August 1987 in the Looe Key National Marine Sanctuary, since normally this disease is rare on reefs (B.D. Causey, Looe Key National Marine Sanctuary, personal communication).

Leptospirosis, a disease associated with multiple hemorrhage syndrome in fur seals and sea lions, is another bacterial disease (Vedros et al., 1971; Smith et al., 1977). The causative agent of this disease, *Leptospirosis* spp., is most frequently acquired through the food chain by pups in their first year of pelagic existence (Smith et al., 1977). Environmental pollution, particularly the tissue accumulation of organochlorine and polychlorinated biphenyl compounds, is believed to increase the susceptibility of these animals to disease (Howard, 1984).

Fungi

Human influences on the incidence of fungal diseases of aquatic organisms are not well documented. However, there are examples of fungi that have impacted living marine resources. *Blastomyces* is a fungus found in dolphins and sea lions. This typical yeast is an opportunistic invader of compromised marine mammals and may cause fatal systemic or respiratory disease (Howard, 1984). *Ichthyophonus hoferi* is the major fungal agent that causes systemic disorders in marine finfish. Fungi of the genera *Lagenidium* and *Fusarium* are responsible for diseases in the embryos and adults of penaeid and palaemonid shrimps, crabs, and lobsters (see reviews in Sindermann, 1990). The chytrid *Pythium porphyrae* causes red wasting disease in the commercially important macroalga *Porphyra* (nori). This disease can substantially reduce crops of the alga and appears most frequently under conditions of reduced salinity and increased water temperatures (Andrews, 1976).

Several species of the slime mold-like protist *Labyrinthula* are known to grow in association with macrophytes. One of these species is a suspected cause of wasting disease in the marine seagrass *Zostera marina* (Muehlstein, 1989). This disease wiped out entire beds of the grass on the northeast and northwest coasts of the United States in the 1930s and, in the 1980s, in isolated estuaries along the east coast (Short et al., 1987). It is suspected that pollution also played a role in the etiology of this disease. *Labyrinthula* has also been implicated in the wasting disease that has recently caused high mortality in the beds of the seagrass *Thalassia testudinum* in the Florida Keys (M. Hall-Ruark, Florida Department of Natural Resources, personal communication).

Protozoa

Protozoa represent a group of pathogens that have been responsible for major impacts to economically important marine resources (Sindermann, 1990). *Haplosporidium nelsoni* causes one of the most devastating epizootic diseases to affect marine resources in the United States. This disease (known as MSX) has reduced eastern oyster (*Crassostrea virginica*) commercial harvests on the east coast of the country, causing mortalities of up to 90 percent of the population in some localities. Widespread loss of oysters was first observed in the Delaware Bay in 1957 (Ford and Haskin, 1982) and in the lower Chesapeake Bay in 1960. *H. nelsoni* was then probably spread to Massachusetts with shipments of infected oysters from the James River in Virginia (Rosenfield and Kern, 1978; Sindermann, 1990). The spread and severity of effects are related to high salinity, with mortalities being observed most often in waters of greater than 15 ppt. Human-influenced alterations in freshwater movement in estuaries and transfer of infected organisms by humans have contributed to the upstream spread of this pathogen.

Another protozoan pathogen of concern to the shellfish industry is *Perkinsus marinus* (also known as "dermo"), which has been responsible for significant, although less dramatic, mortalities of oysters from Delaware Bay to

Florida on the Atlantic coast and through the entire northern Gulf of Mexico, from Florida to Mexico. Prevalence is near 100 percent with mortalities of up to 50 percent of the population each year (Andrews, 1988; Wilson et al., 1990). Again, mortalities are increased in higher salinities and with warmer water temperatures. Recent work by Winstead and Couch (1988) has indicated that virulence of this organism is enhanced in oysters that have been exposed to the chemical carcinogen n-nitroso-diethylamine.

Members of the protozoan phylum Sarcomastigophora cause lethal infections in commercially important crabs. The amoeba *Paramoeba perniciosa* is the etiologic agent of gray crab disease in May-June and October-February in the blue crab, *Callinectes sapidus*, on the Atlantic coast of the United States. It has also been found in rock crabs and lobsters. The dinoflagellate *Hematodinium perezi* is another hemolymph parasite of Atlantic coast crabs (Sindermann, 1990). Recently, systemic infections caused by a *Hematodinium*-like dinoflagellate have caused severe economic losses to the Alaskan Tanner crab (*Chionoecetes bairdi*) industry, with up to 95 percent of crabs infected, depending on the locality (Meyers et al. 1990). Although the parasite is harmless to humans, it causes poor meat texture and a bitter aftertaste, which affects marketability.

Disease Outbreaks of Unknown Causes

There are many cases of diseases where the impact on aquatic resources has been severe but the etiology is unknown. For example, increases in the incidence of bottlenose dolphin and whale beachings along the east coast of the United States and the Gulf of St. Lawrence in the late 1980s aroused interest in determining whether pathogens were involved in this phenomenon (Geraci, 1989). Mass mortalities of commercially important fish and shellfish such as herring, striped bass, menhaden, blue crab, and king crab have been reported, but the causes of such die-offs have been elusive (Williams and Bunkley-Williams, 1990). In 1983, mass mortalities of the long-spined sea urchin, *Diadema antillarum*, resulted in the virtual disappearance of this ecologically important species from coral reefs in the Caribbean basin (Williams and Williams, 1987). Localized mortalities in small remnant or recruiting populations of these urchins are still occurring (E. H. Williams, Jr., University of Puerto Rico, personal communication).

Coral reefs in the Caribbean, Bahamas, and Florida have recently been subjected to damage of unknown causes, besides extensive algal overgrowth resulting from the loss of the herbivorous urchins. In 1982-83, 1987-88, and again in 1990, scleractinian corals, other cnidarians, and sponges were affected by a disease known as bleaching, due to the loss of the dinoflagellate algal cells or zooxanthellae that live within their tissues and give the animals a brown color (Langreth, 1990). Normally the zooxanthellae mutually aid in the metabolic functions of their hosts, utilizing host waste products in photosynthesis to manufacture nutrients used by the coral cells. Loss of the zooxanthellae has resulted in reduced skeletal accretion or growth, reduced reproduction, and tissue necrosis in stony corals in many areas, although other affected corals have recovered their zooxanthellae within a few weeks. The synchronicity of bleaching events throughout the Caribbean raised concern that some biological agent may be involved in this disease; elevated seawater temperatures and other factors, however, have also been implicated in this worldwide problem (Williams and Bunkley-Williams, 1990). Stony corals have also been affected globally by white band disease, in which tissue sloughs off the skeleton at the rate of a few millimeters per day (Antonius, 1984; Rogers 1985). The etiology is still unknown, although a bacterium is suspected in this disease in acroporid corals (Peters, 1984).

Neoplasms present a serious problem affecting many aquatic species. However, the role of viruses and carcinogenic chemicals in genetic damage and the development of various cancers (Bishop, 1987) and the interactions of these agents with other pathogens and pollutants are areas that require further investigation (Mix, 1986). A viral etiology was suspected, but not found, in the development of gonadal neoplasms (germinomas) in quahogs (*Mercenaria* spp.) in the Indian River, Florida (Hesselman et al., 1988). However, germinomas in softshells in Maine appear to be related to herbicide exposure only (Gardner et al., 1991). In fish, epizootics of liver neoplasms have been recognized in 13 species and epizootics of epidermal neoplasms have been found in 6 species from chemically-contaminated sites in marine, estuarine, and Great Lakes environments (Harshbarger and Clark, 1990). Although the case for a chemical etiology is strong in most of the liver lesions, other neoplasms have been shown to be caused by viruses, and questions remain about the etiology of many cellular proliferative disorders. Another example is the recent outbreak of debilitating fibropapillomas in endangered green sea turtles, *Chelonia mydas* (Jacobsen et al., 1989). These tumors can occur in the throat, hindering breathing and feeding; on the eyes, impairing sight; and on the flippers and tail, hampering movement on land and in the water. The cause of fibropapilloma, how it is spread, and what the impact of the disease will be on the recovery of the green turtle are unknown.

Plasmid exchange is also an area of concern. This process, which involves the transfer of genes from one microorganism to another, may confer certain undesirable characteristics to a previously benign agent. Plasmid exchange has the potential of creating virulence or resistance to antibiotics in microorganisms that previously did not have those traits (McConnell et al., 1979). The development of resistance to antibiotics by certain pathogens exposed to outflows or antibiotic dumps has been demonstrated for bacteria associated with mammals (Flint et al., 1987; Wachsmuth et al., 1983). Viruses in aquatic environments are also potential agents of plasmid exchange. Such novel strains may defy attempts to control their spread and prevent their impact on marine resources. In addition, the effects of pollution on these organisms have not been investigated.

Sources of Pathogens

Pathogenic microorganisms can enter the aquatic environment directly as a result of human activities or exist naturally in the water column, sediments, or biota. Also, some populations of such organisms can increase from the low level normally found in the environment to a higher level that can then impact other organisms. These increases in activity or blooms can result from human-induced alterations in environmental conditions. Some microbes may persist in the sediment in the form of cysts, becoming active when resuspended or ingested by the appropriate host organisms.

Pollution can affect the action of a pathogen in two ways. A pathogen may be introduced or proliferate in the environment as a result of human activity. A concurrent increase in the incidence of disease among indigenous organisms may result from increased exposure to those agents. For example, the numbers of the bacteria *Vibrio anquillarum* in the water column and sediment were shown to increase in the vicinity of a discharge of wastewater from a sugar plant (Colwell and Grimes, 1984) and at polluted sites on the coast of Denmark (Larsen and Willeberg, 1984). Alternately, environmental stresses caused by toxic chemicals in the water, or changes in salinity or temperature, could increase the susceptibility of organisms to endemic opportunistic pathogens (Colwell and Grimes, 1984); that is, the defense mechanisms of stressed aquatic organisms may be altered to such an extent that resistance to pathogens is lowered (Sindermann 1990; Weeks et al., 1990). Fin erosion in fish, infections by *Vibrio* spp. and *Pseudomonas* spp., bacterial hemorrhagic septicemia caused by *Aeromonas* spp. and *Pseudomonas* spp., and protozoan and fungal infections (*Costia necatrix* and *Saprolegnia* spp.) are examples of secondary fish infections that occur when fish face environmental stresses (Wedermeyer et al., 1984; O'Connor et al., 1987; Sindermann, 1990). Similarly, viral, bacterial, and fungal diseases of commercially important bivalve molluscs, penaeid shrimp, crabs, and lobsters have been associated with pollution and adverse changes in environmental conditions (Couch and Courtney, 1977; Couch 1978; Sawyer et al., 1983; Estrella, 1984). Most observations on such conditions in aquatic reptiles and mammals have been made on organisms stressed by captive conditions, and more research, such as that conducted by Glazebrook and Campbell (1990) on diseases of wild marine turtles, is required on free-living populations (Kinne, 1985).

Direct sources of pathogens resulting from land- or water-based human activities include:

- Disposal of domestic, industrial, food preparation, and hospital wastes;

- Runoff from feedlots, agricultural areas, or urban areas;
- Accidental or deliberate inputs from research and educational laboratories;
- Application of biological control agents;
- Translocation of species through shipping activities, water ballast, recreational activities, and intentional transplanting;
- Human flora introductions through recreational activities; and
- Introductions associated with aquaculture and aquarium display.

Anthropogenic alterations to environmental conditions that may favor the redistribution, enhanced proliferation, or increased pathogenicity of biological agents include:

- Environmental disturbances (dredging or shipping) resulting in resuspension and transport of sediments and sludges;
- Changes in the physical environment, e.g., temperature (cooling water discharges), salinity (alterations in freshwater flow), and turbidity (dredging, coastal erosion);
- Changes in water chemistry through introduction of chemicals, e.g., nitrogen, phosphorus, micronutrients, or toxic compounds; and
- Changes in pathogenicity of endemic microorganisms by transfers of genetic material from introduced forms (plasmid exchange).

Priority Issues and Information Needs for Pathogens

Pathogenic microorganisms and their impact on aquatic resources have received relatively little attention in the past as compared to other forms of pollution. In many cases, diseases in populations of aquatic organisms have been observed that are suspected of being caused by pathogens, but evidence linking an agent to the disease is lacking or incomplete. Defense mechanisms of aquatic organisms may be reduced to such an extent that resistance to pathogenic microorganisms may be compromised. Stress may be the result of anthropogenic disturbance (e.g., contamination, physical alterations in the habitat) or the presence of other pathogens that facilitate secondary infections in these organisms.

The synergistic and cumulative effects of anthropogenic influences on disease outbreaks cannot be resolved until the agent is identified and some basic knowledge of the biology, ecology, mechanisms of pathogen transmission, and pathogenicity can be determined. Information gaps include fundamental questions of taxonomy (e.g., *Vibrio*) and diseases that have been attributed to pathogens but whose etiology is not completely understood (e.g., *Haplosporidiumnelsoni*). Other gaps include the ecology of nonpathogens as well, since interactions of supposedly harmless microorganisms with known pathogens, unusual environmental conditions, and/or pollutants may lead to their becoming pathogenic.

The National Ocean Pollution Program, in association with the Federal and Scientific Work Groups, has identified the following priority issues that need to be addressed in the next 5 years to understand the role of pathogens in altering aquatic populations and the quality of aquatic environments:

- Establishing the connection between observed problems and specific pathogenic microorganisms and
- Biological characteristics and environmental requirements of pathogens, mechanisms of pathogenicity, and the influence of human activities on pathogens and host susceptibilities.

The following sections of this chapter discuss the rationale, current efforts, and remaining work to be done to address each of these issues.

Priority Issue: Establishing the Connection Between Observed Problems and Specific Pathogenic Microorganisms

Information Need: Knowledge of Pathogens Responsible for and Understanding of the Mechanisms of Outbreaks of Disease and Mass Mortalities. The effects of some pathogens on living aquatic resources are known. However, while problems caused by pathogenic organisms may be apparent, identification of the specific pathogens involved, the environmental factors that increase their pathogenicity or reduce host resistance, the host ranges, and predictions of outbreaks are not as easily determined. Research is required on the normal background levels of disease organisms in a system; the factors, especially environmental, that trigger sudden increases in populations of pathogens; and the extent to which low levels of disease are present in an ecosystem.

The National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency (EPA), the U.S. Fish and Wildlife Service (FWS, Department of the Interior), and the Food and Drug Administration (FDA) have funded the majority of Federal research on pathogens (NOAA, 1990b). Past studies that address the question of basic attributes of pathogens have generally been concerned with those that may impact human health. Such studies are still being conducted by the National Institutes of Health (NIH) and the FDA. The latter agency conducts extensive research on pathogens and other hazards associated with fisheries products at three regional laboratories dedicated solely to fisheries research and fisheries-related activities. The EPA studies pathogens of aquatic organisms at the Environmental Research Laboratories in Gulf Breeze, Florida, and Narragansett, Rhode Island. Within NOAA, the Office of Oceanic and Atmospheric Research (OAR) sponsors studies that address the identification and characterization of pathogens. In particular, the National Marine Fisheries Service (NOAA/NMFS) as well as the FWS have also conducted studies of pathogens causing disease in commercial fish and shellfish stocks. However, diseases in other organisms have usually been neglected, even though such diseases may cause significant mortalities and alter organism interactions, or damage habitats (such as losses of seagrass beds or of living coral tissue from reef areas). To a lesser extent, other programs supporting studies of diseases in aquatic organisms include the Sea Grant Program (NOAA/OAR); and the Coastal and Estuarine Assessments Branch, the Strategic Assessments Branch, and the National Marine Sanctuaries Program of the National Ocean Service (NOAA/NOS). USDA and Sea Grant are now supporting research to develop DNA probes for the rapid identification of the MSX and dermo pathogens.

As more attention is given to declines in aquatic food resources, research must be continued to identify pathogens responsible for epizootics and mass mortalities. The research necessary to address these areas should include the development of rapid, inexpensive, and easy-to-use systems for the detection, isolation, characterization, and quantification of pathogens that cause disease among aquatic organisms. Such research should utilize new equipment and methodologies to provide more rapid and accurate diagnoses of disease problems and to determine the cause of death in mass mortalities of marine fish and shellfish or of standings in marine mammals. Opportunities must be offered to train new scientists in the fields of marine fish and invertebrate pathobiology.

> *Recommendation:* *Conduct research directed at identifying pathogens responsible for disease outbreaks and mass mortalities of marine organisms.*

Another important aspect of the study of diseases in marine organisms is the improvement of techniques for identifying and communicating the occurrence of disease outbreaks and mass mortalities. There must be coordination of Federal, State, and local agencies with fishermen, scientists, and the general public so that disease problems can be investigated promptly.

In addition to the identification of geographically localized events, a more global view regarding such events is necessary. Although many epizootics may appear to be discrete and limited, they may also reflect *in toto* the result of large-scale changes in the environment, the result of stress caused by pollution, or global changes in environmental factors such as temperature. There have been cases of diseases in aquatic organisms that were thought to be of only local concern, but turned out to be widespread and of significant damage (such as MSX and the *Diadema* mass mortality, Williams and Williams, 1987). Examples of worldwide events include increases in coral bleaching and ulceration in fishes. Methods to allow extensive data collection and rapid dissemination of information must be considered, including the development of networks of observers and scientists to provide such data. Conceptual and mathematical models of disease etiology and/or epidemiology should be constructed and revised as new information is collected.

> Recommendation: *Improve techniques for identifying and communicating the occurrence of epizootics and mass mortalities.*

Priority Issue: Biological Characteristics and Environmental Requirements of Pathogens, Mechanisms of Pathogenicity, and the Influence of Human Activities on Pathogens and Host Susceptibilities

Information Need: Biology and Ecology of Pathogens, Including Life History, Host and Pathogen Physiological Ecology, Species Interactions, and Persistence and Dormancy of Microbes. To ameliorate or diminish the effects of pathogens on valuable aquatic resources, researchers must develop an understanding of the biological characteristics and environmental requirements of these agents. There is a general lack of knowledge about the basic biology of most microorganisms, including life cycles and histories and inter- and intraspecies interactions. The effects of the physical and chemical environment on these biological agents is another area in which there is a paucity of data. To gain a better understanding of the impact of pathogens, basic information is needed on the biological attributes of a wide range of agents found in aquatic environments.

A major factor limiting studies of virulence in aquatic systems is the lack of cell and tissue culture systems for invertebrates and for seagrasses and other macrophytes. The development of *in vitro* and *in vivo* cultivation systems for growth of microbial agents could be used for qualitative and quantitative studies of dose response infectivity, disease transmission mechanisms, cell cycle studies, inactivation mechanisms, and the demonstration of cause-effect relationships. Such systems have been developed for mammalian and insect cells and greatly facilitate these sorts of studies. Research effort may also be hampered by the fact that some microorganisms are viable but not culturable; this phenomenon occurs in gram-negative bacteria. It has been seen in some fish and human pathogens as well as nonpathogenic species (Grimes et al., 1986; Grimes, 1991). This phenomenon is important not just because it hampers efforts to isolate and identify suspected pathogens, but because it raises at least two interesting questions about the life cycle of these organisms: Under what conditions do microorganisms exist in this state? Do they remain infectious?

Pathogens are released into aquatic environments from a variety of sources. Human activities such as dredging or sewage discharges may affect population densities of aquatic microorganisms. Pollution may cause the proliferation of certain pathogens that are normally present at low densities such as the influenza virus, *Vibrio parahaemolyticus*, and *Streptococcus* spp. Moreover, human activities may lead to introductions of nonindigenous pathogens. Knowledge of the types and locations of inputs of microorganisms would aid in the development of effective control or treatment strategies. Although potential sources of pathogens are known, it is difficult to quantitatively determine the extent to which pathogens are being introduced from point and nonpoint sources.

The NMFS, EPA, and FWS conduct histopathological studies of infectious molluscan and fish diseases and parasites, as well as the immunological identification of pathogens and life history stages in alternate and reservoir hosts. NOAA is supporting research on the life cycle of *Haplosporidium nelsoni*. The FDA sponsors studies of the genetic characterization of *Vibrio* and *Aeromonas* species. Related activities conducted by NOAA include the collection and analysis of bottom-feeding fish and bivalve molluscs for diseases under the National Status and Trends (NS&T) Program. A similar program has recently been initiated by the EPA—the Environmental Monitoring and Assessment Program (EMAP), Near Coastal Component. The NMFS is also sponsoring studies under the Northeast Fisheries Center's Inshore Research Plan to determine the relationship between pathogen outbreaks and other sources of organism stress, such as contaminants, nutrient overenrichment, and habitat loss. NS&T and EMAP are also examining the correlation of chemical contamination with the prevalence and intensity of diseases in fish and shellfish. EPA's National Estuary Program, the National Sea Grant Program, the Great Lakes Environmental Research Laboratory (NOAA), and, to a lesser extent, the National Undersea Research Program (NOAA) are supporting research on the effects of adverse water quality, including toxic pollution, on commercially and recreationally important fish and shellfish stocks and the ecosystems that support these resources. The FWS conducts field and laboratory research on the prevention and control of diseases affecting free-living wildlife populations, and other activities include technical information transfer, diagnosis, and investigation of mass mortalities.

Long-term studies of problems related to pathogens may aid in the identification of episodic events as they occur and contribute to our understanding of their biology and ecology. The NMFS developed both a Registry of Marine Pathology (ROMP) and a National Shellfish Health and Protection Plan to aid in such monitoring.

The ROMP, consisting of histopathological microslides representing a variety of disease conditions, pathogens, and parasites in fish, molluscs, and crustaceans, was transferred in 1989 to the Registry of Tumors in Lower Animals (RTLA) at the National Museum of Natural History, Smithsonian Institution, Washington, DC. The RTLA also houses the collection of crustacean histopathological material developed by Dr. Phyllis T. Johnson at the NMFS Oxford, MD, laboratory, as well as over 3500 cases of neoplastic and nonneoplastic lesions in aquatic organisms from all over the world. These materials are available for study by qualified investigators. The American Type Culture Collection (ATCC), Rockville, MD, contains cultures of some aquatic microorganisms (viruses, bacteria, fungi, algae, protozoa) that have been identified as pathogens for aquatic flora and fauna, as well as those for humans. Upon publication of new taxa or strains, authors are required to deposit cultures at the ATCC. Also, by law, new cell lines such as those for transgenic fish (see below), including proprietary strains, must also be deposited there. These cultures are maintained and are also available for research and comparative studies.

The implementation of control or eradication procedures and the prediction of outbreaks of disease among aquatic organisms require an understanding of the basic biology of pathogens, as well as transport mechanisms and the persistence and concentration of pathogens in these environments and within organisms. Investigations of the mechanisms by which disease organisms are spread over geographic areas involves fundamental questions concerning physical and biological transport of pathogens. It also includes questions of how organisms become dominant and flourish at particular instances, including information on limiting factors and growth to some threshold level beyond which infected populations cannot defend themselves.

Research must be continued to determine the sources of the most significant pathogens. Comprehensive studies of the ecology of indigenous and exotic pathogens must be performed. Additionally, it will be impossible to determine the interactions of pollution and disease on the abundance of individuals, even those commercially important species, without a better understanding of the natural sources of variability in pathogen populations. Quantitative information on the effect of pollution and disease on aquatic resources is required. This knowledge will significantly improve our capability to predict the consequences of human activities and enhance our ability to treat disease outbreaks.

Recommendations: 1) Quantify the sources of the most significant pathogens; 2) conduct research to determine the persistence and transport mechanisms of pathogens; and 3) perform comprehensive studies of the ecology of indigenous and exotic pathogens.

Information Need: Information Concerning Mechanisms of Pathogenicity. Pathogens may be absorbed by aquatic organisms through direct surface contact, ingestion, or transmission via intermediate hosts. A pathogen may then affect the host organism by producing toxins, causing the growth of tumors, disrupting metabolic pathways or reproductive processes, or causing behavioral alterations. A thorough understanding of the biophysical transmission of the important diseases is necessary in attempting to diminish the severity of the impact that various pathogens may inflict on living marine resources.

Research investigating how changes in physical or chemical environmental factors effect changes in the immune systems of some organisms is also required, as well as studies on the relationship of pollutants to the presence of diseases in various aquatic habitats (Overstreet, 1988; Wilson et al., 1990). The conditions that have resulted in episodic mass mortalities and epizootics are often not well documented and are extremely unpredictable. To understand any anthropogenic and pollution effects, the influence of natural environmental variables must also be understood.

While many research efforts sponsored by Federal agencies are primarily concerned with the mechanisms of pathogenicity of microorganisms in the aquatic environment impacting human health, some of these studies may also apply to the effects of pathogens on aquatic resources. The subject of pathogenic mechanisms in aquatic organisms is being addressed in studies sponsored by NMFS, FDA, EPA, and FWS. The role of infectious disease in population dynamics of commercial and recreational marine species is the subject of studies by NMFS, FWS, and FDA. NMFS scientists are investigating shellfish disease resistance and defense mechanisms in marine molluscs and disease diagnostics and immune responses among Pacific coast salmonid fish species. The U.S. Department of Agriculture is now funding tests of disease-resistant eastern oyster stocks in the northeast Atlantic region and supporting research on the genetic mechanisms of resistance. Studies funded by FDA are directed toward human health aspects of the incidence and pathogenicity of various microbial agents in shellfish and finfish, including pathogenesis of *Aeromonas* and *Vibrio* spp. and evaluating the virulence of various pathogens in marine waters. NMFS scientists on the east coast have studied the mechanisms of pathogenicity of certain bacterial species as it relates to hatchery-related diseases of clams, *Mercenaria mercenaria*, and the eastern oyster, *Crassostrea virginica*. Two toxins that have been isolated and characterized, the pigment prodigiosin produced by *Pseudomonas* spp. and proteinaceous exotoxin produced by *Vibrio* spp., have undergone extensive study to determine the conditions required for extracellular accumulation (Brown, 1981, 1990).

These studies do not necessarily examine the effects of human activities on pathogenicity. However, EPA is continuing to focus on the role of pollutants in infectious disease incidence and severity in fish and shellfish, such as the influence of natural and anthropogenic environmental factors on the incidence of *Perkinsus marinus* on eastern oysters in the Gulf of Mexico. The Department of Energy has sponsored studies to characterize molecular, biochemical, physiological, and pathological processes in marine fish and invertebrates in relation to energy-generated contaminants, using a combination of *in vivo* and *in vitro* approaches, to examine the question of induction of or increased susceptibility to infectious diseases when under pollutant stress.

Evidence exists to suggest that human activities significantly influence pathogens in aquatic environments, and these effects may present a threat to valuable living resources. Human activities may also play a role in the development of diseases for which the etiologic agent is not yet known. Research to determine mechanisms of pathogenicity must include studies of the virulence of various significant pathogens and the conditions under which the host organisms are most susceptible. This research should include the study of the influence of human activities, including habitat alteration, pollution, or pathogen transfers, on susceptibility of organisms to disease, on reducing the proper functioning of host defense mechanisms, and on host-agent interactions. In addition, research on the immunological systems of the afflicted species should also be conducted using a transfer of technology from studies of terrestrial mammalian immunology and genetics.

> *Recommendations: Conduct research to 1) determine the mechanisms of pathogenicity and 2) determine the influence of human activities on disease susceptibility, host defenses, and host-agent interactions.*

Goal Definition: Nuisance Species

Organisms, particularly those that have been introduced into new environments, may act as pathogens (discussed in the previous section), parasites, predators, or competitors of native populations. Introduced organisms have the potential for removing or displacing populations and assemblages of endemic species, thus altering ecosystem structure and function. Table 4.2 presents some nuisance species of concern, with additional information on their sources and known or potential impacts. Examples of introduced nuisance species, genetically engineered organisms, and their sources are discussed below.

Introduced Nuisance Species

Accidental introduction and dispersal of nonindigenous or exotic species into waters of the United States, as well as around the world, have occurred for many years and in a myriad of ways (Carlton, 1991). Some accidental introductions have also occurred when other target species were purposefully introduced into specific habitats. Nontarget species are those macro- and microorganisms that accompany the target species and/or are found on or in the transported species or in the transport media (Carlton, 1991). Carlton et al. (1990) noted that at least 15 species found in San Francisco Bay originated in sites in Asia, and other examples can be found in each marine, estuarine, and Great Lakes habitat examined (Carlton, 1991).

The zebra mussel, *Dreissena polymorpha*, is perhaps the best known of the recent introductions in the United States. This bivalve, apparently brought from Europe in ship ballast water, has invaded and flourished in most of the Great Lakes since 1987 (Hart, 1990). Research in the Great Lakes has indicated that a decline in phytoplankton population in the area may have been due to the rapid growth and extremely efficient filter feeding of the zebra mussel (although reduction in phosphorus may also be a factor). Such diseases may have serious ecological implications for the rest of the system. In addtion to an observed twofold increase in water clarity in some areas (between 1988 and 1989), these mussels may decrease the number of fish with planktonic larval stages by effectively filtering them out, or the increase in sunlight penetration may increase macrophyte growth and habitat for supporting adult fish. Although the effects of these mussels on the balance of aquatic organisms in the Lakes are not yet fully known, the most damaging impact has been the clogging of water intake pipes and valves at power plants, necessitating expensive repairs and measures for prevention of future fouling (Hebert et al., 1989; Buck, 1990).

Another example is the invasion of San Francisco Bay by the Asian clam, *Potamocorbula amurensis*. First collected in the Bay in 1986, these clams are now found throughout the estuary, sometimes in densities greater than 10,000 per square meter. *P. amurensis* is able to live on all types of substrates and in salinities ranging from less than 1 to 33 parts per thousand. An explosive increase in the distribution and abundance of these bivalves throughout the Bay could result in major alterations of trophic and benthic dynamics in the ecosystem (Carlton et al., 1990; Nichols et al., 1990). Other examples of introduced species include the Asiatic clam (*Corbicula fluminea*) in the Potomac River, MD (Cohen et al., 1984)

Table 4.2
Examples of Nuisance Species, Their Sources, Human Influences, and Impact on Living Marine Resources

Category and Agent	Source	Human Influence	Resource Affected	Impact
Bonamia ostreae	U.S. (probably shipped to Europe initially from U.S.)	Introduced into new areas with infected seed oysters	Oysters	Mortalities
Codium fragile spp. *tomentosoides*	Europe	Unknown	Seagrasses, macroalgae	Shades out or smothers indigenous species
Corbicula fluminea	Asia	Brought into San Francisco Bay via ballast water	Molluscs	Has outcompeted indigenous molluscs
Dreissena polymorpha	Europe	Brought into Great Lakes via ballast water	Phytoplankton, molluscs, fish	Reduction in plankton populations, competition with other filter-feeding molluscs, clogging of water intake pipes
Marteilia spp.	Europe	Introduced into new areas with infected seed oysters	Oysters, mussels	Mortalities
Mytilicola orientalis (copepod)	Japan	Introduced with Japanese seed oysters	Olympia oysters	Mortalities, substantial reduction in shellfish stocks
Spartina alterniflora	East coast U.S.	Brought to west coast as packing materials for shipping oysters, pasture grass, and other deliberate introductions	Shorebirds, oysters, juvenile fish, native salt marsh grasses	Altering community structure and composition, destroying mudflat habitats
Petromyzon marinus Sea Lamprey	North Atlantic	Entered Welland Canal in 1921	Fish	Mortality
Gymnocephalus cernua Ruffe	Europe	Ballast Water	Fish	Predates fish eggs and larvae
Lythrum salicaria Purple loosestrife	Europe	Unknown	Wetland ecosystem vegetation	Out competes native plants
Bythotrephes cederstoemi Spiny Water Flea	Europe	Ballast Water	Zooplankton fish larvae	Competes with native zooplank-toners for phytoplankton
Myriophyllum spicatum Eurasian water milfoil	Europe/Asia	Unknown	Fish	Alteration of fish spawning habitats; clogs municipal intake systems; impedes human activities.

and other river systems in the United States (Page et al., 1986); a species of calanoid copepod (*Sinocalanus doerrii*) in San Francisco Bay (Orsi et al., 1983); the copepod *Bythotrephes cederstroemi* in the Great Lakes; and the macroalga known as Irish Moss (*Codium fragile* spp. *tomentosoides*) on the east coast of the United States (Carlton and Scanlon, 1985). The impacts of these and other unintentional introductions are not yet fully understood, and the possibility exists that some of these species may significantly alter entire ecosystems beyond the ability of those systems to recover (Mooney and Drake, 1986; Drake et al., 1989).

One example of significant ecosystem alteration is that due to the introduction of the salt-marsh grasses *Spartina alterniflora* and *S. anglica* to the west coast of the United States *S. alterniflora*, originally traced to oyster shipments from New Jersey in 1894, has spread from Northern California to British Columbia. In addition to outcompeting native *Spartina* in San Francisco Bay, these grasses are destroying shorebird and juvenile fish feeding areas and oyster culture habitats by replacing mudflats with marshes grass. Besides affecting biological resources, waterfront property values may be lowered, and there is concern that increased siltation will alter the topography, with diking at river mouths causing flooding in these areas (Dr. T.F. Mumford, Washington Department of Natural Resources, Olympia, WA, personal communication).

The inadvertent introduction of infectious disease-causing agents carried with other introduced species creates another category of problems. The careless transfer of diseased oyster stocks into previously disease-free areas, for example, was responsible for the spread of *Haplosporidium nelsoni* (Rosenfield and Kern, 1978) and another serious protozoan pathogen of bivalves, *Bonamia ostreae* (Sindermann, 1990; Carlton, 1991). In addition, toxic plankton inoculates and parasitic organisms have the potential to be introduced with cultures of aquatic organisms. Another concern is the recent appearance of a *Marteilia*-like protozoan in the calico scallop, *Argopecten gibbus*, off the east coast of Florida. This pathogen was found when extensive mortalities virtually closed the calico scallop fishery in December-January, 1988-89, and it reappeared in February 1991 (Dr. N.J. Blake, University of South Florida, St. Petersburg, personal communication). The exact identity and source of the pathogen have not been established, but the acetosporan *Marteilia refringens* has produced extensive mortalities of oysters and mussels off France and Spain (Sindermann, 1990).

Studies of the transmission and spread of bitter crab disease indicated that processors and fishermen were responsible for introducing the dinoflagellates into some areas by improper disposal of infected Tanner crabs (Meyers et al., 1990), demonstrating the importance of following various quarantine procedures to control pathogen introductions. This is becoming increasingly evident in aquaculture, as species and their pathogens are being transferred around the world and are entering local habitats through faulty or lacking effluent discharge controls. For example, postlarvae of *Penaeus monodon*, a shrimp native to Asia, India, and Australia, were shipped from aquaculture facilities in Hawaii to the Waddell Mariculture Center in South Carolina, and escaped through pond drain pipes (Carlton, 1991). The shrimp eventually found their way to the open ocean and are now found offshore from South Carolina to northern Florida. These shrimp are susceptible to viral diseases such as infectious hypodermal and hepatopancreatic necrosis and monodon baculovirus, and there is now concern that these viruses may have been carried by the escaped shrimp and will impact native penaeid shrimp species (Lightner et al., 1985). There have been recent efforts to introduce the Pacific oyster *Crassostrea gigas* on the Atlantic coast as an aquaculture species. This oyster is hardier than the indigenous eastern oyster (*C. virginica*) and appears to be more tolerant of the protozoan pathogens that have decimated populations of native oysters. Along with the risk of introducing new parasites and pathogens to the Atlantic coast flora and fauna, there is concern that *C. gigas* will flourish and compete with native species for space and nutrients (W.S. Fisher, EPA Environmental Research Laboratory, Gulf Breeze, FL, personal communication).

Other purposeful introductions of commercial or recreational fish and shellfish have also occurred over the years in U.S. waters. Half the fish species sampled by Moyle et al. (1986) from the Sacramento-San Joaquin estuary were introduced species; the most abundant was the striped bass, an introduced fish. Some species have been introduced for utilitarian reasons such as weed control. However, these introductions have a tendency to disrupt stable endemic assemblages (Moyle et al., 1986), and many questions remain about the value of such introductions (Courtenay and Robins, 1989). The California tunicate, *Botrylloides diegensis*, released by a biologist into the Eel Pond at Woods Hole, MA, in 1973, has now become the dominant species on hard substrates throughout southern New England (Carlton, 1989).

Genetically Engineered Organisms

The category of introduced species also includes those that have been genetically engineered. Genetically engineered organisms are those which are created as new species using recombinant DNA techniques. Transgenic species are species that bear within their chromosomal DNA copies of novel genetic constructs introduced through molecular genetic techniques (Kapuscinski and Hallerman, 1990). This definition may also be extended to include the descendants of individuals so transinfected. Genetically manipulated organisms are strains of breeds that are endowed with desirable characteristics as a result of controlled breeding programs.

Plasmid exchange involves the transfer of genes from one microorganism to another and, as mentioned above, may confer certain undesirable characteristics, from an anthropogenic point of view, to a previously benign agent. Naturally-occurring plasmid exchange could also create novel forms in a process similar to genetic engineering. The effects of pollution on plasmid transfer of genetic material, such as that proposed to occur between marine viruses and other microorganisms, has not been investigated.

Environmental introductions of genetically manipulated animals and microorganisms are commonplace (CEQ, 1985). Such organisms have historically been a major thrust of agricultural developments designed to improve the characteristics of crops and livestock. However, genetically engineered species are more recent developments and less research has been conducted with these organisms. In recent years, genetically engineered microorganisms (GEMs) have been a particular source of concern to the scientific community, the government, and the public. The Biotechnology Research Subcommittee (BRS, formerly the Biotechnology Science Coordinating Committee) was established by the Committee on Life and Health Sciences of the Federal Coordinating Council on Science, Engineering, and Technology to address the issues of research and products of biotechnology by providing a coordinated framework of scientific policy and scientific review. In the future, the BRS will focus more attention on organisms that are the product of intergenetic combinations and combinations involving genetic material from pathogenic organisms. The USDA, NOAA, EPA, and NSF have recently initiated programs to examine the development of transgenic species and other genetically engineered organisms, and to evaluate the risks of potential releases.

Releases of genetically engineered microorganisms have not been permitted in the aquatic environment. However, it is known that genetically engineered microorganisms released on land may persist and be transported to the sea. Recent evidence suggests that these organisms may persist in the marine environment longer than previously believed (Colwell et al., 1985) and may eventually impact living marine resources. Genetically engineered macroorganisms now being developed and studied are kept in carefully controlled and monitored (under 24-hour surveillence) quarantine aquaria or ponds; intentional releases are not planned. Such organisms include carp, goldfish, catfish, and northern pike, in which the growth genes isolated from rainbow trout have been inserted into the genome, resulting in faster growth that would ultimately reduce the time to market. Other research has involved taking the antifreeze protein gene and growth hormone gene from salmon and, more recently, the growth hormone gene from striped bass, and inserting them into bacteria to enable large amounts of the hormone to be produced and administered in the water to promote growth. These studies are still in the preliminary stages, and much more research is required to evaluate the potential environmental as well as economic impacts of such developments (Kapuscinski and Hallerman, 1990).

Sources of Nuisance Species

As in the case of pathogens, nuisance species can come from a variety of sources. Ballast water is a major dispersal mechanism for the introduction of a variety of potential nuisance organisms into U.S. waters because both holoplankters and the meroplanktonic stages of benthic fauna and flora can be contained and transported within these storage tanks on ships (Carlton, 1985, 1987, 1991; Williams et al., 1988); the fouling and boring communities on ship hulls also carry species across oceans. Recreational boating, aquaculture, aquarists, researchers, seafood industry, fishing industry, and the public are also probable sources of exotic introductions into marine and coastal ecosystems. Transcontinental shipments of seed bivalves or bait fish/worms are often packed in water or sediment, or with grasses, kelp, or other seaweeds that harbor additional nontarget species and may be discarded in local waters.

Direct sources include:

- Accidental or deliberate inputs from research and educational laboratories;
- Translocation of species through shipping activities (water ballast, boring/fouling communities), fishing (bait, gear, water wells), recreational activities, sea level and lock canals for ships;
- Introductions associated with aquaculture (accidental releases or intentional transplanting) and public or home aquarium discards; and
- Live organisms intended for consumption, but discarded.

Anthropogenic alterations to environmental conditions that may favor the redistribution and enhanced proliferation of nuisance species include:

- Changes in the physical environment, e.g., temperature (cooling water discharges), salinity (alterations in freshwater flow), and turbidity (dredging, coastal erosion);
- Changes in water chemistry through the introduction of nutrients or toxic chemicals; and
- Overfishing or other extermination of native stocks of potential biological control organisms.

Priority Issues and Information Needs for Nuisance Species

The impacts of introduced, exotic species on aquatic ecosystems are poorly understood. As in the case of pathogens, the role of anthropogenic influence on disease outbreaks cannot be resolved because of a lack of fundamental information concerning the biology, ecology, and even the accurate identity of the nuisance species of concern.

Priority issues identified by the National Ocean Pollution Program, in association with the Federal and Scientific Work Groups, that need to be addressed during the next 5 years to increase our understanding of nuisance species that have been introduced or influenced by human activities are the following:

- The potential sources of introduced nuisance species;
- Nuisance species biology, ecology, and effects on aquatic ecosystems; and
- Biologically sound control mechanisms for nuisance species.

This section includes a discussion of the rationale, current efforts, and remaining work associated with the information needs for each of the above issues.

Priority Issue: The Potential Sources of Introduced Nuisance Species

Information Need: Identify Transport Mechanisms and Potential Pathways of Introduction. A large proportion of the organisms responsible for adverse effects on aquatic resources have been artificially introduced, either by accident or intentionally. Not all species introduced to new areas are injurious or harmful to resident biota; the deliberate introductions of some desired species have been beneficial to humans. On the whole, however, introductions of new species into an area have caused perturbations in the natural system. In many cases, the effects are not well understood or studied.

The major Federal legislative mandates relating to discharges into marine waters that potentially affect or contain nuisance species, as well as pathogens, are the Federal Water Pollution Control Act, as amended (FWPCA or Clean Water Act); the Marine Protection, Research and Sanctuaries Act (MPRSA); the Ocean Dumping Ban Act of 1988; and the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990. These acts regulate and require research and monitoring to assess impacts from such discharges.

The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 established a seven-member interagency Task Force cochaired by the Under Secretary for Oceans and Atmosphere (NOAA Administrator) and the Director of the Fish and Wildlife Service. Other agencies represented are the Environmental Protection Agency (EPA); Army Corps of Engineers (ACOE); U.S. Department of Agriculture, Animal and Plant Health Inspection Service (APHIS); U.S. Coast Guard; and U.S. Department of State. Representatives from affected industry and nongovernmental organizations are *ex officio* members of the Task Force. The Task Force is currently developing a Federal Aquatic Nuisance Species Program to prevent, detect, monitor, and control the introduction of nonindigenous species into the waters of the United States and its territories. The program is focusing on ecological/biological interaction and impacts of nuisance species (i.e., competition, predation, hybridization, diseases, parasites, and description of food web) as well as direct impacts of nuisance species on human activities. The Task Force functions as a coordinator of aquatic nuisance species activities on the Federal, State, and local government levels.

As a result of the formation of the Task Force, agency activities related to nonindigenous species are now being better coordinated to avoid duplication of effort. This includes the efforts of NOAA's National Sea Grant program, which has assumed a major role in funding research on nonindigenous marine organisms. The Ocean Studies Board, National Academy of Sciences, has received approval from the National Research Council to proceed with a project to study nonindigenous species in the marine environment. The Office of Technology Assessment is conducting a similar study on nonindigenous species in the freshwater environment. Besides identifying potential sources of introductions and examining how they replace native species, the various agencies are also involved in assessing the risks that an introduced aquatic organism may become a nuisance species and must determine whether measures to prevent an introduction are environmentally sound. Technological and engineering requirements for aquaculture facilities are also being examined to prevent the accidental release of potential nuisance species as well as pathogens.

To facilitate research on introduced aquatic nuisance species, a centralized information service should be developed to track introductions of nonindigenous species, as well as their spread through each habitat. Such a service has been started by the New York Sea Grant program for the zebra mussel (the "Zebra Mussel Clearinghouse"). The data collected for each species should be used to study the relationships between organism life histories, pathways of introduction, and affected communities. As for pathogens, the development of networks of scientists and observers should improve the ability for resource managers to recognize potential problematic species early. (See previous section on pathogens.)

Recommendations: 1) Develop a centralized information service for tracking introductions of nonindigenous species, and 2) conduct research on the relationship among organism life histories, introduction pathways, and affected communities.

Priority Issue: Nuisance Species Biology, Ecology, and Effects on Aquatic Ecosystems

Information Need: Basic Biology and Ecology of Nuisance Species, in Both Their Natural and Receiving Habitats. Surveys performed in the National Estuarine Research System, established in 1972 by NOAA as part of the Coastal Zone Management Act, have identified many introduced species in these reserves (Carlton, 1989). Rapid collection of information on the basic biology and ecology of these species should enable scientists to develop means of preventing their spread and mitigating their impact. Data gained from these and other efforts can be used to assess risk that an exotic aquatic species may become an ecological problem. The National Marine Fisheries Service (NMFS/NOAA) Northeast Fisheries Center, Oxford Laboratory, has been working on protocols for importation of nonindigenous aquatic species into the United States. The Oxford Laboratory currently screens mollusc imports for pathogens. They are also developing a policy for importation of nonindigenous species into the United States.

There are several Federal projects concerning introduced species. The EPA and NOAA Sea Grant are funding zebra mussel research in the Great Lakes. The U.S. Geological Survey conducts research on and monitors the species composition in San Francisco Bay, as mentioned, a body of water heavily impacted by nonindigenous organisms. The EPA is conducting basic research on the zebra mussel (*Dreissena polymorpha*), the spiny water flea (*Bythotrephescederstroemi*), and the river ruff (*Gymnocephalus cernua*). Research planned at the EPA Environmental Research Laboratory, Duluth, includes determining the potential ecological role of these species, identifying the environmental limits or tolerance of the organisms, and defining life history characteristics (e.g., fecundity, vagility). The Great Lakes Environmental Laboratory (NOAA) is focusing research on the biology, ecology, physiology, and impact on food webs of larval and adult stages of *Dreissena* and *Bythotrephes*. The FWS is monitoring the rate of spread of the zebra mussel, its distribution, ecology, effects on fisheries, evaluation of control methods, and use by waterfowl. The FWS Research Center in Gainesville, Florida, conducts national monitoring of exotic fishes, including work on their distribution, identification, and biology.

Fundamental research examining the biology (e.g., life histories, disease vectors, dispersal mechanisms) and ecology (e.g., species interactions and potential ecological impacts) of nuisance species is required. To these ends, studies on organisms in the field or under natural conditions in the laboratory are required, including the study of microorganisms in more natural environments with other organisms rather than in pure cultures. Also, increased research on successfully introduced, non-nuisance species should be pursued in order to gain a better understanding of ecosystem responses to introduced exotics. Careful research on the biology and ecology of intentionally introduced species prior to introduction must also be undertaken.

> *Recommendations:* *Conduct basic and applied research on the biology and ecology of nuisance species.*

Multidisciplinary studies of the effects of introduced organisms on the receiving ecosystem are also important. A greater understanding of the structure and functioning of natural communities and ecosystems will be critical. Also, studies of the effects of persistent, nonindigenous organisms (introduced as pest control agents) on nontarget aquatic biota would improve our understanding in this area.

> *Recommendations:* *Conduct research on the impacts of nuisance species on the receiving ecosystem.*

Information Need: Human Influences on Introduction Pathways and Environmental Conditions Allowing Nuisance Species to Flourish and Impact Indigenous Species. Little information is available on the number of accidentally introduced exotic organisms that have created environmental problems, although the total number is believed to be small. However, those few that do become problematic have had disastrous impacts on some aquatic systems. Removal or displacement of members of an existing community may cause the rest of the system to collapse, leading to the loss of vital living marine resources.

The effects of introducing new species into an area are not well understood or studied. The effects and potential danger of introduced species to marine ecosystems are often difficult to predict. Mathematical models of past introductions and ecological analysis of invading species in their likely new habitat have been examined; however, the success or failure of introduced species cannot be reliably predicted (Williamson, 1989). Prediction is difficult because happenstance and good timing play key roles in invasions. Rare events, under certain conditions and in a particular place or time, may cause major alterations to ecosystem structure and function. The same event under slightly different circumstances may lead to different alterations or no effect on marine ecosystems. Therefore, prior assessments of introduced species are never risk free (Levin, 1989).

The Aquatic Nuisance Prevention and Control Act of 1990 directs Federal agencies to examine the role of humans in the spread of nuisance species. The EPA is responsible for the regulation of Microbial Pest Control Agents (MPCAs), i.e., viruses, bacteria, fungi, or protozoans that are intentionally released into the environment as insecticides or herbicides. Potential MPCAs of all types are tested by the EPA for fate, survival, and pathogenic or toxic effects on nontarget aquatic organisms. The EPA is also developing aquatic test systems for genetically engineered MPCAs. As discussed above, research on the zebra mussel and other aquatic nuisance species should also provide some insight into the role of human activities and pollution effects on these organisms.

Human influence and its relation to successful invasions are still not clearly understood. Research in this area is necessary to enable ecosystem managers to determine how species become established and whether certain human activities can alter the relationships of native species and their environment, contributing to the development and spread of nuisance species. Such research must include studies of the environmental conditions that facilitate the spread of and damage by nuisance species, and will require coordinated multidisciplinary efforts.

Recommendations: *Conduct research on 1) human activities contributing to exotic species introductions and 2) environmental conditions facilitating the spread of and damage by nuisance species.*

Priority Issue: Biologically Sound Control Mechanisms for Nuisance Species

Information Need: Preventive and *in Situ* Control of Nuisance Species. The potential effects of introductions of exotic species or recombinant forms present a concern that should be addressed more fully. Each introduction, prior to release—whether of an organism that is indigenous to another geographical area or one that is biologically engineered—should be evaluated on an individual basis regarding its potential effects on existing populations of other species. Although it is important to study those species that have been introduced and are clearly nuisances, it is just as vital that future unintentional introductions be prevented and that intentional introductions be severely limited.

Introduction of pathogenic organisms and species detrimental to aquatic environments must ultimately be reduced at the source by controlling inputs from land-based sources, by properly evaluating species targeted for introduction prior to release, by controlling unintentional introductions where possible, and by limiting inputs of other detrimental organisms associated with the species for introduction.

Such approaches have been implemented at the quarantine facility in Conway, Wales, where a central laboratory has been established for the evaluation of the potential effects of all organisms prior to their release into the marine environment. All organisms are classified according to their potential for pathogenicity and ecological damage. Later generations of these laboratory-bred organisms are released only after it has been determined that they will not threaten the indigenous biota. More recently, the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 directs the U.S. Coast Guard to effect controls on ballast water in ships to prevent additional accidental introductions, and the American Fisheries Society is also promoting studies on potential controls of ballast water introductions (Moyle, 1991). The Task Force formed under the 1990 Act will develop control programs to minimize harm to the environment and protect public health and welfare, while coordinating control efforts with Federal agencies and State and local governments.

Treating the effects of nuisance species that are already present in aquatic environments presents a difficult problem. For example, a work group consisting of representatives from Federal, State, and local (county) agencies, tribal groups, and environmental groups has been formed to examine different methods of controlling or eliminating *Spartina alterniflora* on the U.S. west coast. One such project will investigate the impacts of this marsh grass on the benthic mudflat communities at Willapa National Wildlife Refuge, where the spread of *S. alterniflora* has escalated (K. Kilbride, FWS, Vancouver, WA, personal communication). Although techniques such as moving and covering mudflats with black plastic have been used, this project and others overseen by the work group are studying the relative efficacy and environmental impacts of using a herbicide to quickly control the marsh grass, since biological controls may still be years away. These studies will be carefully monitored to assess and minimize damage to nontarget species, the natural biota, and habitat.

Other nuisance species may require more creative and expensive approaches to control their adverse effects without impacting native populations. The economic effects of pathogens might be lessened by the development of resistant fish or shellfish stocks. In the majority of situations involving introduced nuisance species, however, reduction or elimination of environmental stresses on all the biota is necessary to lessen the total ecosystem impact. This can be achieved only by reductions of pollutant loadings and other environmental stressors. The determination of which factors cause stress responses would be a first step in researching the means of combatting this problem. Controls on introductions of micro- and macroorganisms by regulation based on scientific information must be a major step in limiting future problems.

The development of potential control mechanisms of macroorganisms unintentionally introduced into aquatic ecosystems should be pursued. Such controls may include natural or man-produced controls of a biological, mechanical, or chemical nature (e.g., native species that may prey on the introduced species, seasonal changes in environmental conditions, filtration, biocides, exchange of ballast waters well offshore). The potential effects of each type of control on the nuisance species as well as on native species and the ecosystem must be fully examined before the control is applied.

Recommendations: Conduct research on natural controls of nuisance species populations as well as biological, mechanical, and chemical controls.

Additional research on the efficacy of different types of monitoring for potential introductions of nuisance species is also required. As mentioned above, surveys of ballast waters have revealed a variety of established and potential introductions of nonindigenous species into marine environments. Many government and private laboratories offer certification programs for shipments of commercial bivalve mollusc seed stocks, but typically only 10 percent of the shipment is inspected, and histochemical and histopathological examinations may not detect certain pathogens in seasonal resting stages or in the transport media. Furthermore, such shipments may be accompanied by numerous other species of macro- and microorganisms with the potential to escape and become established in new habitats. Routine monitoring of marine environments and possible sources for exotic species may aid in the early detection of potential pathogens and nuisance species.

> <u>Recommendations:</u> *Conduct research on the feasibility of monitoring of nuisance species.*

Conclusions

The subject of human-influenced biological agents that affect aquatic organisms has been largely neglected in the past. Most research has been directed toward human health concerns or economically important species. The current base of knowledge on the effects of biological agents is primarily observational, including observations from monitoring programs and the characterization of sporadic incidents. The lists of species in Tables 4.1 and 4.2 are a fair representation of the current most significant pathogens and introduced nuisances. This list, however, will have to be updated frequently as new information becomes available and means of mitigating the effects of certain agents are developed.

The following conclusions relating to the current state of knowledge concerning sources, fates, and effects of biological agents in aquatic environments are based on the discussion of priority issues and information gaps presented in the previous section.

1) Progress is being made in understanding the agents responsible for some disease outbreaks in living marine resources, but the causes of many episodes of mass mortality are unknown and require further investigation.

2) While the identification and characterization of microorganisms are essential, we should also be looking at the whole ecology of the organisms (e.g., species interactions, physical and chemical environmental factors, persistence).

3) Human activities and natural events are known to impact marine organisms, but information gaps exist as to the extent of these events and the mechanisms that cause them.

4) It is becoming increasingly clear that pollution may cause stress in aquatic organisms, rendering them more susceptible to infection by pathogens; less clear is the role of pollutants in changing abundance, distribution, and pathogenicity of the infectious microorganisms.

5) Micro- and macroorganisms are being introduced and dispersed in aquatic habitats by human activities, and future ecological effects of these introductions are poorly understood.

6) Genetically engineered and transgenic organisms offer great promise for treating environmental problems as long as the ecological implications of such treatment are understood prior to their use.

Recommendations for addressing problems that are caused by pathogens and nuisance species can be divided into three categories based on the current level of knowledge. Each category requires a specific approach to attain most efficiently the necessary level of knowledge concerning the problems that are suspected or known to be caused by biological agents:

1) <u>Observed adverse impacts to organisms or ecosystems for which there is no known cause</u>

In the case of events where the cause of the disease, mass mortalities, or replacement of indigenous species is unknown, research should be directed broadly to look at biotic causative agents. Once the identity of the agent is known, research could then be directed at developing more complete knowledge of the impact of the agent on living marine resources. It will be important to emphasize studies on forensic pathology, especially for those organisms where laboratory experimentation is difficult, impractical, or impossible, such as on marine mammals.

2) Pathogens and nuisance species that are suspected of affecting organisms or ecosystems for which evidence is lacking

If it is fairly clear that the incident is due to an organism, research should be directed at determining the type of pathogen or nuisance species. Koch's postulates for culturable bacteria (Brock, 1979) and River's postulates for viruses (Rivers, 1937) are starting points for studies of pathogens. Deductive reasoning and field sampling are often the method for detecting exotic introductions. Once the type of organism has been determined, research should focus on gaining a better understanding of the impact of the agent on the living marine resources.

3) Pathogens and nuisance species that are known to affect organisms or ecosystems for which knowledge of the impact is incomplete

In cases where a biological agent is known to affect aquatic organisms but knowledge concerning the causes of the impact is incomplete, research on the relationship between the agent and its effects, natural events, and human activities should be conducted. A description of pathogen relationships should include natural habitat, persistence and transport mechanisms, host and alternative host(s)/vector ranges, and pathogen virulence and host defense mechanisms. Likewise, research on introduced species should include source characterizations, persistence and transport of the agent, physiological and population ecology of the biological agent and affected native species, and population interactions. Rapid, reliable diagnostic techniques should also be investigated for their feasibility in detecting and characterizing impacts due to these agents. Once knowledge concerning the agent and its interactions with biotic and abiotic factors is gained, research may be undertaken to determine methods to treat current problems and to prevent further impacts to marine ecosystems.

The timely dissemination of information to government agencies, the scientific community, and the general public is equally important to gathering information and is therefore highly recommended. Easy access to archived data, including tissue blocks and slides, and microbial culture collections, is also recommended. Furthermore, it is recommended that intra- and interagency work groups be established to discuss and assess progress toward goals. Perhaps an annual review or report on the state of the science could be produced by each work group. The goal is to facilitate communication, integration, and coordination among Federal agency monitoring and/or analytical efforts prior to further data collection.

The following recommendations are made to improve our understanding of the sources, fates, and effects on aquatic organisms of pathogens and nuisance species that are introduced or influenced by human activities.

Recommendations

Pathogens

Problems Associated with Pathogens

- Conduct research directed at identifying pathogens responsible for disease outbreaks and mass mortalities.
- Improve techniques for identifying and communicating the occurrence of epizootics and mass mortalities.

Characteristics, Requirements, and Mechanisms of Pathogenicity

- Quantify the sources of the most significant pathogens.
- Conduct research to determine the persistence and transport mechanisms of pathogens.
- Perform comprehensive studies of the ecology of indigenous and exotic pathogens.
- Conduct research to determine the mechanisms of pathogenicity.
- Conduct research to determine the influence of human activities on disease susceptibility, host defenses, and host-agent interactions.

Nuisance Species

Sources

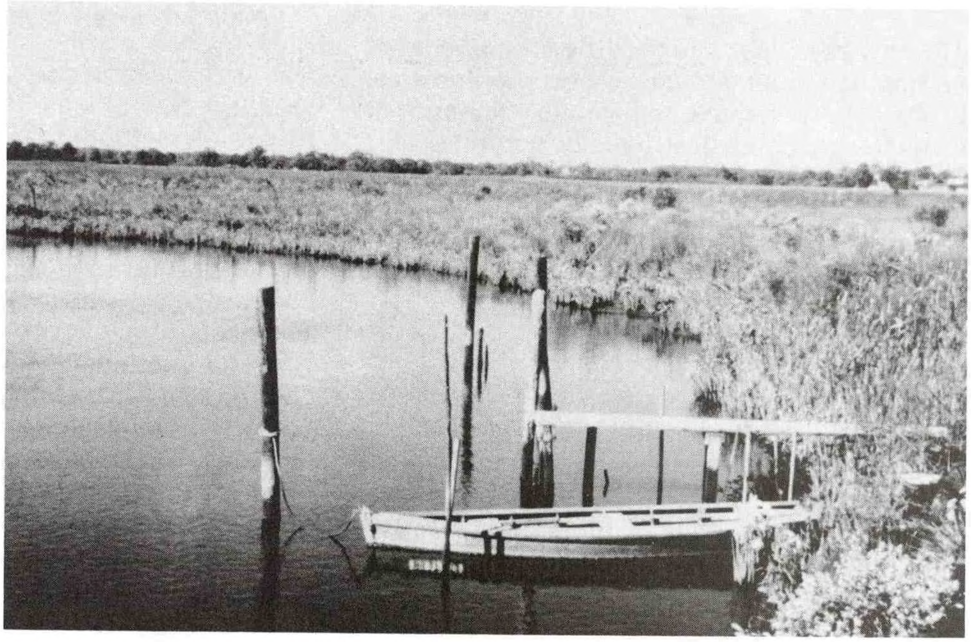
- Develop a centralized information service for tracking introductions of nonindigenous species.
- Conduct research on the relationship among organism life histories, introduction pathways, and affected communities.

Biology, Ecology, and Effects

- Conduct basic and applied research on the biology and ecology of nuisance species.
- Conduct research on the impacts of nuisance species on the receiving ecosystem.
- Conduct research on human activities contributing to exotic species introductions.
- Conduct research on environmental conditions facilitating the spread of and damage by nuisance species.

Control Mechanisms

- Conduct research on natural controls of nuisance species populations as well as on biological, mechanical, and chemical controls.
- Conduct research on the feasibility of monitoring nuisance species.



Chapter V

Understand the Effects of Losing or Modifying Marine Habitat as a Result of Human Activities

The coastal zone encompasses shallow water and intertidal areas together with immediately adjacent uplands. This zone includes marine and estuarine habitats vital to the survival and well-being of many marine organisms. Changes in coastal zone land use may affect these critical habitats required for spawning, feeding, and refuge. In particular, loss of coastal wetlands (the focus of this chapter), which consist of emergent and submergent vegetation (salt marshes, mangroves, macroalgae, and seagrass beds), may decrease recruitment of larval and juvenile stages to estuarine and coastal fisheries.

Growing concern over the social and economic effects of reducing the quantity and quality of coastal marine and estuarine habitats has led to increased efforts to evaluate the functional value of these habitats within the overall regional landscape; to classify, monitor, and predict impacts from various human activities; and to develop the ability to restore or create habitats. The vulnerability of the coastal environment is directly related to the diversity and intensity of activities that take place in the coastal zone. In the future, coastal environments will experience increasing human populations, increased coastal development, greater contaminant inputs, and more extensive physical alterations to natural habitats (GESAMP, 1990c). Changes in sea level and precipitation associated with global climate change may further alter marine habitats. Therefore, understanding the effects of human activities on coastal marine habitats is one of the six goals of the National Ocean Pollution Program.

Goal Definition

The causes of loss and modification of coastal marine habitats may vary by geographic area. In coastal Louisiana, substantial amounts of wetlands are being destroyed by natural events (e.g., subsidence, sea-level rise, and wave action) and by human activities (e.g., dredging and dredged material disposal, mineral extraction, levy construction, and drainage). Alteration of habitat by eutrophication is a major problem in the Northeast. The diversion of freshwater inflow poses major problems in Florida, San Francisco Bay, and other areas.

Some threats to marine habitats have been discussed in other chapters of this Federal Plan. For example, the roles of toxic materials and eutrophication in altering habitat character and quality are discussed in Chapters II and III (toxic materials and nutrients, respectively). The focus of this chapter is primarily on the effects of land use and land use changes on coastal wetlands, including salt marshes and submerged aquatic vegetation (SAV, i.e., submerged meadows dominated by one or more species of seagrass).

Most of the significant changes in habitat can be attributed to the following processes:

- Eutrophication - nutrient enrichment from land sources (see Chapter III).
- Physical Destruction - actual loss of habitat from filling, dredging, erosion, or storms. Most destruction of coastal habitats occurs in "piecemeal" fashion, resulting in fragmentation of critical areas.
- Hydrologic Change - changes in transport and delivery of fresh water and sediments that alter the integrity of wetland habitats. These include:
  - Diversion of freshwater inflow - alterations in the physical and chemical properties of estuarine waters (e.g., changes in salinity).
  - Dredging and filling - changes in sediment transport.
  - Submergence - rising sea levels or local subsidence, which increase rates of submergence.
- Toxics - destruction of wetlands by toxic materials (see Chapter II).

Habitat concerns have been recognized in previous Federal Plans. The Federal Plan for Fiscal Years 1988-1992 recommended that an ad hoc Habitat Loss and Modification Working Group be formed to address some of these critical issues (Kiraly et al., 1990, 1991a, 1991b). This Working Group, an interagency technical committee established by the National Ocean Pollution Policy Board, was jointly chaired by NOAA's National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (FWS) of DOI. The activities of the Working Group were coordinated through NOAA's National Ocean Pollution Program Office (NOPPO). Many of the observations and recommendations presented in this chapter are based on the input from the Habitat Loss and Modification Working Group.

The National Ocean Pollution Program Office, in association with the Federal and Scientific Work Groups identified the following three priority issues that need to be addressed in order to understand the effects of modifying coastal marine habitats as a result of human activities: (1) status of coastal marine habitats and how it is changing; (2) function of coastal marine habitats in supporting living marine resources; and (3) effects of coastal habitat loss and modification on marine organisms.

Status of Coastal Marine Habitats and How It Is Changing

Documenting the extent, location, and rate of loss of the Nation's coastal wetlands is important for effective management. It is also important to monitor adjacent upland cover because of its role in determining the water quality of coastal habitats. Loss of wetlands results in not only diminished habitat area but also in declining yields of associated faunal species. Spatial and temporal patterns of coastal habitat change need to be related to changes in living marine resource (e.g., fisheries) production.

Significant losses of coastal wetland habitat have occurred throughout the Nation. Up to 50 percent of New England's salt marshes have been filled, built on, or otherwise lost. Large acreages of wetlands also are being lost along the Gulf coast. In the 1960s and 1970s the Chesapeake Bay experienced a dramatic Bay-wide decline in the distribution and abundance of its SAV (USEPA, 1982), although increases recently have been documented (Chesapeake Bay Program, 1989). Selected areas in Florida have lost as much as 82 percent of their mangrove forests (Seaman, 1985), while California has lost 90 percent of its wetlands. Current projections for United States population growth in the coastal zone suggest that losses of wetlands and adjacent habitats will accelerate as waste loads and competition for limited space and resources increase (U.S. Congress, 1989). Agencies responsible for coastal management must, therefore, currently be aware of the extent and status of wetlands and adjacent uplands.

Function of Coastal Marine Habitats in Supporting Living Marine Resources

Loss and degradation of coastal marine habitats are now recognized to result in changes in habitat ability to support resident and transitory species. The concept of habitat "function" has developed as a means to compare the ability of different habitats (e.g., seagrass beds) to support living marine resources and also to compare the relative value of restored or created habitats to original habitats.

Included in the term "function" are all the ecosystem processes that characterize a habitat. A simple view of habitat function would be to consider which marine and estuarine organisms, including birds, mammals, and fish, use a specific habitat for spawning, feeding, and refuge. A more complicated view might be to consider the potential recruitment of larval and juvenile stages to estuarine and coastal fisheries. The totality of functional support would consider such factors as nutrient flows, trophic dynamics, community structure, and population distribution and abundance over space and time, as well as linkages between and among organisms and habitats. This in-depth knowledge is not available for most coastal wetlands, where some advances in the study of function have been made in recent years. Much less is known for other types of marine habitats.

Currently, many scientific and institutional uncertainties regarding wetland restoration and creation exist. The record of success is mixed (Battelle, 1990). On the national level, where the degree of wetland creation/restoration has been measured over the short term, nearly one-half of the projects have failed in some significant respect (Kusler et al., 1988). The poor record in restoration/creation in part results from an incomplete understanding of natural wetland ecosystems, a tentative and poorly coordinated national effort to experimentally manipulate and model these systems, and a disappointing record of monitoring and follow-up studies.

Effects of Coastal Habitat Loss and Modification on Marine Organisms

While there are many factors affecting habitat modification, hydrology is becoming an increasing concern. Changes in hydrologic regime may result in increased or decreased freshwater flows. Mitsch and Gosselink (1986) state that "the hydrology of a wetland is probably the single most important determinant for the establishment and maintenance of specific types of wetlands and wetland processes." Other functions of tidal marshes such as nutrient cycling, organic matter accumulation, and import and export of organic matter are also affected by hydrologic conditions (Broome, 1989).

Factors that influence the hydrology of tidal marshes are precipitation, surface water inflows and outflows, groundwater, and evapotranspiration (Mitsch and Gosselink, 1986). Human activities that affect hydrology include dredging and filling, sedimentation from nonpoint source activities, construction of navigational canals, and agriculture (irrigation returns). Diversion of fresh water and withdrawal of ground water lower the amount of freshwater inflow as well as accompanying nutrient and suspended sediment loadings. In San Francisco Bay, extensive use of fresh water for irrigation and domestic consumption has decreased fresh water inflow to the bay, which in turn has affected migratory fish populations (Day et al., 1989). Semi-impoundment by devices such as levees, weirs, or other water-control structures not only causes problems with salinity and sedimentation but also interferes with migratory cycles and seriously reduces populations of many commercially important fishery species (Herke and Rogers, 1989).

The discussions that follow identify the information needs associated with each of the priority issues described above:

- Status of coastal marine habitats and how it is changing;
- Function of coastal marine habitats in supporting living marine resources; and
- Effects of coastal habitat loss and modification on marine organisms.

Current Federal activities that address these information needs, and recommendations for future Federal research and monitoring activities are also discussed.

Priority Issues and Information Needs

Priority Issue: Status of Coastal Marine Habitats and How It Is Changing

Information Need: Timely Information on the Status and Trends of Coastal Habitats. Delineating the areal extent of the Nation's coastal habitat resources is fundamental to determining the rates and locations of habitat losses and the implications of these losses to living marine resources.

The Report of the Wetland Inventory Subgroup of the Domestic Policy Council Interagency Wetlands Task Force (1990) indicated that the Federal role in wetland mapping and inventorying should be to develop and disseminate a technically sound, comprehensive data base containing information on the characteristics, status, conditions, and trends in our Nation's wetlands. The National Wetlands Policy Forum (Kean et al., 1988) also suggests that the United States needs better information on the condition of its wetland resources and the rate at which they are being altered. This information needs to be more widely available to those involved in wetlands protection and management. In addition, accurate maps depicting where wetlands exist are needed. Current surveying efforts are too infrequent in regions where wetlands are being rapidly lost, are under substantial threat, or are of unusual value (Kean et al., 1988).

Three major Federal activities to assess the status and trends of the Nation's wetland resources are currently under way: the FWS's National Wetlands Inventory (NWI); NOAA's Estuarine Habitat Program (EHP), initiated in 1990 as part of the agency's Coastal Ocean Program; and EPA's Environmental Monitoring and Assessment Program (EMAP), initiated in 1989. Both the NOAA and EPA programs are not yet fully operational. Although all three programs address the status and trends of the Nation's wetlands, they differ in the scope of geographical area encompassed, frequency of surveys, methods for data collection, and type of information produced. To avoid duplication and promote coordination, the programs will cooperate with one another and perform joint efforts in selected areas.

The NWI is the most extensive national wetlands mapping program. It was initiated by the FWS in 1975 to produce detailed wetland maps and reports on wetland status and trends. NWI maps are based on aerial photographs; trends analyses are performed using a stratified random sampling method comparing time periods 10 years apart. The NWI has produced maps covering all coastal wetlands in the contiguous United States. To date, 10 percent of the coastal wetland maps have been digitized for inclusion as a national mapping data base category in the U.S. Geological Survey's National Digital Data Base. NWI products also provide the basis for many other Federal and State mapping efforts (Kiraly et al., 1991a).

NOAA initiated the EHP in 1990 as a component of its Coastal Ocean Program (COP). The EHP is a cooperative effort of the National Marine Fisheries Service (NMFS); the Office of Oceanic and Atmospheric Research (OAR); the National Environmental Satellite, Data, and Information Service (NESDIS); and the National Ocean Service (NOS). One portion of the EHP is developing a comprehensive, nationally standardized information system for land cover and habitat change in the coastal United States. This effort has been designated the CoastWatch-Change Analysis Program (C-CAP)(Thomas et al., 1991). The program will be standardized based on a series of regional protocol workshops being held throughout the United States.

Satellite imagery, aerial photography, and surface geographic data for SAV, emergent coastal wetlands, and adjacent uplands will be interpreted, classified, analyzed, and integrated into a geographic information system (GIS). Many of these efforts will be performed on a cooperative basis with the FWS, EPA, and coastal States. The program will delineate wetland habitats and monitor changes for the entire U.S. coastal region on a cycle of 1 to 5 years. Experimental efforts are also under way to develop procedures to evaluate the quality of coastal wetland habitats from remotely sensed data.

EPA's EMAP, part of EPA's Office of Research and Development (ORD), was initiated to characterize the Nation's ecological resources over time. Three components of EMAP—Near Coastal, Wetlands, and Landscape Characterization—include elements that address long-term status and trends of coastal wetlands. These elements include mapping SAV and emergent wetlands and assessing the functional health and condition of wetlands. The work is intended for selected sites throughout the United States, and in some case will be performed with one or more Federal agencies (e.g., NOAA, FWS) and coastal States. Satellite imagery, aerial photography, and NWI products will provide the basis for the EMAP wetland programs, and products will be provided in digital form for incorporation into GISs.

In its review of the overall Federal coastal wetland mapping effort, the Habitat Loss and Modification Working Group recommended that this effort be accelerated so that more accurate assessments of the status and trends of coastal wetlands on national, regional, and local scales can be made. The Working Group further recommended that a centralized, national digital mapping data base which would provide information on wetland habitat changes in a variety of forms (e.g., statistical and mapped) be developed. This could serve as an important tool for resources managers evaluating the effectiveness of regulatory programs. Utilizing this data base, changes in coastal wetland acreage could be monitored in a timely manner and appropriate management strategies implemented. This would be particularly important in areas characterized by rapid habitat loss or in critical habitat area. Concurrently, to facilitate an accelerated national mapping effort, more focused research is needed to support the development of cost-effective state-of-the-art mapping technologies. This is important for programs that utilize aerial photographs as well as for those that utilize detailed digital satellite images. These newer technologies will make it possible to map coastal areas more frequently and accurately, thereby providing up-to-date information to resource managers (Kiraly et al., 1990).

It is also important that an integrated, coordinated Federal/State national protocol for determining land/habitat cover and change in the coastal regions of the United States be developed. The protocol should include methods to assess qualitative as well as quantitative status and change in coastal habitats. Such habitats should include submerged aquatic vegetation, emergent coastal wetlands, and adjacent uplands. The Federal Geographic Data Committee (FGDC) was established under OMB Circular A-16 to coordinate these interagency data needs. A subcommittee of the FGDC is devoted specifically to coordinating wetland mapping data and promoting the development, use, sharing, and dissemination of wetlands-related spatial data. Federal funding to support this cooperative effort would provide a foundation for States to focus on important resources in need of protection and preservation and to meet current Federal mandates (Nelson et al., 1990).

Recommendations: 1) Develop a national protocol integrating and coordinating the activities of Federal, State, and local agencies to determine land/habitat cover and change in the coastal region of the United States on a 1- to 5-year basis; 2) develop mechanisms to integrate Federal, State, and local data bases (including ground and remotely-sensed surveys) into geographical information systems; and 3) improve cooperative efforts among Federal, State, and local groups to identify and document causes of regional changes in coastal marine habitats.

Priority Issue: Function of Coastal Marine Habitats in Supporting Living Marine Resources

Information Need: Relative Functional Values of Habitat Types to Living Marine Resources. Functional values of both emergent and submergent wetlands can be described as those values that are directly related to the physical, chemical, and biological characteristics and processes of the wetlands. Some functions of wetlands are perceived by the public as providing a positive value (e.g., production of shellfish), while others have a negative implication (e.g., breeding ground for mosquitoes). Positive functions are groundwater recharge/discharge, floodflow alteration, sediment stabilization, toxic sediment retention, nutrient removal/transformation, and production of living marine resources (USEPA, 1990e).

Although numerous methods have been proposed to assess wetland functions (Lonard and Clairian, 1986; USEPA, 1989b), most functions are not easily measured. The majority of available methods are qualitative and provide procedures for assessing overall wetland quality (Simenstad et al., 1989). Many authors cite the lack of understanding and methods to measure and assess specific habitat function as a key research need. (Kean et al., 1988; Simenstad et al., 1989; Kusler and Kentula, 1989a).

Submerged meadows dominated by one or more species of seagrass function as important habitat for living marine resources. Research in the NMFS Habitat Program has demonstrated that they are a productive habitat type found in many coastal marine areas. Seagrasses function as important spawning, nursery, feeding, and refuge habitat for many estuarine and marine species and also enhance sediment stability through their root and rhizome systems and by use of their shoots to slow water currents (Kenworthy et al., 1988; Fonseca, 1989). Nevertheless, most of the information about seagrass ecosystems centers around their function as a primary producer; much less is known about their role in the support of faunal production in the system (Fonseca, 1989).

Knowledge of the functional value of habitat types was identified as an issue in the Federal Plan for Fiscal Years 1988-1992. Since that time, several programs have attempted to address the problems associated with defining the functional value of coastal and estuarine habitats. The Estuarine Habitat Program (EHP), a part of NOAA's Coastal Ocean Program, was initiated in FY 1990. One of the main topics associated with this program is estuarine habitat function and restoration (Sutherland, 1991). Research being conducted includes determination of factors causing habitat degradation and loss and development of methods for wetlands restoration. Specific research will include how stresses impact seagrass habitat and consequences of the loss of this habitat to estuarine productivity; the effects of hydraulic manipulation on salt marsh viability and functional role; and the production of mechanistic models to evaluate the functional health of wetlands. Research is also being conducted to determine which ecosystem characteristics (physical and biological) regulate the functions of wetlands. C-CAP, another part of the EHP, is attempting to evaluate the functional health of habitats by using information gained by satellite remote sensing.

In addition to the EHP, NOAA's Sea Grant Program has long conducted research on the structure and function of estuarine habitats and the impact of anthropogenic changes on critical habitat functions. Also, the newly established NOAA Restoration Center in NMFS has a research component to conduct basic and applied research on the functional values of artificial and natural resource habitats and to assess methodologies designed to enhance habitat recovery and/or development.

Recommendations: 1) Augment research to understand habitat processes and functions and how changes in these functions affect the support of marine organisms, and 2) continue to develop new methods to measure and assess habitat function.

Information Need: Habitat Needs of Key Species and Life Stages of Living Marine Resources. It is well known that many commercially important species complete at least part of their life cycles in tidal marshes (Herke and Rogers, 1989). These organisms include brown shrimp, white shrimp, Gulf menhaden, Atlantic croaker, red drum, and speckled trout. Tidal marshes appear to provide the high-quality habitat needed by these organisms for food, protection from predators, calm water, and favorable physiological ranges of temperature, salinity, and turbidity (Day et al., 1989). The determination of habitat requirements of key species and life stages of organisms that utilize wetlands and seagrass habitats is requisite to judging functional relations and predicting impacts of habitat modification on living marine resources.

As human-induced stresses on coastal ecosystems continue, there is a growing need for basic ecological research on the habitat requirements of marine organisms that utilize these areas. Research on the key elements affecting growth, survival, and reproduction of key species to determine the effects of altered habitat functions is being conducted in the NMFS Habitat Program with funding from NMFS, the NOAA Coastal Ocean Program, the U.S. Army Corps of Engineers, and State environmental agencies. The NOAA Restoration Center is designed to be the focal point for restoration activities in NOAA and, as such, not only will conduct a basic research program within NMFS but also will be responsible for development and implementation of restoration plans associated with damage claim cases.

Key factors need to be assessed to determine the effects on key species of alterations to habitats. These factors include the role of specific limiting nutrients, the source and reduction of nutrients from upstream locations, transformations of nutrients during transport from fresh to marine waters, and internal recycling of nutrients as related to external nutrient load. The quality of the habitat of key species will also be affected by eutrophication. Nutrient loading may alter the relative dominance of phytoplankton, seagrass, and macroalgae in coastal habitats. Additional research on elements affecting the growth, survival, and reproduction of species that are of commercial, recreational, or trophic importance also is needed.

Another issue of concern is the effects that loss of wetlands may have on the estuarine food web. Teal (1962) reported that a portion of the organic material produced by tidal plants is transported by tidal flushing to the surrounding waters, providing a source of organic detritus that becomes part of the estuarine food web. There is considerable evidence linking primary production of wetlands to aquatic secondary production, suggesting that wetland destruction may result in lowered production of estuarine organisms (Odum and Skjei, 1974).

The need for information on habitat requirements of key species and life stages was identified in the Federal Plan for Fiscal Years 1988-1992. Although much work has been initiated, the need still exists. A more complete understanding of habitat processes and functions is necessary to determine how they affect key species.

Recommendations: Conduct research on key habitat factors for growth and survival of marine organisms and determine key trophic pathways and linkages among habitats.

Information Need: Effectiveness of Marine Habitat Restoration and Creation Efforts to Replace the Functional Values of Lost or Degraded Natural Wetland Habitat. The discussion in the Federal Plan for Fiscal Years 1988-1992 on this information need centered on the success of past projects and the most effective methods and approaches available. Since that time, substantial work has addressed the problems associated with restoration and creation of wetland habitat. An EPA document summarized current work and trends in wetland creation and restoration (Kusler and Kentula, 1989a, 1989b) and identified a variety of measures that require future research. These topics include systematic monitoring of created and restored wetlands, demonstration projects, more traditional scientific research, and continued synthesis of existing scientific knowledge. NOAA conducted a national symposium on restoring the Nation's coastal and marine environment in September 1990. This symposium provided information on emergent and submergent wetlands, including salt marshes, mangroves, seagrasses, kelp forests, salmon and trout rivers and streams, urban areas, and use of artificial reefs. It also demonstrated that a considerable amount of information is still needed to improve the success of wetland restoration and creation efforts.

Marine habitat restoration and creation efforts have increased at all levels of the government, in the scientific community, and in the private sector. Most of the problems that have been identified in wetland restoration and creation focus on the need for establishing clear project goals and objectives to be measured by specific methods (Horner and Raedeke, 1989; Simenstad et al., 1989; Lewis, 1989; Erwin, 1989a). If goals are established at the outset of restoration and creation attempts, the success of the project is much easier to assess. Ideally, the success of a project should be measured as the degree to which functional replacement of the habitat has been accomplished. More intensive research is needed to understand the complex functions of natural systems before the success of a created or restored system can be evaluated (Kiraly et al., 1991b).

Methods have been developed to assess some wetland functions, such as food chain support for breeding and rearing waterfowl, ecosystem diversity, and wildlife habitat. A protocol developed by Simenstad et al. (1989) was intended to describe techniques that could be used to quantitatively measure how wetlands support fish and wildlife species. A growing need remains for methods and techniques to measure and assess other wetland functions. Some functions for which methods need to be developed are fish habitat, flood storage and desynchronization, water pollutant removal and retention, shoreline anchoring, and groundwater recharge and discharge (Horner and Raedeke, 1989).

Standardized methods are also needed for evaluation and monitoring to determine the success of created or restored wetlands (Kusler and Kentula, 1989a). Most restoration projects to date have had limited goals that have focused on habitat structure, and, as a consequence, it is not known whether functional values have been developed or the length of time it has taken for them to develop. The NMFS Restoration Center is currently drafting restoration guidelines which emphasize the importance of monitoring and maintenance as well as the flexibility to allow for mid-course corrections. Monitoring created or restored tidal marshes or any habitat can range from intermittent visual observations to detailed sampling and comparison with natural systems. Both long-term and short-term monitoring are needed to provide accurate interpretations of creation and restoration success (Kusler and Kentula, 1989a; D'Avanzo, 1989).

A major issue related to monitoring that, in many cases, has not been adequately addressed by scientists and policy makers is how restored/created habitats compare structurally and functionally to similar natural systems (Broome, 1989; Simenstad et al., 1989; Erwin, 1989b; Lewis, 1989). Ideally, restoration success should be measured as the degree to which the functional replacement of natural systems has been achieved. Variability among natural wetlands of the same type and among different types, however, makes comparison very difficult. Comparative studies between natural and created wetlands will be necessary to provide data to be used in establishing criteria or in making mitigation decisions (Broome, 1989; Kusler and Kentula, 1989a; Simenstad et al., 1989). Horner and Raedeke (1989) suggest that criteria may be obtained from three sources: values reported in the literature, results from reference sites, and results from the wetland site that will be replaced. There is a critical need for monitoring to develop a comprehensive data base on the condition of measurable parameters of the habitats of natural systems. This data base on reference or natural conditions could be used to assess the degree of progress made by a created or restored system (Thom et al., 1990).

Several studies have identified some critical factors that appear to be most important in successful attempts at creation and restoration of wetlands (Lewis, 1989; Broome, 1989; Horner and Raedeke, 1989). These factors include correct elevations for target species, adequate drainage and sufficient tidal connections, siting to avoid wave damage, appropriate plant species, proper salinity, and proper soil chemical and physical properties. *A Manual for Assessing Restored and Natural Coastal Wetlands* (Pacific Estuarine Research Laboratory, 1990) presents standardized methods for assessing restored, enhanced, or constructed wetlands with a focus on monitoring regional biodiversity.

Two objectives of the NOAA Coastal Ocean Program's Estuarine Habitat Program (EHP) specifically address habitat restoration (Sutherland, 1991). The first objective is to ascertain habitat function to determine factors causing habitat degradation and loss and to help develop methods for habitat restoration. A second objective is to attempt to synthesize new and existing information into useful models that may be used in restoring critical habitats. Specifically, this program initiated research in FY 1990 (continuing through FY 1992) to better understand how habitats function to support living resources and to determine how seagrass and salt marsh habitat can be restored to ensure that they are functionally equivalent to the natural habitats. Another aspect of this research includes investigation into how this process can be improved and accelerated.

The U.S. Environmental Protection Agency (EPA) recently adopted a Wetlands Research Plan to assist the Agency in implementing its responsibilities to protect the Nation's wetland resources. One of the research areas identified in the plan has three goals related to restoring wetlands: 1) provide a framework for making permit decisions based on the needs of the Clean Water Act Section 404 permitting process; 2) provide guidance for the design of projects through improved methods of creating, restoring, and enhancing wetlands and wetland functions; and 3) develop methods describing and evaluating natural and created wetlands. Activities to address these goals are currently under way.

Future research should assess the current level of knowledge of habitat restoration by evaluating recent efforts on a regional and habitat-specific basis. Such an effort, coupled with basic research to fill gaps in our knowledge, could result in the development of better methods for wetland restoration and creation.

> *Recommendations: 1) Develop improved approaches (including long-term monitoring activities) to assess the effectiveness of habitat restoration and creation techniques, and 2) improve methods for habitat restoration and creation.*

Priority Issue: Effects of Habitat Loss and Modification on Marine Organisms

Information Need: Effects of Hydrologic Changes (Including Alteration of Freshwater Inflow) on Marine Habitats. NOAA's Estuarine Habitat Program (EHP) identifies hydrology as the dominant factor controlling the ecological structure, function, and productivity of salt marsh ecosystems (Sutherland, 1991). Research for FY 1990 and 1991 in the EHP has focused on the identification of the mechanisms of hydrologic control of salt marsh productivity.

Hydrologic alterations of wetlands may significantly affect salinity regimes, sediment deposition, water quality, nutrient cycling, organic matter accumulation, and import-export of organic matter. Additionally, water-control structures (e.g., levees and weirs) cause semi-impoundment which interferes with the migration of many commercially important fishery species, thereby reducing populations (Herke and Rogers, 1989).

Factors such as salinity and water quality are affected when the exchange of water is decreased or stopped through diversions in upstream freshwater sources. Modifications of habitat caused by such hydrologic alterations may cause disruptions in the marine resources through changes in species composition and productivity. Changes in salinity have the potential to reduce productivity in brackish marshes by affecting photosynthesis rates in some plants (Pezeshki et al., 1989). Models need to be constructed to predict changes in salinity due to diversion of water upstream. Other models are also needed to predict changes in sediment patterns and to gather more information on the link between salinity and sedimentation and the resultant effects on wetland populations.

> *Recommendations: 1) Conduct research to study the effects of sediment, salinity, and water quality changes on habitat quality/status; 2) develop a suite of interlinked models (geological, physical, and biological) to predict/describe habitat changes and effects on living marine resource productivity and economic value; and 3) conduct research to study responses of populations to habitat changes.*

Information Need: Cumulative Effects of Human Activities on Coastal Marine Habitats. Cumulative effects of human activities on wetland functions are difficult to assess because of the complexity of marine environments, the multiple projects or land uses impacting wetlands, and the extended time frames required to make such assessments (Witmer, 1986). In addition, climatic changes may cause widespread regional impacts to habitat resulting from an increase in sea level and salinity changes. There have been few studies that specifically evaluate the cumulative effects of many projects or land uses over time and space. Such studies are expensive and time consuming. One approach to evaluating cumulative effects is making use of existing data bases and GISs and designing computer models to predict the effects of wetland habitat loss and modification on the marine resources and integrity of the Nation's coastal ecosystems. The development of predictive computer models will rely on integrating data bases with GISs. By making use of computerized data bases, the models will be especially accurate and valuable.

> *Recommendation: Expand efforts to develop methods for assessing the cumulative impacts of human activities in coastal marine habitats, including the development of models to predict the effects of region-wide habitat loss and modification on coastal ecosystems.*

Conclusions

It has become apparent that our coastal marine habitats are being modified and lost at a rapid rate. Concern is mounting over the social and economic effects of reducing the quantity and quality of marine and estuarine habitats. This concern has led to increasing efforts to study the ecology of these habitats and to classify, monitor, and predict the impact of human activities. The development of our coastal watersheds has resulted and will continue to result in the alteration and elimination of coastal habitats. It is essential that research continue to address the effects of habitat loss and modification on marine organisms.

The following conclusions are based on the discussions of the issues and information needs. These conclusions focus on the status of and changes in marine habitats, the functions of marine habitats in supporting living marine resources, and the effects of habitat loss and modification on marine organisms.

- A comprehensive nationwide mapping program is vital to determine the status of coastal wetland habitats and must be continued and accelerated.

- Coordination among agencies is necessary to develop mechanisms to integrate data sources and to identify and document the causes of changes in marine habitats.

- Researchers currently do not have sufficient understanding of estuarine processes and their importance and their effect on habitat function.

- Without an adequate understanding of the natural processes and functions of habitats, the effects that human activities will have on habitat quantity and quality cannot be accurately determined. In addition, how successfully wetland restoration and creation attempts actually replace the functional values of the lost habitat cannot be determined without understanding functional processes.

Based on these conclusions, the recommendations which follow are made to improve our understanding of the effects of loss and modification of marine habitats as a result of human activities.

Recommendations

Status of Coastal Marine Habitats and How It Is Changing

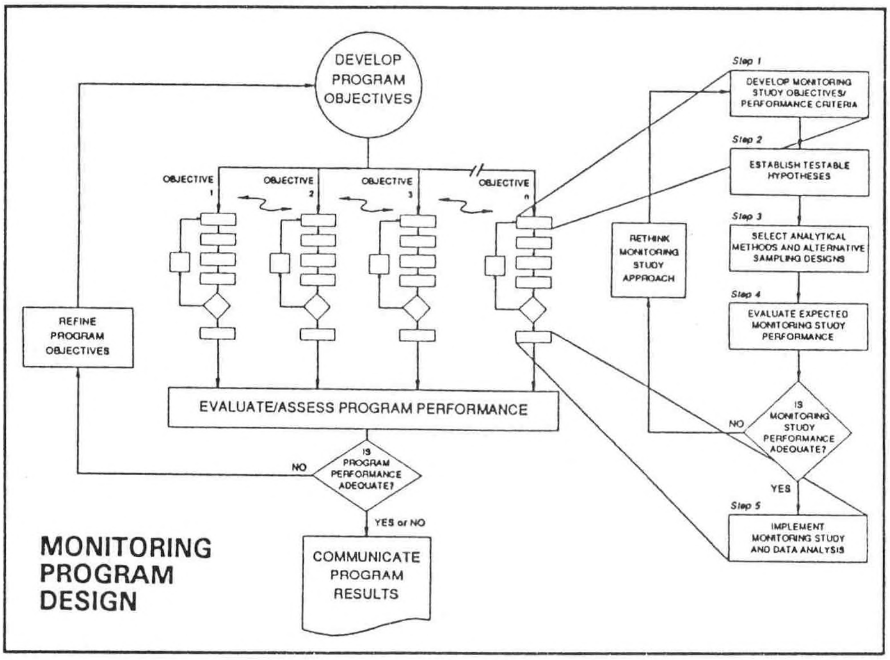
- Develop a national protocol integrating and coordinating the activities of Federal and State agencies to determine land/habitat cover and change in the coastal region of the United States on a 1- to 5-year basis.
- Develop mechanisms to integrate Federal, State, and local data bases (including ground and remotely-sensed surveys) into geographical information systems.
- Improve cooperative efforts among Federal, State, and local groups to identify and document causes of regional changes in coastal marine habitats.

Function of Coastal Marine Habitats in Supporting Living Marine Resources

- Augment research to understand habitat processes and functions and how changes in these functions affect the support of marine organisms.
- Continue to develop new methods to measure and assess habitat function.
- Conduct research on key habitat factors for growth and survival of marine organisms and determine key trophic pathways and linkages among habitats.
- Develop improved approaches (including long-term monitoring activities) to assess the effectiveness of habitat restoration and creation techniques.
- Improve methods for habitat restoration and creation.

Effects of Habitat Loss and Modification on Marine Organisms

- Conduct research to study the efects of sediment, salinity, and water quality changes on habitat quality/status.
- Develop a suite of interlinked models (geological, physical, and biological) to predict/describe habitat changes and effects on living marine resource productivity and economic value.
- Conduct research to study responses of populations to habitat changes.
- Expand efforts to develop methods for assessing the cumulative impacts of human activities in coastal marine habitats, including the development of models to predict the effects of region-wide habitat loss and modification on coastal ecosystems.



Chapter VI

Document the Trends in the Status of Marine Ecosystems

Marine, estuarine, and Great Lakes waters support a wealth of living resources, provide recreational opportunities, and sustain many commercial enterprises. In particular, the ocean-margin environment, including tidal rivers, estuaries, and nearshore waters, contains some of the most productive ecosystems. The effects of human activities on these valuable aquatic ecosystems are primarily felt in this area, which receives a wide range of contaminants from terrestrial runoff, industrial and municipal waste discharges, dredged material disposal, atmospheric fallout, and other sources. These ecosystems are also subject to physical disruptions associated with human activities, which may result in the loss or deterioration of important habitats.

Competition for use of these waters will increase as our population continues to shift to the coastal zone. Because of the increasing human activity and demand for aquatic resources, it is important to assess conditions and trends in the quality of aquatic ecosystems and to be aware of early warning signals of unacceptable conditions. Therefore, documenting the trends in the status of marine, estuarine, and Great Lakes ecosystems is a goal of the National Ocean Pollution Program.

Goal Definition

Assessing the status of marine ecosystems consists of observations performed on various biological, chemical, ecological, physical, and habitat parameters to establish the quality of the ecosystem and the relative health of its components. Because the cumulative effects and complex interactions of different human activities on the environment are difficult to foresee, it is not possible to predict with confidence the effects of human activities on the marine environment. The determination of past and present conditions is essential in order to examine trends in the quality of marine ecosystems and to identify sources of degradation.

Unfortunately, significant gaps exist in our understanding of the relationships between the condition of marine ecosystems and the parameters that can be estimated in marine environments. These uncertainties are further complicated by natural variations in time and space for which many components of marine ecosystems are notorious. However, these variations do not necessarily prevent detection of pollution effects, as has been demonstrated by studies in many industrialized estuaries of the Nation and in the Great Lakes. Monitoring environmental conditions and trends within marine ecosystems can provide early warning signals of pollution effects and generate information needed to avoid or remediate unreasonable or socially unacceptable degradation.

For the purposes of this goal, monitoring is defined according to NOAA (1979): "Monitoring is the continued, systematic time-series observation of pre-determined pollutants or pertinent components of the marine ecosystem over a period of time sufficient to determine (1) the existing level, (2) trends, and (3) natural variations of measured components." Data obtained through such observations can be used most effectively by environmental managers if monitoring programs have specific objectives that provide the levels of environmental quality to be predefined as "acceptable" or "unacceptable" (Segar and Stamman, 1986). Monitoring is also conducted to evaluate the effectiveness of management actions.

This goal is concerned with monitoring required to establish present conditions of the ecosystem and to follow long-term trends on a regional scale. This involves developing and detecting early warning signs of potential pollution problems and following trends to show how the status of the ecosystem is changing. Initially, the goal is not to establish causes and sources; these would be investigated through more comprehensive diagnostic studies after a problem has been identified.

Regulatory compliance monitoring that addresses specific sources of pollution is pertinent to this goal when it is possible to integrate local and regional activities. Monitoring methods that are effective in identifying problem areas around marine discharge and disposal sites in fact measure signs of poor marine ecosystem status. Such signs of local deterioration may be more easily recognized and agreed upon than are regional measures of ecosystem health (Phelps, 1988).

Status of Marine Ecosystems Monitoring

As pointed out by the National Research Council (NRC) in its recent report, *Managing Troubled Waters* (NRC, 1990a), there is a growing public perception and concern that coastal environments in the United States are deteriorating and that this deterioration is accelerating. However, although the deterioration of some marine environments is fairly well documented, other perceptions of environmental degradation and its relation to human activities are not supported by scientific evidence (NRC, 1990a). Although numerous Federal and State agencies commit considerable effort and money for marine monitoring, these programs have been criticized for failing to provide adequate information to environmental managers. The causes of these perceived inadequacies are both institutional (lack of communication and coordination among programs) and technical (inadequate monitoring design) (NRC, 1990a).

The agencies responsible for conducting these monitoring programs are well aware of the problems identified by NRC and are taking action to address them. Two examples include 1) the cooperation between NOAA's National Status and Trends Program and EPA's Environmental Monitoring and Assessment Program to improve monitoring of the Nation's ecosystems through sharing of information and development of clear and compatible objectives and 2) EPA's development of National Estuary Program Monitoring Guidance, which stresses the importance of proper monitoring design.

The Federal Plan for Fiscal Years 1988-1992 (NOAA, 1988) discussed the establishment of long-term programs of trend assessment monitoring coordinated by the National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Agency (EPA) under the Federal Water Pollution Control Act (FWPCA) amendments of 1987 and other Federal legislation. A variety of monitoring programs are being conducted by the National Marine Fisheries Service (NMFS) and the Ocean Assessments Division (OAD) of NOAA, including the National Status and Trends Program of OAD. Other major monitoring programs are being conducted by the Environmental Research Laboratories and National Estuary Program of EPA; the Minerals Management Service (MMS), U.S. Fish and Wildlife Service (FWS), and U.S. Geological Survey (USGS) of the U.S. Department of the Interior; the Food and Drug Administration (FDA) of the U.S. Department of Health and Human Services; and the U.S. Army Corps of Engineers (COE) of the U.S. Department of Defense.

As discussed in the 1988 Plan, the scope of monitoring diverse aspects of marine ecosystems required cooperative efforts among Federal, State, and local scientists and managers. A consensus of marine pollution managers from all regions of the United States suggested that the most effective monitoring activities occurred at the regional level, and national monitoring programs should be the sum of regionally planned programs coordinated at the national level (Segar, 1981). Examples where Federal agencies and programs interfaced well with regional activities and facilitated the exchange of information included the NOAA, EPA, and Coast Guard Accidental Spills Scientific Response Programs (National Contingency Plan); the NMFS Fishery Centers' regional research program; EPA's National Estuary Program; and the EPA Regional Offices' interactions concerning discharge permits and compliance monitoring. This point was further emphasized in the NRC (1990a) report, which calls for cooperative efforts with national programs providing guidance for regional monitoring.

Recent events have increased public interest in the status of marine ecosystems. In the summer of 1988, numerous public beaches were closed as a result of medical debris washing ashore, high bacterial counts in the water, and sewage treatment plant overflows. Lost business to the tourist economy of coastal states was estimated to be in the billions of dollars (Kitsos and Bondareff, 1990). Concerns about marine debris include not only medical wastes but also the quantities of plastics that leave beaches unsightly and negatively affect marine organisms, including endangered mammals and sea turtles, and drifting gill nets from commercial fishing vessels that continue to "fish" after the net has been lost. Current national monitoring efforts are described in Table 6.1 and are discussed further under the "Issues and Information Needs" section below. Other ocean pollution monitoring data are provided by the National Environmental Satellite, Data, and Information Service (NESDIS) of NOAA, through the Polar-orbiting Operational Environmental Satellites (POES), as well as multispectral 30-meter resolution Landsat data for coastal margins, with other data to be acquired from foreign satellites.

For all marine monitoring programs, selection, testing, and application of various indicators of the quality of marine ecosystems were considered to be of the utmost importance in establishing conditions and trends in these ecosystems. Close collaboration between scientists and managers is required to ensure that these indicators provide informative interpretations. Numerous studies developed indices for specific monitoring purposes (Farrington et al., 1983; Phillips and Segar, 1986; Dames & Moore, 1984). For example, the United Nations' Food and Agriculture Organization (FAO) sponsored a workshop to evaluate indices for measuring responses of ecological systems and to emphasize indices that could discriminate among natural factors and fishery exploitation (FAO, 1976). The necessity of matching indices of marine environmental quality with management needs was discussed by Wolfe and O'Connor (1986). These authors also suggested that environmental parameters for establishing trends could be expressed most informatively relative to normal values accounting for variability in measurement. O'Connor et al. (1987) constructed an index to detect above-normal disease prevalence in fish and shellfish that warrants a warning or alarm for management purposes.

Recently, the National Research Council (NRC, 1990a, 1990b) evaluated current marine monitoring programs and practices, identified needed improvements in monitoring strategies, and made a series of recommendations to improve the usefulness of monitoring information. The extensive NRC review of

Table 6.1
Current National Monitoring Efforts

	NOAA National Status and Trends Program (NS&T)	EPA Environmental Monitoring and Assessment Program (EMAP)
OBJECTIVES:	To determine the status and long-term trends of toxic organic compounds and trace metals in bottom-feeding fish, shellfish, and sediments.	To estimate the current status, extent, changes, and trends in indicators of the condition of the Nation's ecological resources on a regional basis with known confidence; to monitor indicators of pollutant exposure and habitat condition and seek associations between human-induced stresses and ecological conditions.
SAMPLING SITES:	300 coastal and estuarine sites throughout the United States.	15,056 (one point per 640 km^2) throughout the United States; unknown number in coastal and estuarine areas.
PROGRAM DATE:	1984 - present.	Data collection started in 1990 (monitoring to continue for at least 20 years).
SAMPLING FREQUENCY:	Once per year.	Once per year.
FUNDING LEVEL:	$5,700,000 (FY 1991).	$7,200,000 (FY 1991) - coastal only.

PARAMETERS SAMPLED: (NOAA NS&T)

Component	Media	Constituent
Mussel Watch	Bivalves	Trace and major elements, PAH, PCBs, chlorinated HCs, histopathology and visible lesions, % lipids, gonadal index, size and weight.
	Sediments	Trace and major elements, PAH, PCBs, chlorinated HCs, chemical sewage tracer, grain size, TOC/carbonate.
Benthic Surveillance	Bottom Fish	Trace and major elements, PAH, PCBs, chlorinated HCs, PAH metabolites, histopathology and visible lesions, % lipids, length, weight and age, other biomarkers.
	Sediments	Trace and major elements, PAHs, PCBs, chlorinated HCs, chemical sewage tracer, microbial sewage tracer, grain size, TOC/carbonate.

PARAMETERS SAMPLED (TENTATIVE): (EPA EMAP)

Component	Constituent
Near Coastal Waters	Dissolved oxygen, benthic abundance, biomass and species composition, biological sediment mixing depth, extent and density of submerged aquatic vegetation, fish abundance and species composition, presence of large indigenous bivalves, gross lesions and histopathology of fish, acute sediment toxicity, chemical contaminants in sediments, water clarity, water column toxicity, and chemical contaminants in fish and shellfish.
Wetlands	Organic matter and sediment accretion, wetland extent and type diversity, abundance and species composition of vegetation, leaf area, solar transmittance, greenness, macroinvertebrate abundance, biomass and species composition, soil and aquatic microbial community structure, nutrients (water and sediments), hydroperiod, bioassays, and chemical contaminants in tissues.

Table 6.1. (Continued)

	USGS National Stream Quality Accounting Network (NASQAN)		USGS National Water-Quality Assessment (NAWQA)
OBJECTIVES:	To collect stream flow and water quality data from large and moderate rivers to identify trends in biological, chemical, geological characteristics.		To implement studies that will assess cause-and-effect relations within study units for sediment, nutrients, trace inorganic compounds, and trace compounds.
SAMPLING SITES:	412 sites with 140 sites in or near the coastal zone; sites are on moderate to large rivers. Freshwater sites only.		20 large-scale monitoring and assessment studies in a total of 60 areas throughout the country; the number of coastal sites not known. Freshwater sites only.
PROGRAM DATE:	1973 - present.		In 1991, the NAWQA program began a 4-year transition from a pilot program to a full-scale program.
SAMPLING FREQUENCY:	River flow - daily. Water quality - bimonthly.		A rotational investigation of 60 study areas incorporating 60-70 percent of the Nation's water use and population served by public water supply. For each study unit, 3-4 year periods of intensive data collection and analysis will be alternated with 6-7 year period during which the assessment activities will be less intensive.
FUNDING LEVEL:	$4,400,000 (FY 1991).		$18,000,000 (FY 1991) - coastal and noncoastal.
PARAMETERS SAMPLED:			**PARAMETERS SAMPLED (TENTATIVE):**
River Flow		River stage, tidal height.	Hydrologic factors, nutrient levels, organics, inorganics.
Water Quality		Conductance, temperature, sediment, dissolved and total nutrient, dissolved inorganics, major ions, trace elements, and bacteriology.	

monitoring practices found that although more than $133 million is expended on marine monitoring programs each year, there are numerous inadequacies in the design and use of monitoring data. Three broad problem areas were identified:

- There are numerous unresolved technical problems dealing with the quantification and interpretation of observed effects in terms meaningful to society. Individual monitoring programs are usually not closely linked with research programs or other monitoring efforts designed to identify sources and to understand the transport, fate, and effects of human activities on the ecosystem.

- The results of monitoring programs are not presented in a form that is useful in developing public policy or evaluating specific control strategies. It is essential to link data management strategies and data analysis methods to the objectives of the monitoring effort. It is also necessary to devise a plan for effectively communicating monitoring results to the identified audience.

- Monitoring programs are often poorly designed. While some of the identified problems could be attributed to the inherent difficulty of separating the effects of human activities from natural variability, the primary deficiencies in current monitoring practices resulted from the failure to clearly define monitoring objectives, link monitoring programs to management actions, and apply available design tools.

Ecosystems Monitoring Working Group

In response to the recognized need to improve marine ecosystems monitoring identified in the 1988 Federal Plan, the National Ocean Pollution Policy Board was directed to established an ad hoc working group on Monitoring Environmental Quality of Marine Ecosystems. This working group, which included members of Federal agencies, was formed to examine the status of Federal marine ecosystems monitoring programs. The group was further charged to examine the need for a national marine ecosystems monitoring strategy based on the current Federal effort in this area.

The working group concluded that a national marine monitoring strategy must be developed that will supplement the findings of the NRC reports (NRC, 1990a, 1990b), to address the concerns for safe seafood, high-quality recreation, related commerce, aesthetics, and a healthy ecosystem (Kiraly et al., 1991). The objectives of the strategy are:

- Assess the status and trends in the quality of the U.S. marine and estuarine environment.

- Provide a national framework of information to assist regulators in making decisions for the protection of human health and the marine/estuarine environment.

- Provide feedback to decision makers on the effectiveness of compliance programs.

- Assist in identifying research needs and priorities.

A framework of three levels was identified to: 1) perform a broad, national survey to assess existing information; 2) perform regional surveys directed at specific threats identified under 1); and 3) use site-specific evaluations to determine causes and solutions. Information categories to be addressed at each level include toxics, nutrient enrichment, sanitary quality, habitat loss/modification, acidification, pathogens, and nuisance species. This information should help to identify the condition of ecosystems.

The ad hoc working group also recommended that a mechanism be established to promote coordination among existing marine ecosystems monitoring programs in order to enhance comparability of data, facilitate exchange and synthesis of data, avoid duplication of effort, and ensure that national needs are being met. Quality assurance/quality control, parameters measured, data management, types of indicators, methodology, and ancillary data (e.g., point/nonpoint source discharges, atmospheric inputs, and studies of small-scale landscape alterations) would initially be examined.

The National Ocean Pollution Program Office, in association with the Federal and Scientific Work Groups, has identified two research priority issues reflecting information gaps that need to be filled to improve our understanding of the effects of human activity on marine ecosystems and to improve monitoring effectiveness:

- The use of indicators in monitoring programs to detect changes in biological populations and to quantify risks to the ecosystem and
- Design of monitoring programs and objectives.

Priority Issues and Information Needs

The following sections of this chapter discuss current Federal activities to address priority issues related to the status of marine ecosystems, identify the information needs associated with each of the priority issues, and recommend future research and monitoring activities.

Priority Issue: The Use of Indicators in Monitoring Programs to Detect Changes in Biological Populations and to Quantify Risks to the Ecosystem

Information Need: What Indicators Should Be Used in Monitoring Programs to Examine the Changes Occurring in Biological Populations and to Identify the Causes of These Changes? A wide range of biochemical, cellular, histological, species, population, and community indicators have been used to assess the impacts of pollutants on marine life. While the use of indicators has had some success in determining chemical-specific effects on individual species, success in using these indicators to evaluate trends in the status of the marine environment or the effectiveness of regulatory strategies has been limited (NRC, 1987, 1990a). This limited success can be partially attributed to an inability to establish quantitative relationships between observed responses of indicators or sets of indicators and the existence, magnitude, and persistence of effects on regional populations and communities. Indicators must characterize environmental features that are of interest or concern to whoever pays for their use: scientists, the public, decision makers, and others. Indicators truly useful to decision makers in particular agencies, for instance, must be perceived as valuable by them if these indicators are to be monitored for long periods. The purpose of monitoring the indicator must be clear and important to the supporting institution (NRC, 1990a). This underlines the importance of participation by the putative users of indicators in the definition of such indicators, to ensure that they are truly of interest, cost-effective, etc.

Several ongoing programs are developing and testing potential indicators of marine environmental health for use in environmental monitoring programs. Two of the most comprehensive Federal programs are NOAA's National Status and Trends Program for Marine Environmental Quality (NS&T) and, since 1990, EPA's Environmental Monitoring and Assessment Program - Near Coastal Component (EMAP-NC). Through an interagency agreement, these two programs are working together to improve monitoring of the Nation's marine ecosystems and are sharing the information collected by each program to develop a more comprehensive analysis of the health of coastal waters.

NOAA began the Benthic Surveillance Project of the NS&T Program for Marine Environmental Quality in 1984 and the NS&T Mussel Watch Project in 1986. The Benthic Surveillance Project annually monitors more than 70 contaminants in surface sediments and in the livers of certain benthic fishes at about 75 sites, located away from known point sources and dumpsites, around the coast of the United States. Along with the contaminant analyses, prevalence of external and internal disease, stomach contents, length, age, and gender of the fish are noted, and bile metabolites and mixed-function oxygenase enzyme levels are also measured. (More recently, aryl hydrocarbon hydroxylase and DNA adducts are also being examined.) The Mussel Watch Project analyzes the same suite of contaminants in surface sediments and tissues of oysters and mussels at 220 sites nationwide and histologically evaluates the stage of gonad maturation, since chemical concentrations in bivalve tissues can be affected by the reproductive stage. The NS&T Program has developed an extensive quality assurance program to promote comparability of analytical results by all laboratories participating in the program. Samples of sediment, bivalves, and fish livers are collected from 10 percent of the monitoring sites each year and stored at -150°C for future analyses of contaminants. Although primarily concerned with accumulation of xenobiotics and metals in fish and shellfish, the NS&T studies have identified biomarkers of value in monitoring programs of population dynamics, such as reproductive impairment at sites correlated with known pollutant excesses. The results of the NS&T Program have recently been reviewed by Turgeon et al. (1991).

The NOAA Great Lakes Environmental Research Laboratory (GLERL) has a project to monitor long-term trends in benthic populations in selected areas of the Great Lakes, and to determine the most probable reasons for the changes observed. GLERL conducts routine ecological monitoring of critical biological and chemical parameters to detect seasonal and vertical variations in phytoplankton, and to detect changes in phytoplankton dynamics in the Great Lakes caused by increases in atmospheric CO_2.

The purpose of EMAP is to characterize the condition of the Nation's ecological resources on regional and national scales and over long periods of time (USEPA, 1990a). One of the goals of this program is to develop and test indicators of pollutant exposure and ecological conditions. One of the ecological resource categories included in EMAP is near coastal waters. The NS&T Program, along with NOAA's National Marine Fisheries Service (NMFS) and the Coastal Ocean Program, is interacting with EMAP-NC in this area to produce a comprehensive Federal program. Under a cooperative agreement with the NS&T Program, NMFS develops and tests indicators of pollution exposure to "important" fish species in coastal waters (Casillas et. al., 1989; Collier et al., 1989; Johnson et al., 1989; Myers et al., 1987; Stein et al; 1989; Varanasi et al., 1989).

Many of these indicators, as well as several others, are being evaluated for use in the EMAP-NC category, including:

- Response Indicators–characteristics of the environment measured to provide evidence of the biological condition of a resource at the organism, population, community, or ecosystem level of organization.
  - Benthic species composition and biomass
  - Gross pathology of fish
  - Fish community composition
  - Relative abundance of large burrowing shellfish
  - Histopathology of fish
  - Apparent redox potential discontinuity
  - SAV
  - DNA adducts
- Exposure Indicators–characteristics of the environment measured to provide evidence of the occurrence and/or magnitude of an exposure to a physical, chemical, or biological stress.
  - Sediment contaminant concentration
  - Sediment toxicity
  - Contaminants in fish flesh and stomach contents
  - Contaminants in bivalves
  - Water column toxicity
  - Continuous and instantaneous measurements of dissolved oxygen concentration
- Habitat Indicators–physical attributes measured to characterize nonpollutant environmental conditions.
  - Salinity
  - Sediment characteristics
  - Water depth
  - Temperature
  - pH
- Stressor Indicators–characteristics measured to quantify a natural process, environmental hazard indicator, or management activity that may affect habitat and resource quality.
  - Fresh water discharge
  - Climate fluctuations
  - Pollutant loadings by major category

- Land use patterns of watershed by major categories
- Human population density/demographics
- Fishery landings statistics

Although a wide variety of biological indicators for examining the effects of adverse environmental conditions have been investigated, the value of some of these remains uncertain. For example, an extensive study, the Field Verification Program, was carried out by EPA's Environmental Research Laboratory, Narragansett, RI, and the U.S. Army Corps of Engineers, in the early 1980s. This study examined the effects of contaminated disposed dredged sediments on a variety of marine invertebrates under similar conditions both in the laboratory and near the site of sediment disposal in Central Long Island Sound. To do this a variety of indicators (e.g., scope for growth, bionenergetics, histopathology, sister chromatid exchange, adenylate energy charge) were employed as well as analyses of chemical contaminants from the sediments and tissues. While some of the biological indicators examined gave similar results under the lab and field experiments, others did not or did not indicate effects unique to the sediment exposures (see, for example, Pesch et al., 1985, 1987; Yevich et al., 1987). Other problems arising from recent work on indicators are discussed in research reports compiled by McCarthy and Shugart (1990) and others.

All reviewers of the current Federal programs have identified as a priority issue the development of biological indicators that can be used to assess the quality of marine ecosystems and help identify causes of change in biological populations. In addition to continued efforts by the NS&T Program and EMAP, EPA's Office of Water, Criteria and Standards Division, is currently developing for the States technical guidance on biological criteria to assess water quality and the potential impacts of effluent discharges to surface waters. Biological criteria are designed as numerical values or expressions that describe the biological integrity of aquatic communities that inhabit receiving waters. Technical guidance for biological criteria is scheduled to be produced for wetlands (estuarine/marine and freshwater) in 1994 and for estuaries in 1995 (USEPA, 1990b). Additionally, EPA's Office of Wetlands, Oceans and Watersheds is planning to develop rapid bioassessment protocols for estuaries, similar to those that have already been developed by EPA for small streams and rivers. Sediment quality criteria are being developed and tested as indicators of ecosystem status by various Federal agencies. Sediment criteria are based on concentrations of individual chemicals that will not adversely impact the structure and functions of benthic ecosystems. Currently, several methods of setting these criteria are based on the phenomenon of equilibrium partitioning of contaminants between the solid phase and dissolved state. The alternative approach, correlation of biological impacts with sediment contamination, is being evaluated and tested. The ultimate goal of each of these programs will be to determine appropriate and effective indicators for monitoring programs that can lead to the development of ecological risk assessment frameworks (see below).

Because of the importance of assessing the status and health of biological populations in compromised environments, further development of relevant biological indicators for different ecosystems is crucial. To enhance the interpretation of these indicators research should encompass the determination of factors influencing the distribution, abundance, and population structure of sensitive indicator species. The nature and extent of natural and human-induced alterations in environmental quality must also be integrated into these studies of population dynamics. Combined laboratory and field studies should help to interpret and confirm/deny the value of biological indicators.

Recommendations: Continue development and application of relevant biological indicators to ascertain the status and health of different ecosystems.

Information Need: How Can Monitoring Results Be Integrated into Models to Determine Risks to the Ecosystem? The most recent work within Federal agencies related to the use of indicators has focused on the development of ecological risk assessment procedures to address the issue of how to characterize the ecosystem's response to disturbance. EPA is particularly interested in this topic and has formed the Ecotoxicity Work Group. The Work Group has three short-term projects: 1) develop a Framework Document that provides guidance on the basic principles and paradigms appropriate for conducting ecological risk assessments; 2) prepare Case Study Reports that provide interim guidance in the form of ecological assessments conducted to support various regulatory statutes; and 3) prepare a Strategic Planning Report that outlines the Agency's long-term commitment to develop from three to five subject-specific Ecorisk Guidelines in this decade (Gentile and Slimak, 1991).

An anticipated benefit of ecological risk assessments is the development of an analytical and decision-making framework for defining ecological endpoints and identifying effective indicators. As discussed above, one of the problems identified in many monitoring programs is the inability to define clear ecological endpoints. Vague questions such as "Are the things that we are measuring changing?" or "Are the things that we are measuring different at these two sites?" are ineffective as repeated, long-term sampling is highly likely to detect spatial or temporal change in any variable (Suter, 1990). A clearly defined ecological endpoint, on the other hand, indicates which indicators are worth measuring and how intensively they must be measured.

Ecological endpoints are measures of ecosystem response to stress. They are defined as measurable or estimable biological or ecological attributes associated with one or more levels of biological organization that are the focus of the risk assessment (Gentile and Slimak, 1991). Criteria that have been proposed for ecological endpoints (Suter, 1990; Kelly and Harwell, 1989; Gentile and Slimak, 1991) include their social or biological relevance, the existence of clear conceptual and operational definitions, the ability to measure or predict them, and their susceptibility to stress or hazard.

For each ecological endpoint that is selected for the monitoring program, the next step is to identify the indicators that will be measured to detect change. Previously identified considerations in choosing indicators (Kelly and Harwell, 1989; Harwell et al., 1987; Gentile et al., 1990; USEPA, 1990b) are:

- Relevance to ecological endpoints;
- Reliability and specificity of response;
- Ease and economy of monitoring;
- High signal-to-noise ratio;
- Rapid response; and
- Standardized measuring techniques.

The endpoints selected must then be linked to management actions.

High specificity and reliability may be critical to establishing causal relationships and directing management decisions (Kelly and Harwell, 1989). Easily measured and economical indicators, however, with broad response characteristics, may also be important as screening indicators. Additionally, the availability of indicators that respond rapidly to change is important to ensure rapid management responses.

Standardized methods that allow comparisons among sites, monitoring programs, or analytical methods are very important. Investigations of the function of a selected array of coastal marine systems, conducted in a comparative mode, would provide the opportunity to develop understanding that can be transferred to other coastal regions not as heavily studied. This need for a strategically planned array of ecosystem studies was emphasized in a recent report published by the Joint Oceanographic Institutions (JOI) entitled *At the Land-Sea Interface: A Call for Basic Research* (JOI, 1990). Models for such programs, which may be modified to meet this need or expanded, exist in the National Science Foundation Program's Long-Term Ecological Research (LTER) Network, which includes the Land-Margin Ecosystem Research (LMER) Programs in Chesapeake Bay, the Columbia River Estuary, Waquoit Bay, and Tomales Bay (LTER, 1990). The Northeast Fisheries Center (NEFC) of NMFS, along with EPA and FDA, recently completed a 3-year program to monitor the abatement of sewage sludge dumping at the 12-mile dumpsite in the inner New York

Bight. This study provided a unique opportunity to monitor the natural recovery of a degraded area.

Biological populations are potentially ideal ecological indicators. Populations of many organisms have economic, recreational, aesthetic, and biological significance that is easily appreciated by the public, and population responses are better defined and more easily quantified than community or ecosystem responses (Suter, 1990). However, defining causal relationships between human-induced stress or disturbance and population changes remains a difficult challenge. The lake trout (*Salvelinus namaycush*) is now a widely accepted indicator of ecosystem-level quality for some of the Great Lakes (Ryder and Edwards, 1985), and a few indicators of specific effects on marine bird populations have been identified (Gilbertson, 1989).

A variety of models have been proposed for ecological risk assessment (USEPA, 1988b), including a number that attempt to link laboratory-derived toxicity test data with population models to evaluate the population-level risks of contaminant exposure. Numerous life-table response experiments have been conducted with zooplankton to develop predictive models that assess the population consequences of pollutant and environmentally-induced stress (e.g., Gentile et al., 1982; Rao and Sarma, 1986; Caswell, 1989). Various approaches to ecological risk assessment have been investigated by the EPA's programs in pesticides, toxics, and water quality (Bascietto et al., 1990). Beasley and Schaeffer (1989) explored the possibilities of using methods developed by the National Animal Poison Information Network (NAPINet) to identify risks to ecosystems through "epizootiologic ecotoxicology," also utilizing laboratory and field data in comparative studies.

However, many uncertainties remain in the extrapolation of laboratory test data to population responses in the field (Kelly and Harwell, 1989; USEPA, 1988b; Barnthouse et al., 1990), and in predicting risks to ecosystems. As noted by Capuzzo (1981), responses at each level of biological organization (organismal, population, community) may be adaptive or disruptive, and those occurring at one level will only result in the degeneration of the next level when compensatory or adaptive mechanisms begin to fail (Figure 6.1). Unfortunately, the degree of system complexity, the number of compensatory mechanisms available, and the lag time to measure response all increase exponentially as an effect moves through these levels, thus increasing the difficulty of making valid predictions at each level (see also Kelly and Harwell, 1989).

Effective monitoring programs and ecological risk assessment frameworks depend on research to identify effective ecological endpoints and indicators that can be used to detect trends in the status of the marine ecosystem. Long-term, broad-scale measurements are prerequisites to confidently inferring cause-and-effect relationships.

> *<u>Recommendation:</u> Develop ecological protocols that link monitoring results with modeling to relate population, community, and ecosystem effects to environmental changes.*

Priority Issue: Design of Monitoring Programs and Objectives

<u>Information Need: Continued Improvement in Monitoring Program Design and Program Comparability.</u> As noted above, the National Research Council's recent evaluations of the role of marine environmental monitoring (NRC, 1990a, 1990b) and the National Ocean Pollution Policy Board's ad hoc working group identified several concerns with ongoing monitoring efforts. These reports concluded that monitoring programs need to be better designed and monitoring methods more appropriately applied if they are to fulfill the expectations of those who depend on the data. The basic elements of designing and implementing a monitoring program as described in NRC (1990a) are presented in Figure 6.2. Several recommendations were made for the design and implementation of marine monitoring programs in the NRC report:

- In the design of monitoring programs, clear statements of the problems (hypotheses to be tested) must be developed. Additionally, it is essential to involve the

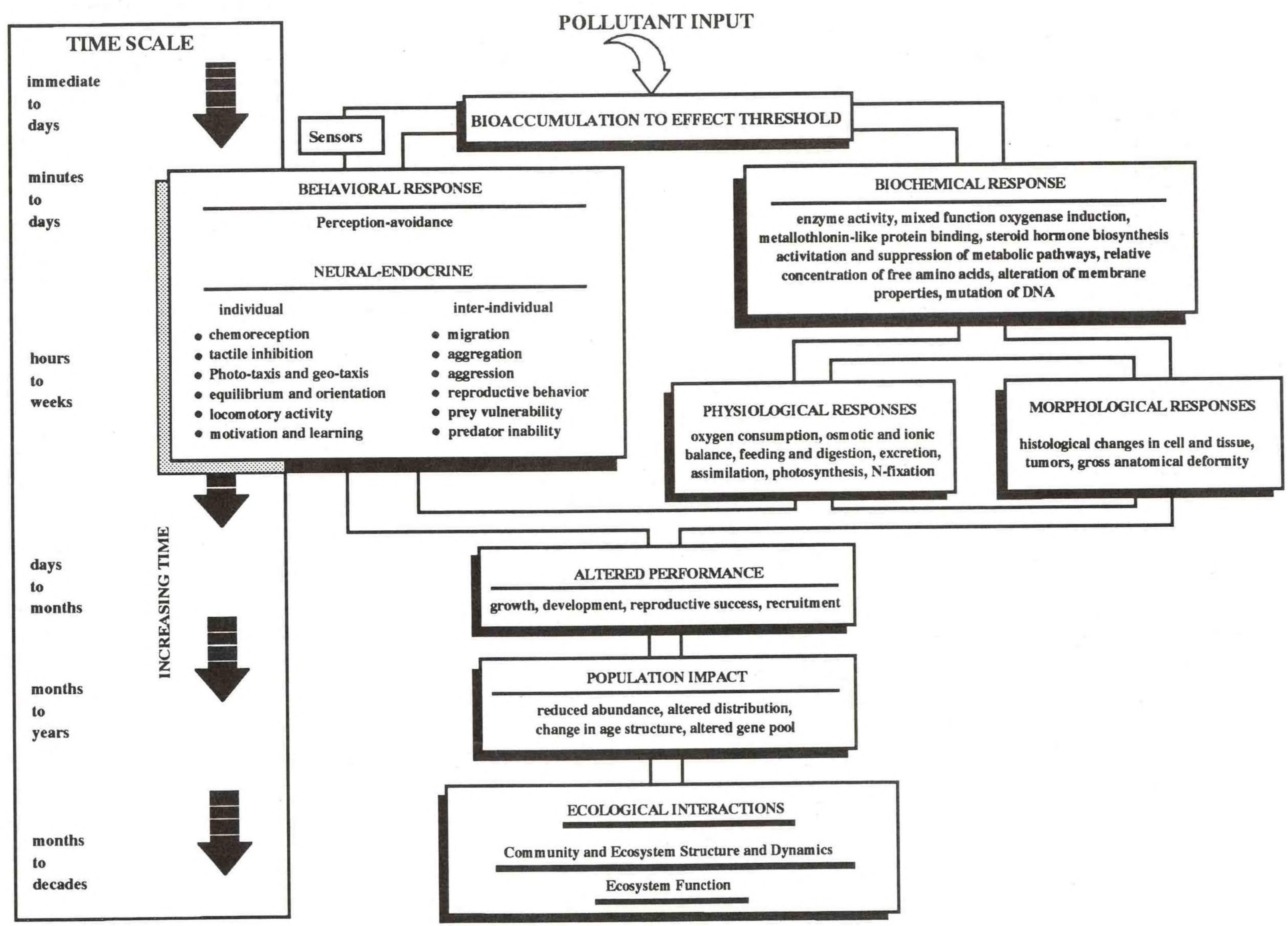


Figure 6.1. Conceptual chronology of biological and ecological effects following exposure of the ecosystem to toxicants (Source: Sheehan, 1984)

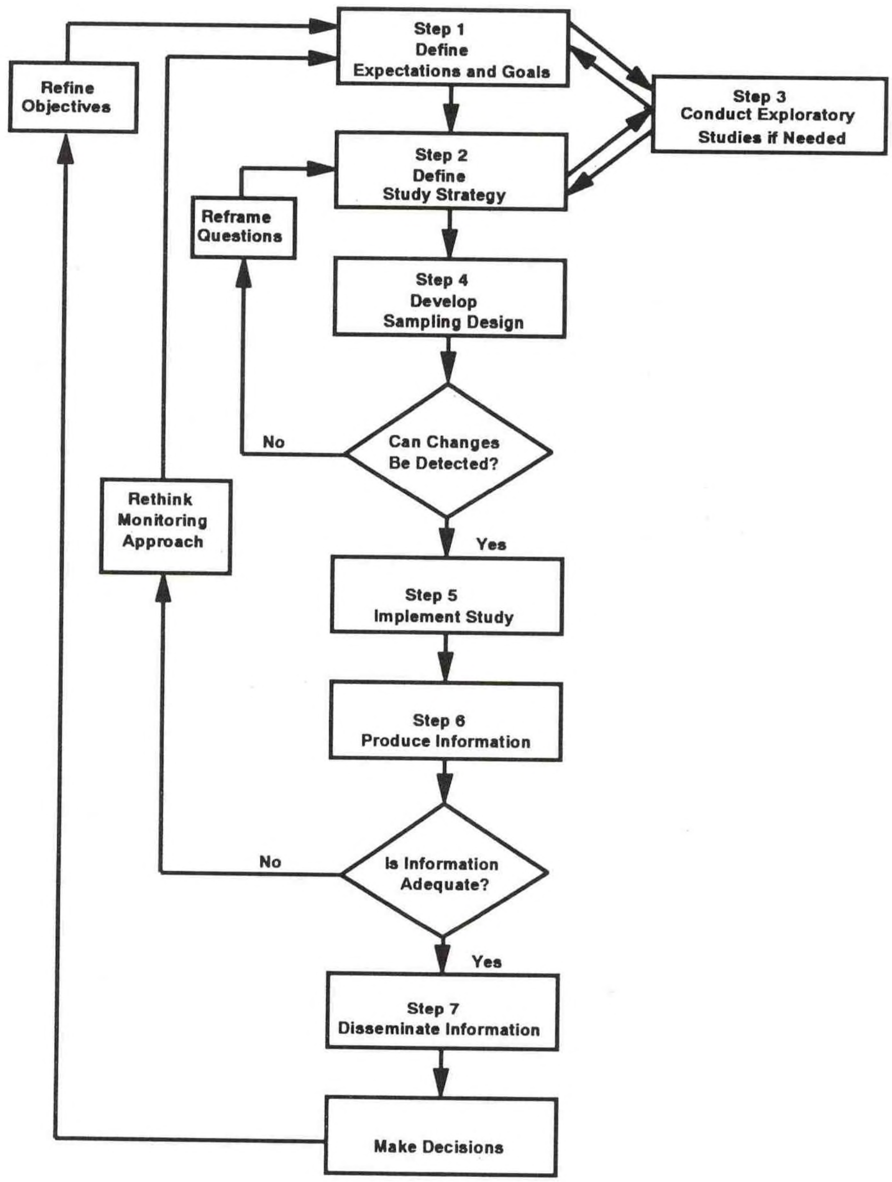


Figure 6.2. The elements of designing and implementing a monitoring program (Source: NRC, 1990a)

users of the program (e.g., regulatory and management personnel) in the development of monitoring goals and objectives.

- Threshold values of change that are to initiate management actions must be identified.
- Standardized protocols should be developed to ensure that the data collected by different groups participating in the monitoring program are directly comparable.
- Procedures for quality assurance need to be clearly specified.
- Data management and data analysis are as important to the success of the monitoring effort as the collection and laboratory analysis of field data, and adequate resources are needed not only for data collection but also for detailed analysis and evaluation over the long term.

EPA's National Estuary Program (NEP) has developed guidance for the design of the monitoring programs that will be conducted to evaluate the effectiveness of management actions taken under the Program (USEPA, 1991b). The document provides guidance on the design, implementation, and evaluation of the required monitoring programs. Also described is a systems design approach that places emphasis on the assessment of tradeoffs between individual aspects of the monitoring program and the use of feedback mechanisms to modify individual monitoring components based on periodic assessments of overall program performance. Monitoring methods are described, and emphasis is placed on the importance of developing and using standardized basin-wide monitoring protocols. Although the NEP is not encouraging the use of nationally standard protocols, NEP monitoring programs are encouraged to use standard methods within a basin.

Since limited Federal funds are available for these programs, emphasis is placed on the integration of existing monitoring efforts into the estuary monitoring program. The importance of data management, effective data analysis, and the communication of the results of monitoring to a wide range of audiences at several technical levels is also discussed. Quality assurance is stressed, as exemplified in the procedures developed by the EPA Office of Wetlands, Oceans and Watersheds for the Ocean Data Evaluation System and those of the NOAA NS&T Program. Such assurance is necessary to enable users to make informed decisions about the comparability of historical data sets. Finally, a case study describes the steps involved in the development of the Puget Sound Ambient Monitoring Program, the goals of the program, the monitoring design, and the roles of the participating Federal, State, local, and tribal governments. Formal comprehensive monitoring plans have also been developed for Narragansett Bay and Buzzard's Bay, with others currently being prepared.

A joint EMAP-NC and NS&T Program Office is planned for 1991 to ensure effective integration of these national monitoring efforts. Toward this end, EMAP-NC requires its laboratories to participate in and financially support NOAA's QA/QC Program. In fact, the International Mussel Watch, Gulf of Maine Monitoring Program, California's Mussel Watch, and most coastal States already participate in NOAA's QA/QC Program. EMAP-NC and the NS&T Program also have committed to a joint Scientific Advisory Committee and will produce a joint Regional Assessment in the Virginian Province (a geographical sampling area). This assessment will include EMAP-NC's findings in its first year's Pilot Project and NS&T's findings for the first 5 years at its monitoring and biological effects studies sites.

Marine pollution data are acquired, processed, and managed by NOAA's National Oceanographic Data Center of the National Environmental Satellite, Data, and Information Service, with all data subjected to quality control/quality assurance evaluations. NOAA's Coast Watch, within the Coastal Ocean Program, provides a rapid supply of up-to-date, coordinated environmental information (remotely sensed/satellite, chemical, biological, and physical) to allow Federal and State researchers and managers access to a near-real-time decision support system. This program focuses on unusual environmental events, such as accumulating algal biomass, and mapping of tidal wetland changes, critical to specific regional and national priorities. NOAA's Ocean Communications Network (NOCN) provides communications and data quality enhancement for this program, with two prototype activities under way on the North Carolina coast and in the Chesapeake Bay. Further data and information from some marine monitoring programs are aquired, processed, and managed by NOAA's National Oceanographic Data Center, with all data subjected to quality control/quality assurance evaluations.

Because of the complexities involved in monitoring different ecosystems, it is essential to develop explicit statements (including testable hypotheses) of monitoring program objectives as well as to establish performance criteria with which to measure monitoring program success. The process of developing explicit statements of program objectives will provide the platform for communication between the scientific experts responsible for designing the monitoring program and the managers/decision makers who are responsible for developing policy and regulations. The definition of performance criteria, in terms of the level of precision that is necessary to make decisions regarding the success of the monitoring effort, provides a basis for evaluating monitoring program performance. These criteria, and a timetable for meeting them, should be established early in the design of the program. Results of the performance assessment should be used to refine program objectives and to modify individual study elements to meet these objectives.

Another important task will be to examine the comparability of data collected by the Federal monitoring programs with national and regional scope, as well as to link these programs with the numerous non-Federal marine ecosystem monitoring efforts, as in the National Estuary Program. Such review of monitoring programs is necessary not only to avoid duplication of goals and objectives, but also to provide the best information for resource managers and regulatory agencies. The data collected from monitoring, as well as the predictive models to be developed from them, must also be made available to the widest possible audience. Continued support for a national centralized system for the archiving, synthesis, and analysis of data is essential to provide assistance in the development of comparative predictive models and to provide other resources for managers to help protect human health and marine, estuarine, and Great Lakes ecosystems (URI, 1989).

Recommendations: 1) Continue to develop and refine regional and national marine ecosystem monitoring programs and evaluate their ability to meet specific program objectives, and 2) continue to develop protocols to ensure comparability of data and information from Federal monitoring programs with national and regional scope.

Conclusions

Congress has specifically mandated the collection of fundamental information on the status of marine ecosystems with respect to pollution effects. The scientific and technological capability exists to perform such monitoring. Ongoing Federal programs have made progress in identifying effective indicators of organismal, population, and community responses to changes in environmental conditions. Future monitoring could soon be substantially more valuable to science and management if relevant science and management understanding is applied widely.

Many problems have been identified in monitoring programs. However, consistent adherence to a few principles now recognized as universally important (NRC, 1990a; URI, 1989; Kiraly et al., 1991) would rapidly enhance the cost-effectiveness of marine monitoring. A most important concern is the ability of such monitoring programs to meet their specific program objectives. Users of monitoring programs (regulatory and management personnel) must be involved in the development of monitoring objectives and must establish performance criteria for assessing the value of such programs for measuring the status and documenting the trends of ecosystem responses to human-induced environmental changes. The issues of data comparability and quality control/quality assurance in the data collected will be more carefully assessed to ensure compliance with guidelines and the data's usefulness to the programs. Inclusion of QA/QC information with data sets allows future users of the data to make informed decisions regarding the comparability of historical data sets.

Based on these conclusions, the following recommendations are made for documenting the trends in the status of marine ecosystems.

Recommendations

Use of Indicators

- Continue development and application of relevant biological indicators and their variability to ascertain the status and health of different ecosystems.
- Develop ecological protocols that link monitoring results with modeling to relate population, community, and ecosystem effects to environmental changes.

Monitoring Program Design

- Continue to develop and refine regional and national marine ecosystem monitoring programs and evaluate their ability to meet specific program objectives.
- Continue to develop protocols to ensure comparability of data and information from Federal monitoring programs with national and regional scope.

Chapter VII

Understand the Implications of Marine Pollution to Human Health

Human health concerns related to marine pollution center on toxic substances and pathogenic microorganisms that are introduced into marine ecosystems as a result of human activities. Another concern is the extent to which nutrient loading of coastal and estuarine waters due to human activities increases the risk of illness due to pathogenic microorganisms or their toxic products. Typical routes of human exposure include consumption of seafood and swimming. Although acute toxic responses have not been reported to have resulted from consumption of chemical contaminants in U.S. seafood, certain groups of people with high exposure to contaminated seafood may be at risk. In addition, seafood may contain pathogenic microorganisms as a result of harvesting seafood from sewage-contaminated areas, colonization with human pathogens that occur naturally in the marine environment, or contamination that occurs during improper processing or shipping of seafood products. Governmental programs, such as the National Shellfish Sanitation Program, have been effective in protecting the public from major outbreaks of disease. Important public health concerns related to marine pollution remain to be addressed, however, including sporadic outbreaks of gastroenteritis caused by viruses and latent effects that may result from chronic exposure to chemical contaminants in seafood. Therefore, understanding the implications of marine pollution to human health is one of the six goals of the National Ocean Pollution Program.

Goal Definition

A number of pollutants that can cause adverse human health effects have been identified in the marine environment. Although the presence of these agents in the marine environment does not alone constitute a public health risk, some health risk may result if human exposure exceeds threshold levels of these agents. Adverse health effects from these substances arise from either the toxicity or pathogenicity of the agent and the extent to which the population is exposed. To understand the relationship between exposure of humans to pollutants in the marine environment and the risk of developing an adverse health effect, it is necessary to characterize the toxicity and pathogenicity of, and human exposure to, marine pollutants. The priority issues discussed in this section are structured around the information needs related to these topics. Also addressed in this section are the current efforts to generate the needed information and recommendations to fill the important existing data gaps.

The pollutants of concern with regard to human health effects can be broadly grouped into two categories: toxic chemical contaminants and human pathogens. Substances in these categories 1) are known to be present in the marine environment, 2) have the potential to come into contact with human populations, and 3) are known to cause various adverse effects such as birth defects, cancer, liver disease, neurological disorders, and infectious diseases.

Chemical Contamination

According to the National Academy of Sciences (NAS, 1991), the levels of toxic chemicals in seafood in certain areas are high enough to warrant additional control measures. It is suspected, however, that the risks from toxic chemicals are not of the same magnitude as environmental health hazards associated with human pathogens for the population as a whole (NAS, 1991), although certain groups within the population may be at high risk, e.g., recreational and subsistence fishermen, children, and pregnant women. Quantifying the potential human health effects resulting from exposure to toxic chemicals in the marine environment is difficult since the effects may not take the form of obvious acute effects. Few studies have been able to actually measure the impacts of exposure to toxic chemicals (D'Itri and D'Itri, 1977; Fein et al., 1984); however, this should not necessarily imply that effects do not occur. Exposure to toxic chemicals may induce chronic effects such as an increased incidence of cancer, which may not be detectable in an epidemiological study of an exposed population.

Toxic chemicals of primary concern have the following properties:

- High persistence in the aquatic environment;
- High bioaccumulation potential;
- High toxicity to humans; and/or
- Common chemicals released to the environment by human activity (USEPA, 1989a).

Chemicals with these properties that have been found in fish tissue and the marine environment include dioxins and furans; polychlorinated biphenyls (PCBs); polycyclic aromatic hydrocarbons (e.g., benzo(a)pyrene); pesticides; and some metals such as arsenic, lead, mercury, and selenium. In addition, a variety of toxic chemicals are introduced into the marine environment from aquaculture. Of these, chemotherapeutic drugs such as sulfonamides, antibiotics (e.g., chloramphenicol), and nitrofurans are among the primary ones of concern to human health (NAS, 1991). In addition to toxic chemicals, it should be noted that malachite green, a color additive widely used in aquaculture, also poses risks for human health. Although the effects of many of these compounds on different organ systems in man and/or animals are known, it is difficult to establish with certainty the degree of hazard posed by their presence in seafood. Information is lacking on the exact concentrations present in edible fish tissue and, in the case of metals, the form in which they exist (e.g., inorganic vs. organic, oxidation states). Moreover, the health effects of exposure to complex chemical mixtures are not known, and the relationship between chemical contaminants and susceptibility to infectious disease has not been explored.

Once an indication of the relative hazard posed by a marine pollutant has been established, the next step is to characterize the potential risk to the human population from exposure to the particular contaminant using risk assessment methods. This involves quantifying the levels of the contaminant in seafood, identifying the populations exposed to the toxic agent, estimating the duration and nature of human exposure, and evaluating the toxicity of the chemical contaminant. Several methods have been developed recently to assess the human health risks from exposure to toxic chemicals in the marine environment (USEPA, 1989a; Brown et al., 1988; Friberg, 1988). However, there are several data gaps and uncertainties associated with the risk assessment process that may be improved by further research in this area.

Identifying the populations likely to be exposed to marine pollutants and estimating the duration and frequency of exposure require accurate seafood consumption data. The wide range of national seafood consumption values currently available to regulatory agencies is a recognized source of uncertainty in assessing the human health risks posed by marine pollutants. For consumption data to be useful, they should be based on measurements from regional and national surveys of high-risk subpopulations in areas where problems exist. They should also be specific to certain seafood species. Any characterization of the degree to which populations are exposed to contaminants through consumption of seafood requires knowledge of the source of the contaminated seafood. This chapter focuses on seafood harvested in U.S. waters. A significant quantity of the seafood consumed in this country, however, is imported (NAS, 1991). An assessment of the risk to human health from consuming seafoods must take into account the consumption of imported seafood products.

This chapter reviews the existing seafood consumption data and addresses the need for updating this information. Consistent approaches are needed to evaluate exposure and risk from ingestion of contaminated fish. This does not mean that the same exposure parameters, such as fish ingestion rates, should be used in all cases, but rather that a consistent approach for quantifying region-specific exposure and risk should be adopted.

Other routes of exposure to chemical contaminants in the marine environment may include occupational handling of contaminated seafood. Although workers in the seafood industries are among those with the highest incidence of occupational skin disease, these problems appear to be the result of bacterial infections from abrasions and cuts caused by handling fish and not the result of handling chemically contaminated seafood. In addition, results of two epidemiological studies of seafood handlers suggest that the development of many adverse health effects in this population originates from exposure to water, noise, cold, and dampness, or to ergonomic factors leading to musculoskeletal stress and discomfort (NIOSH, 1986). No evidence exists to indicate that occupational exposure to chemically contaminated seafood is a health concern. Therefore, no high-priority research needs have been identified in this area.

Direct human exposure to toxic compounds in the marine environment could also occur through swimming or diving in polluted waters. Existing information indicates that exposure to chemical contaminants during swimming and diving does not pose a serious or widespread threat to human health (USEPA, 1987). For these impacts to be significant, very elevated levels of toxic chemicals would need to be present. Thus, the problem would tend to be isolated to highly contaminated areas near ocean dumping sites or industrial effluents. No high-priority research needs have been identified in this area.

Pathogenic Microorganisms and Marine Toxins

The primary human health concerns resulting from ingestion of seafood are associated with exposure to pathogenic microorganisms and marine toxins (NAS, 1991). Many of these pathogenic microorganisms have been associated with point and nonpoint source marine pollution. For example, certain pathogenic microorganisms such as Hepatitis A virus (HAV) and Norwalk viruses may be present in seafood as a result of fecal pollution from municipal discharges, industrial/agricultural discharges, and surface water runoff. Of these sources, municipal wastewater sewage presents the greatest risk of infectious disease via direct contact, recreational activities (e.g., swimming, surfing, etc.), and consumption of seafood. Stormwater runoff typically contains little human fecal waste but may contain high levels of fecal indicators and possibly pathogens because of animal waste.

There are two groups of microorganisms that are native to coastal and estuarine waters that can cause human health effects via the recreational and shellfish transmission routes. The first consists of several species of bacteria, primarily of the genus *Vibrio*, which cause infectious processes but are largely opportunistic pathogens (Grimes, 1991). Indigenous *Vibrio* species associated with contamination of shellfish include *V. parahaemolyticus*, *V. vulnificus*, and other species. Consumption of seafood contaminated with *V. parahaemolyticus* has been associated with outbreaks of gastroenteritis, while consumption of *V. vulnificus*-contaminated shellfish can result in primary, frequently fatal, septicemia (blood poisoning) in patients with liver disorders and in diabetic and immunocompromised individuals (Tacket et al., 1984; Blake et al., 1979; NAS, 1985, 1991). This same microorganism also has been responsible for wound infections among users of coastal and estuarine waters. These infections have been relatively few in number, but very severe in nature. Finally, there have been highly infrequent cases of shellfish-associated cholera-like disease caused by non-01 strains of *V. cholerae*, which are indigenous to all three coasts. In addition, a few cases of Asiatic cholera due to 01 strains of the organism have become established at specific locations in the Gulf of Mexico because of shellfish consumption. Other bacteria derived from estuarine and marine environments also cause human disease, but the incidence of reported disease is low (Grimes, 1991).

The second group of native microorganisms is algae, specifically certain dinoflagellates, which produce marine biotoxins that are accumulated in certain filter-feeding shellfish. Intoxication occurs by consumption of fish, which receive the toxin through their food chains. In addition, scombroid poisoning, which was the second most frequently reported disease associated with eating fish in the United States between 1977 and 1981 (Bryan, 1980; CDC, 1981, 1983), results from eating fish that have become toxic as a result of microbial decomposition of histidine to histamine during improper handling and storage (NAS, 1985). *Clostridium botulinum*, a bacterium found in soil and aquatic sediments, also forms a highly toxic neurotoxin. Human outbreaks associated with *Clostridium botulinum* usually result from faulty food processing or storage practices.

Ciguatoxin is a naturally occurring substance manufactured by certain dinoflagellate species (Bagnis et al., 1980) and transferred to fish through the food chain (Brown and Dorn, 1977). It is the disease most frequently reported from eating fish in the United States (CDC, 1983). Exposure to the biotoxins released from naturally occurring dinoflagellate species other than ciguatera represents a less frequent hazard to human health. The dinoflagellate *Gonyaulax tamarensis* is responsible for producing paralytic shellfish poisoning (PSP) in exposed human populations along the New England Atlantic coast. *G. cantenella* is the organism responsible for cases of PSP on the Pacific coast (Steidinger, 1983). PSP, which has not been clearly linked to marine pollution, is one of the most toxic forms of food poisoning. Severe and often fatal human intoxications following ingestion of contaminated bivalve mollusks have occurred sporadically in widely scattered areas around the world (Ray, 1971). Statistically, PSP does not constitute a major public health concern in the United States, due in large part to successful State monitoring programs, although infrequent incidents have been reported along the Atlantic and Pacific coasts (CDC, 1983). Shellfish involved most frequently are mussels, clams (hard and soft-shelled), butter clams, and scallops (NAS, 1985, 1991).

The dinoflagellate *Gymnodinium breve* causes neurotoxic shellfish poisoning (NSP) in consumers of shellfish taken along the seacoast of North Carolina, South Carolina, Florida, and Texas. While able to kill fish and some invertebrates, *G. breve* toxins accumulate in oysters and clams without harming them (Steidinger, 1983). These toxins can produce acute neurological effects in humans if sufficient quantities of shellfish meats are consumed. Since the toxins are heat stable, cooking does not protect consumers. Public health protection depends on control at harvest sites.

The association between exposure to human pathogens, either through ingestion of contaminated seafood or by swimming in contaminated water, and the development of human illness has been established for some agents, especially enteric pathogens such as viruses and bacteria. Diseases such as hepatitis, gastroenteritis, and cholera are known to be caused by water- and seafood-borne pathogens. Many data gaps exist, however, with regard to potential health risks from exposure to other pathogenic microorganisms, particularly for the *Vibrio* species. Information gaps exist concerning the levels of microorganisms and marine toxins in seawater and seafood, survivability, transmission, and life cycles of pathogenic microorganisms and dinoflagellates, as well as the best methods for monitoring these microorganisms. Research in these areas may help control the potential health threat from exposure to pathogenic microorganisms and marine toxins.

NAS (1991) concluded that the health risks associated with exposure to pathogenic microorganisms and marine toxins may not be adequately controlled by increasing seafood inspection efforts alone. Rather, efforts should be focused on reducing contamination in the marine environment and ensuring that fish are harvested in a cleaner environment. To this end, a number of options are available for reducing the potential exposure and risk associated with the ingestion of seafood, including:

- Developing effective water quality criteria for issuing public health advisories;
- Issuing public health advisories, closing finfish and shellfish harvesting areas, and closing beaches when these criteria are exceeded;
- Removing and/or inactivating human pathogens from municipal wastewater discharges and sewage sludge; and
- Removing and/or inactivating human pathogens from fish.

These options are discussed below.

Effectiveness of Water Quality Criteria. Concentrations of coliform bacteria, expressed as Most Probable Number (MPN) per 100 milliliters, have been employed for decades as a component of microbiological standards to monitor the quality of waters for swimming and shellfish harvesting (OTA, 1987; DHEW, 1965). Although currently used microbial indicators have been effective in protecting the U.S. population from shellfish-derived epidemics, existing water quality standards have been questioned as true indicators of the overall potential for human disease. The indicators and standards have not been related to disease through epidemiological studies, and although indicators used generally reflect the presence of fecal wastes, they are not specific to humans nor to two common causes of disease: viral pathogens and free-living, opportunistic pathogens such as *V. vulnificus* (Ronk, 1988). Water quality criteria may need to be developed based on the direct enumeration of the pathogen or other parameters that are highly correlated with the pathogen in question. States will need assistance and guidance in the formulation of both State- and region-specific standards and the development of compliance monitoring programs for these pathogens. The development of all criteria should take into account health impact issues, as well as economic and sociological factors and the nature and extent of the resource usage.

The hazards posed by fecal wastes from various animal species are poorly understood, although human pathogenic bacteria are found in animal wastes. For example, the calicivirus group affects mammals in general, and serotypes of calicivirus from marine animals have infected humans, producing clinical illness. In the overall risk assessment, "animals" cannot be dismissed (G. Hoskin, U.S. Department of Health and Human Services, U.S. Food and Drug Administration, personal communication, 1991).

Effectiveness of Public Health Advisories, Closing of Finfish and Shellfish Harvesting Areas, and Beach Closures. To reduce potential exposure to toxic chemicals, pathogenic microorganisms, and marine toxins, agencies have issued public health advisories and have closed finfish and shellfish harvesting areas and beaches. Current information suggests that these methods may be only partially effective (Belton et al., 1986; Cabelli et al., 1979). With respect to public health advisories, surveys and interviews of urban fishermen, conducted by Belton et al. (1986), revealed that many fishermen were not aware of the advisories, and that some had either misinterpreted the guidance or chosen to ignore it. Although through the

National Shellfish Sanitation Program serious enteric diseases such as hepatitis, cholera, and typhoid have been largely eliminated (FDA and NOAA, 1985), it is still unclear whether finfish and shellfish harvesting area closures are effective and efficient, especially for viral-induced types of gastroenteritis. With respect to beach closures, Cabelli et al. (1979) observed that symptom rates among swimmers at New York City beaches that were rated either "barely acceptable" or "relatively unpolluted" by a graduated pollution index were higher than those of nonswimmers at the same beaches. The public perception of risk and the ability of the regulatory agency to communicate that risk plays a large role in determining the effectiveness of public health advisories and closures. Further research on the effectiveness of these management tools, development of better means of communicating risk, and improved criteria for issuing health advisories and closures need to be pursued.

Treatment of Municipal Waste and Sewage Sludge. The contamination of marine waters with municipal wastewater and sewage sludge, through outfalls, ocean dumping, and combined sewer overflows (CSOs), presents the greatest risk of infectious disease via direct contact during recreational activities and ingestion of contaminated fish. Factors that may influence the potential impact of municipal wastewater discharge include:

- The number of pathogens in wastewater;
- The specific wastewater disposal strategy, including the degrees of treatment and disinfection and the location of the outfall;
- Reduction of the pathogen levels via dilution, sedimentation, and die-off;
- The nature and degree of exposure to the population at risk; and
- The number of sensitive individuals in the population (e.g., number of persons who may have immunodeficiencies).

Chlorination is the most commonly used disinfection technique in the United States (OTA, 1987). Traditionally viewed as an effective and economic mechanism to reduce the concentration of pathogens in municipal effluent and sewage sludge, a growing body of evidence suggests that present methods and technologies vary in their effectiveness depending upon the particular type of pathogen. For example, Miescier and Cabelli (1982) noted that viruses are relatively resistant to chlorination, especially the Norwalk virus, and many bacteria also are resistant to chlorination (Grimes, 1986). Effective methods for the removal and/or inactivation of human pathogens from municipal effluent and sewage sludge need to be developed.

Treatment of Contaminated Fish. Even with the best treatment technology to reduce marine pollution, there is still the potential for seafood to be contaminated with pathogenic microorganisms. Self-cleaning of shellfish after transplanting from contaminated to cleaner waters (i.e., depuration) may not reduce levels of certain pathogenic microorganisms. Several methods such as low-dose gamma radiation, lactic acid treatment, freezing before ingestion of raw shellfish, heating, and harvesting methods may be useful in reducing the risk associated with ingestion of fish grown in areas with certain levels of marine pollution. Effective methods for the removal, reduction, and/or inactivation of pathogens in fish need to be explored further.

An understanding of the adverse human health effects that may result from exposure to chemical contaminants and pathogenic microorganisms in the marine environment is important for managing these problems. The National Ocean Pollution Program Office, in association with the Federal and Scientific Workgroups, has identified two priority issues reflecting this need for information:

- Human health concerns associated with exposure to chemical contaminants in the aquatic environment.
- Human health concerns associated with exposure to pathogenic microorganisms and marine biotoxins in the aquatic environment.

Priority Issues and Information Needs

The discussion that follows identifies the information needs associated with each of these priority issues, discusses current Federal activities to address these information needs, and recommends Federal research and monitoring activities.

Priority Issue: Human Health Concerns Associated with Exposure to Chemical Contaminants in the Aquatic Environment

Information Need: Lack of Information and Consistent Approaches Needed for the Evaluation of Exposure and Risk from Ingestion of Contaminated Fish. Although most of our seafood is safe for human consumption, available information on chemical contaminant concentrations in marine species suggests that risks to human health could result from consumption of finfish and shellfish from U.S. coastal waters (NAS, 1991). Evaluating the impacts from exposure to toxic chemicals using epidemiological studies typically cannot be done since the impact from exposure may not take the form of an obvious acute effect. Thus, risk assessment methods are necessary to evaluate the impact to human populations. The conceptual approach to estimating potential health risks associated with exposure to contaminants in fish tissue is diagramed in Figure 7.1. The results of a quantitative risk assessment, however, are only as accurate as the data used to derive the risk estimates. Of primary importance is improving our methods for evaluating exposure and risk from ingestion of contaminated fish. These methods can then be used to derived water quality criteria, establish public health advisories, and evaluate National Pollutant Discharge Elimination System permits.

Some pollutants are discharged into U.S. waters in large quantities. Among these are metals and organic chemicals. Typical chemical contaminants found in fish tissue include dioxins and furans; PCBs; polycyclic aromatic hydrocarbons (e.g. benzo(a)pyrene); pesticides; and some metals such as arsenic, lead, mercury, and selenium (NAS, 1991). In addition, a variety of toxic chemicals are introduced into the marine environment from aquaculture. Chemotherapeutic drugs used in aquaculture such as sulfonamides, antibiotics, and nitrofurans are the primary chemicals of concern to human health (NAS, 1991).

Current Federal monitoring programs include those of the NOAA National Status and Trends (NS&T) Program, and NOAA's National Marine Fisheries Service. NS&T's Mussel Watch Project includes annual sampling of mussels and oysters from 150 coastal and estuarine sites along the U.S. Atlantic, Gulf, and Pacific coastlines. Organisms and sediments have been analyzed for selected PAHs, synthetic chlorinated compounds, PCB congeners, and trace metals. Research performed by the NOAA National Marine Fisheries Service focuses on the impact of chemical contaminants and pathogens in the marine environment on human health. As part of the NS&T Program for Marine Environmental Quality (NOAA, 1987, 1989), chemical concentration data have been compiled from these monitoring programs.

The FDA has estimated the exposure of U.S. citizens to chemical contaminants in their food through Total Diet Studies (also known as the Market Basket Program) since the early 1960s for adults, and since 1974 for infants and toddlers (Gartrell et al., 1986). In these studies, samples representing the annual average diet are analyzed for selected pesticides and industrial chemicals. The Total Diet Studies include a seafood component. Overall, however, relatively little of the fish caught and sold in this country is exposed to or screened for chemical contaminants.

Programs for monitoring chemical contaminant concentrations in seafood could be improved in the following ways:

- Intensify monitoring. Existing Federal and State programs provide limited data on the concentrations of chemical contaminants in edible tissues of commercial and recreational fish species. Frequency of sampling is too limited on both temporal and spatial scales. Monitoring programs should focus on chemical contaminants typically found in fish tissue including dioxins and furans; PCBs; polycyclic aromatic hydrocarbons (e.g., benzo(a)pyrene); pesticides; heavy metals such as arsenic (inorganic), lead, mercury, and selenium; and chemicals used in aquaculture such as chemotherapeutic drugs (sulfonamides, antibiotics, and nitrofurans) (NAS, 1991). In addition, our ability to address emergency situations (e.g., spills of toxic materials) affecting public health and the aquatic environment requires rapid detection of contaminants and an assessment of their potential risk. For such emergency situations, monitoring

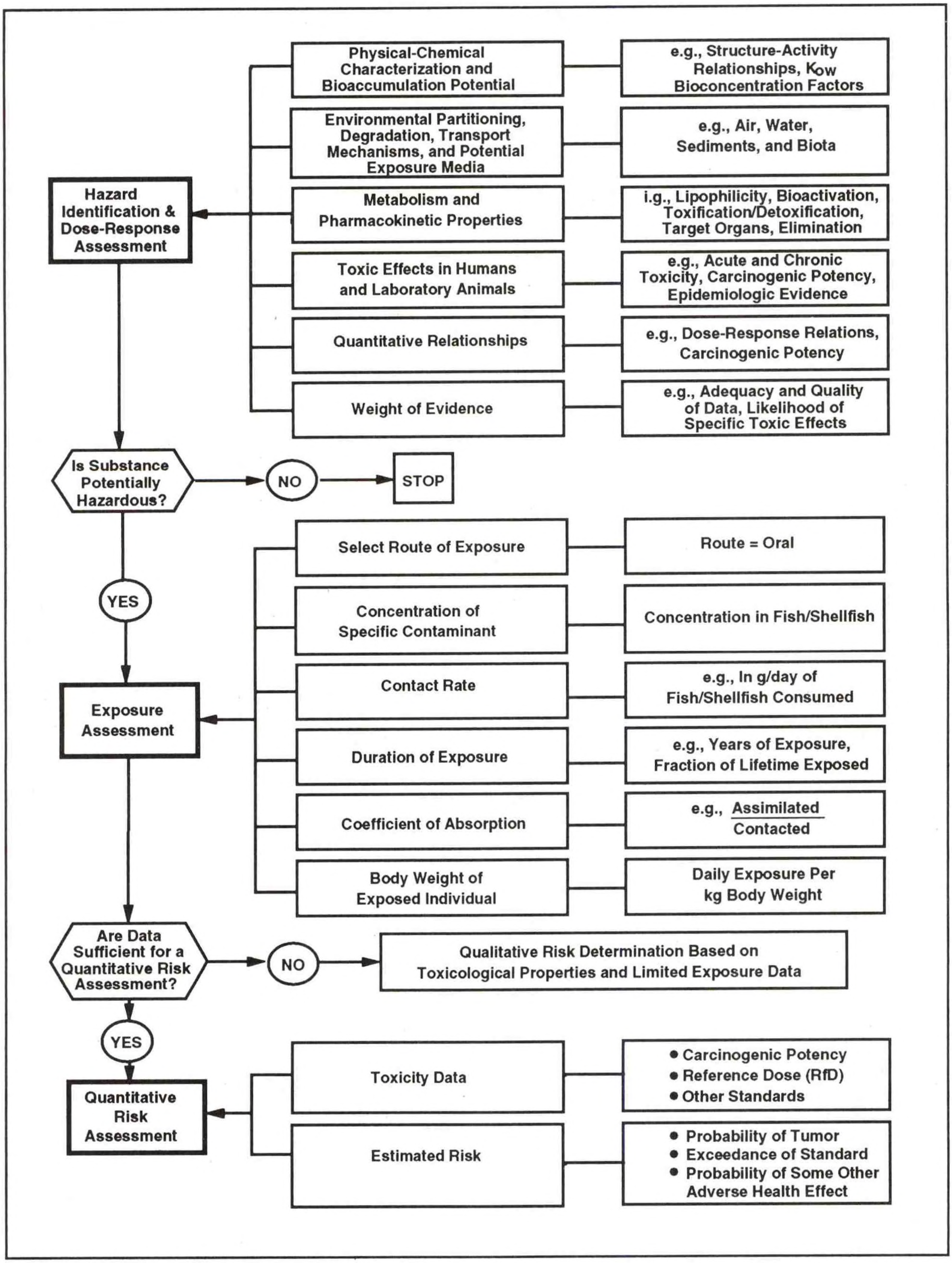


Figure 7.1. Conceptual approach for estimating potential health risks associated with exposure to contaminants in fish tissue (USEPA, 1989a).

should focus on parent compounds and breakdown products of the chemicals released.

Existing Federal programs such as the NS&T Program are not designed to manage human health risks and, although they serve other important needs, do not provide sufficient information for protecting human health. Alternative sampling methods may involve determining the species that represent the greatest percentage of the catch of commercial and recreational fishermen and analyzing the edible tissues of those species (Malins et al., 1980; MacLeod et al., 1981). Another approach would involve selecting an indicator species that is thought to represent a special concern because of the ability of that species to bioaccumulate potentially toxic substances, or because of a higher rate of consumption of this species by individuals in a specific geographical area. This was the approach taken by NOAA/NMFS (1986b), in conjunction with the FDA and EPA, in its extensive survey of PCBs in Atlantic coast bluefish.

- Study pharmacokinetics of chemicals. There is a need to quantify the pharmacokinetics (i.e., biouptake, accumulation, deprivation, etc. in the human body) of chemical contaminants in fish. For example, to assess the potential short-term and long-term impacts of oil contaminants from the *Exxon Valdez* oil spill on fishery resources, there is a need to ascertain in both a qualitative and quantitative manner the degree to which the oil contaminants of greatest concern to human health are accumulated, metabolized, and deposited by relevant fishery species. Bioaccumulation studies are needed for chemicals of concern used in aquaculture. Such information also is important when developing criteria for surface water. For example, pharmacokinetics can be used to estimate the surface water concentration that would correspond to a target fish tissue concentration derived from a risk assessment model.

- Standardize methods. Sampling and analysis protocols should be established by the Federal Government for critical factors such as the tissues to assay, specimen size (or age) class, sex and reproductive condition, sampling season, number of replicates, and methods of chemical analysis (USEPA, 1989a). Standard protocols are especially important because much of this monitoring is conducted individually by the States. The standardized methods for sampling and analyzing fish tissue should be developed specifically for risk assessment purposes. Lipophilic toxic chemicals such as dioxins, furans, and PCBs partition to fat tissue rather than unpalatable portions of the fish, which are typically discarded by most recreational and subsistence fishermen. Thus, whole-body concentrations of these chemicals may result in an underestimation of risk. Concentrations of lipophilic compounds in fish fillets may be more representative of the actual exposure to an individual than a whole-body concentration. In certain cultures of Native Americans and Asian Americans, however, the whole body of the fish is consumed and whole-body analysis may be most representative. Therefore, sampling protocols may need to be adjusted in some cases to fit the exposure pathway being considered. EPA is currently developing a guidance document for the sampling and analysis of fish tissue for issuing fish advisories. Representatives on the work group developing this guidance include NOAA, FDA, U.S. Fish and Wildlife Service, and 13 States. A draft of this document is due for release in October 1991.

Recommendation: Develop consistent methods for sampling and analyzing fish tissue for chemical contaminants designed specifically for risk assessment purposes.

Data on seafood consumption patterns in the United States are available on an average basis for the U.S. population. Standard values for seafood consumption rates have usually been based on previous analyses of dietary patterns of the U.S. population (USEPA, 1980; SRI, 1980). The NMFS seafood consumption study of 1973-1974 reported that the average U.S. per capita daily consumption of seafood was 18.7 grams, which could be subdivided into 6.5 grams of estuarine fish and shellfish, 2.0 grams of freshwater fish, 2.8 grams of marine fish, and the remaining 7.4 grams being primarily tuna and some unclassified imported fish. A figure of 6.5 grams per day for consumption of commercially and recreationally harvested fish and shellfish from estuarine and fresh waters was used by EPA (1980) to develop water quality criteria based on human health guidelines. This value is an average per capita consumption rate for the U.S. population based on the data of SRI (1980). Such a rate may not be protective of certain sensitive subpopulations such as recreational and subsistence fishermen.

The United States Department of Agriculture (USDA) accumulates fish consumption data by surveying customers and by collecting market data. The USDA Nationwide Food Consumption Surveys for individuals reported average fish consumption rates of 12 grams per day in 1977-1978; and 5, 11, and 21 grams per day in 1985 for children, women, and men, respectively. The USDA agricultural market survey data indicate a per capita intake of all fish (marine and freshwater) in 1983 of 18.4 grams per day, similar to that estimated by NMFS market data for per capita fish and shellfish consumption in 1986.

The EPA Office of Pesticide Programs (OPP) has examined the various surveys and market data available and concluded that the 1977-1978 USDA Nationwide Food Consumption Survey is the most reliable data base for this information, based on sample size and data collection methods. Data from this survey were employed to develop the EPA Tolerance Assessment System (TAS), which breaks down seafood consumption data by age group for the U.S. population.

Data available on fish and shellfish consumption in the United States are neither comprehensive nor current. The question of consumption rates in certain geographic or cultural subpopulations is a major source of uncertainty. Average daily seafood consumption rates do not adequately describe the dietary patterns of certain sectors of the U.S. population. For example, Finch (1973) estimated that 0.1 percent of the U.S. population consumes 165 grams per day of commercially harvested fish and shellfish. More recently, Pao et al. (1982) estimated that 5 percent of the U.S. population consumes in excess of 128 grams per day of fish and shellfish. High rates of consumption tend to be correlated with geographic and cultural patterns. Thus, Humphrey et al. (1976) reported that Great Lakes sport fishermen consumed an average of 31 grams per day of fish from Lake Michigan alone; one individual was reported to consume 10 times this amount. In another example of very high fish consumption, Marsh et al. (1974) described a group of fishermen in American Samoa that consumed up to 250 grams of fish per day. Additionally, the impact of the release of information advising the United States public to lower cholesterol levels on fish consumption patterns has yet to be evaluated. NOAA/NMFS is currently developing models for seafood consumption surveys suitable for risk assessment analysis.

Current and more specific information (e.g., surveys) on the consumption of fish and shellfish in this country, including quantitative intake, species, geographic origin, and methods of preparation would greatly improve our ability to estimate risks to human health associated with consumption of seafood. The consumption data presently in use were collected at least a decade ago, and their applicability to estimating the current consumption of seafood in this country is questionable. Methodologies for collecting data on fish consumption, as well as approaches for using limited data to estimate intake, should be improved. The surveys should include information on seafood consumption, not only on a national level, but also on a regional level because the consumption of seafood is determined to a great extent by regional factors (e.g., availability and access to fishery resources).

Recommendation: Design and conduct appropriate surveys on seafood consumption patterns suitable for risk assessment purposes relative to commercial, recreational, and subsistence fisheries.

Many agencies are concerned with potential human health effects associated with ingestion of contaminated fish that contain toxic chemical residues. In the past, several modeling approaches were developed for quantifying exposure and potential risk to human health including Cordle et al. (1978); U.S. Office of Technology Assessment (OTA) (1979); EPA (1980a, 1989); Food Safety Council (1980, 1982); Connor (1984); and Tollefson and Cordle (1986).

EPA (1989a), seeing the need for a standardized approach, has developed a guidance manual entitled *Assessing Human Health Risks from Chemically Contaminated Fish and Shellfish*. This manual describes the issues, uncertainties, and procedures for conducting a human health risk assessment for the fish ingestion pathway. In general, a chemical intake formula is used to estimate exposure and standardized toxicity criteria values developed by EPA (Integrated Risk Information System [IRIS] and Health Effects Assessment Summary Tables [HEAST]) are combined to estimate both potential carcinogenic and noncarcinogenic effects. In this guidance manual, exposure parameter values such as fish ingestion rate are summarized and site-specific rates are recommended for estimating exposure.

A study conducted by the American Fisheries Society, with a grant from EPA, identified developing consistent EPA/FDA risk assessments as one of the key actions for improving the fish advisory program. The report cited the need for consistent bioconcentration factors, slope factors (toxicity criteria that quantify the cancer potency of a chemical), and consumption rates. This need was later confirmed at a Federal-State forum held in Pittsburgh in 1990, where representatives from 27 States identified this issue as their number one priority.

A standardized approach for estimating exposure and risk from ingestion of fish, however, does not necessarily imply that standard exposure parameter values be used. Rather, it is recommended that site-specific values for parameters such as ingestion rate be used when available. Such region-specific values may be derived using an actual survey or using Geographic Information System (GIS) technology (USEPA, 1991a). It may be more appropriate to develop a standardized approach for estimating region-specific exposure parameter values rather than recommending specific values that should be applied in all regions. It should be noted, however, that region-specific surveys, may be too costly for many risk assessment projects.

Recommendation: Develop and recommend methods for assessing exposure and risk, particularly to high-risk groups, from seafood consumption.

Priority Issue: Human Health Concerns Associated with Exposure to Pathogenic Microorganisms and Marine Biotoxins in the Aquatic Environment

Information Need: Information on the Occurrence, Exposure, and Health Risk from Pathogenic Microorganisms and Marine Toxins in the Aquatic Environment Which Are Related to Marine Pollution. Human pathogens found in the marine environment include viruses, bacteria, protozoa, and fungi. Surface runoff and sanitary wastes discharged directly or indirectly (via rivers) into the marine environment may contain microorganisms that are capable of causing adverse human health diseases such as hepatitis and gastroenteritis, primarily when molluscan products are eaten raw or partially cooked or are mishandled or improperly prepared. In the United States, viruses and bacteria are the most important human pathogens, in terms of both the number of organisms released to the environment and the severity of the diseases they cause (OTA, 1987). People can be exposed to pathogens either directly from ocean water or indirectly through ingestion of contaminated seafood. Both pathways may be significant since as few as 10 to 100 bacteria are capable of inducing disease under the appropriate conditions (OTA, 1987); additionally, many pathogens can reproduce in wastes, contaminated media, and infected organisms.

The most prevalent illness via the recreational and shellfish transmission routes is a relatively benign illness, acute gastroenteritis (AGI), which is also spread by other routes of transmission (NAS, 1991). The Norwalk-like viruses have been increasingly shown to be the etiological agents responsible for AGI outbreaks that have resulted from consumption of contaminated seafood and from swimming in contaminated waters (Kaplan et al., 1982). Other pathogenic microorganisms responsible for causing AGI are presented in Table 7.1.

Systemic disease caused by *V. vulnificus* via the consumption of raw molluscan shellfish or infected wounds is very infrequent. Although the incidence is low, the morbidity and mortality rates are high. The fatal form of the disease, primary septicemia, occurs almost exclusively in compromised individuals, principally those with existing liver disease. The reported cases of primary septicemia from shellfish consumption have occurred exclusively with animals taken from coastal and estuarine waters in the Gulf of Mexico, although wound infections have a much wider geographic distribution.

Some microorganisms capable of causing human diseases occur naturally in the marine environment and may or may not be enhanced by marine pollution. For example, the association between marine pollution and increased incidence of health effects related to *Vibrio* species have not been well established. For the pathogenic microorganisms and marine toxins which are associated with marine pollution, further research is needed to improve our understanding of the cause- and-effect relationship between pathogens in the marine environment and adverse health effects. The association between exposure to human pathogens, either through ingestion of contaminated seafood or by swimming in contaminated water, and the development of human illness has been established for some agents such as enteric pathogens caused by certain viruses and bacteria. Diseases such as hepatitis, gastroenteritis, and cholera are known to be caused by water- and seafood-borne pathogens. However, many data gaps exist with regard to potential health risks from exposure to other pathogenic microorganisms such as *Vibrio* species.

Recommendation: Continue research to determine which marine pollution-related pathogens are causing human health effects.

Coliform bacteria standards have been employed for decades to monitor the quality of waters for swimming and shellfish harvesting (OTA, 1987; DHEW, 1965). However, fecal coliform standards as well as enterococcus standards have been questioned as true indicators of the overall potential for human disease from ingestion of seafood (Gerba et al., 1979; Portnoy et al., 1975).

Fecal coliform bacteria also are thought to be inadequate for predicting the risks associated with direct exposure to pathogens in the marine environment. In a study of New York beaches, Cabelli et al. (1979) presented evidence that measurable health effects are associated with swimming in sewage-polluted waters and that, in some cases, these effects were observed even in waters that were in compliance with existing recreational water quality guidelines and standards. Cabelli et al. (1982) expanded these studies to additional beaches in Louisiana and Massachusetts. Of the indicators quantified, the density of enterococci was highly correlated with the incidence of AGI among swimmers at both locations. Additionally, they reported that swimming-associated AGI symptoms were poorly correlated with fecal coliform densities, the indicator used most in Federal and State standards for recreational waters and seafood.

The standard criteria for evaluating water quality may be ineffective for many nonculturable pathogenic microorganisms. For example, Norwalk-like viruses are not culturable and there has been no method developed for enumerating this virus. Also, *V. cholerae* (Colwell et al., 1985), *Campylobacter jejuni* (Rollins and Colwell, 1986), and *Salmonellaenteritidis* (Roszak et al., 1984) may exist in a viable but nonculturable state in the marine environment. In the dormant state, the presence of these organisms cannot be detected using standard microbial assays. However, these pathogens

Table 7.1
Microorganisms Responsible for Causing Acute Gastroenteritis in Humans *

Pathogenic Organism	Seafood Source	Reference
Aeromonas hydrophilia and *Plesiomonas shigelloides*	Shellfish	Holmberg and Farmer (1984)
Vibrio mimicus	Raw oysters	Shandera et al. (1983)
Vibrio parahaemolyticus	Clams and snails	Roland (1979)
	Raw oysters Crab Shrimp Lobster	Nolan et al. (1984) Dadisman et al. (1973) Baker et al. (1974) Baker (1974)
Vibrio vulnificus	Raw oysters	Brady and Concannon (1984)
Vibrio cholerae 0 group	Raw oysters Boiled shrimp Boiled crab	Pollak et al. (1983) CDC (1980)
Vibrio cholerae Non-0 group 1	Raw oysters	Wilson et al. (1981) Morris et al. (1981) CDC (1979)
Norwalk virus	Raw oysters	Linco and Grohmann (1980)
	Raw clams	Murphy et al. (1979) Guinn et al. (1982) CDC (1982)
Small round structured virus	Raw oysters	Gill et al. (1983)
Campylobacter jejuni	Raw clams	Griffen et al. (1983)

* Includes naturally occurring microorganisms as well as microorganisms associated with pollution.

may be "reactivated" within a suitable host organism (Colwell et al., 1985; Grimes et al., 1986). Thus, the apparent lack of human pathogens in the open ocean and near-shore coastal waters may simply reflect an inability to detect these potentially viable, but non-culturable microorganisms (Grimes, 1986). Therefore, water quality standards based on the direct enumeration of these pathogenic microorganisms would be preferred.

The ineffectiveness of MPN and fecal coliform indicators to predict the potential for an adverse health effect has led government agencies and researchers to find new methods of directly detecting pathogenic microorganisms of concern. Recently developed monoclonal antibody and gene probe techniques permit the direct detection and quantification of both culturable and nonculturable microorganisms. Polymerase chain reaction (PCR), which is a nucleic-acid sequence-amplification technique, can be used to detect a single virus in a sample. Fluorescent antibody detection is another technique for direct detection of pathogens. Since these methods have the ability to detect nonculturable organisms, they may serve as more precise techniques for monitoring microbiological water quality.

NOAA investigators are conducting research to detect and quantify pathogens in marine water and shellfish. These projects include a study by the NOAA/NMFS Charleston Laboratory to develop and evaluate methods for extracting and assaying enteric viruses such as hepatitis A virus and Norwalk virus from molluscan shellfish. NOAA Sea Grant-sponsored research is being conducted at the Baylor College of Medicine to evaluate the merits of a new A-ELISA test for detection of hepatitis A virus in the estuarine environment and to determine the extent of hepatitis and rotavirus occurrence in polluted waters. FDA also has developed an ELISA test for *V. vulnificus.* A serological test for identification of species of *Vibrio* is under development by the Louisiana Sea Grant College Program. At the University of Maryland, an epidemiological study of the microbiological hazards associated with diving in polluted waters is currently being conducted. These researchers also are studying the feasibility of adapting rapid serological techniques for use in a field hazards test kit for divers. New Hampshire Sea Grant researchers are working on gene probes for Hepatitis A virus, Norwalk viruses, and *V. vulnificus.*

Traditional indicators of microbial contaminants appear to be inadequate for predicting human health risks associated with both consuming molluscan shellfish and swimming in waters that contain sewage-associated viruses, naturally occurring bacteria, and, occasionally, sewage-associated bacteria. The need exists to identify microbial indicators specific to human fecal wastes that survive wastewater treatment, disinfection, and residence in marine waters and that are effective in predicting the presence of viral pathogens. Methods suitable for the direct detection of pathogens of concern also need to be developed and implemented. An effective approach to identifying appropriate indicators and pathogens of concern may include the implementation of a battery of tests. The feasibility of using new methodologies such as monoclonal antibody and gene probe techniques should be compared to existing methods such as fecal coliform Most Probable Number (MPN) to determine the most useful methods. There is a need to provide States with assistance and guidance in the formulation of State and even site-specific standards.

Human disease is also caused by naturally occurring marine toxins. Three of these of direct significance to the U.S. consumer are ciguatera, paralytic shellfish poisoning (PSP), and scombroid poisoning. Prevention of ciguatera and PSP is possible only by interdiction of the supply. The presence of these toxins cannot be detected organoleptically, and no reliable tests are available. Research is needed to develop simple, rapid tests for these toxins as well as to develop predictive indices that can be used to close areas to fishing before human intoxications occur.

Recommendation: Continue efforts to improve our ability to monitor seafood and water quality for the human pathogens and marine biotoxins associated with marine pollution, including development of rapid detection methods.

To develop methods for controlling pathogenic microorganisms, it is necessary to understand the life cycles and routes of transmission of these organisms. For example, it is known that some bacteria (including human pathogens) in the marine environment may remain in a dormant state and retain their viability for extended periods of time (e.g., months to years). *V. cholerae* (Colwell et al., 1985), *V. vulnificus* (Grimes, 1991), and *Salmonella enteritidis* (Roszak et al., 1984) may exist in a nonculturable dormant state while in the marine environment, but may again be reactivated in the host organisms (Colwell et al., 1985; Grimes et al., 1986). Also, basic research on the survivability of the HIV virus needs to be done to determine whether this virus may be transferable to humans via ingestion of shellfish grown in areas contaminated with fecal wastes or via abrasions exposed to contaminated seawater. Basic research on the Norwalk-like viruses also needs to be done. Research in the following areas may assist in our understanding of the survivability, transmission, and life cycles of pathogenic microorganisms (including those that produce marine toxins):

- Environmental factors that influence population densities of pathogenic microorganisms;
- The survivability of pathogenic microorganisms in certain marine environments;
- Transfer of pathogens through the food chain; and
- Dormancy of pathogens during certain environmental conditions.

> Recommendation: *Continue research on the survivability and transmission of pathogenic microorganisms and biotoxins.*

Information Need: Methods for the Removal, Reduction, and/or Inactivation of Pathogenic Microorganisms and Marine Toxins from the Marine Environment and Fish Tissue. The NAS (1991) concluded that the health risks associated with exposure to pathogenic microorganisms and marine toxins may not be adequately controlled by increasing seafood inspection efforts (e.g., organoleptic inspection system). Rather, efforts should be focused on reducing contamination in the marine environment and ensuring that fish are harvested in a cleaner environment. Thus, effective treatment of municipal effluents and sewage sludge is an important method for reducing the potential exposure and risk associated with ingestion of fish.

As previously discussed, chlorination is the most commonly used disinfection technique in the United States (OTA, 1987). However, a growing body of evidence suggests that present methods and technologies vary in their effectiveness depending upon the particular type of pathogen. Conventional treatment processes (e.g., chlorination, thermal activation, anaerobic digestion, liming) can destroy some of the microorganisms present in municipal wastewaters (OTA, 1987). The effectiveness of the process depends on the techniques employed, the operating conditions, and the organisms in question. Waterborne pathogens have a wide range of susceptibility to disinfection techniques. Miescier and Cabelli (1982) noted that viruses are relatively resistant to chlorination, especially the Norwalk virus, and there are potential ecological and health effects associated with its use. Secondary treatment does decrease the bacterial indicator levels by about 10- to 30-fold. Nevertheless, the post-secondary levels are still considerably higher than those of the resource standards. Additional dilution can be achieved when the effluent is discharged into receiving waters. The degree of effectiveness of these processes against bacteria is generally high, but they are not particularly effective against viruses and parasites such as protozoan cysts (Miescier and Cabelli, 1982; OTA, 1987).

It has been known for some time that most of the "culturable" human enteric viruses, notably poliovirus and adenovirus, survive wastewater chlorination and residence in marine systems and molluscan shellfish better than do the coliform indicators. The survival of enterococci in marine waters and shellfish was found to be better than that of the coliform in marine waters. In addition, viable coliforms cannot be recovered from hard clams, *Mercenaria mercenaria*, residing in highly polluted waters during the winter in temperate zones. Also, chlorination of conventional secondary-treated wastewater effluents, under conditions that can markedly reduce the levels of poliovirus 1 and simian rotavirus and hence those of the coliform and enterococcus indicators, is minimally effective against the Norwalk virus and the F male-specific bacteriophage, f-2.

Several approaches have been proposed and studied for eliminating pathogenic microorganisms that cannot be removed by conventional methods. One approach is further nitrification treatment followed by breakdown chlorination to achieve a full chlorine residual. Free chlorine over short contact periods effectively inactivates the Norwalk virus. However, this practice raises the additional concern of increasing the levels of chlorinated byproducts in the environment. Of particular concern are low-molecular-weight halogenated hydrocarbons such as chloroform, bromo dichloro- methane, and dibromochloromethane. The extent and significance of occurrence of known and suspected carcinogens (e.g., trihalomethanes) was the principal objective of an early nationwide survey of organic chemicals in drinking water conducted by the EPA (USEPA, 1975). Additional research has focused on determining the mutagenicity, carcinogenicity, and target organ (renal, reproductive, and endocrine system) toxicity effects of disinfectants and disinfectant byproducts (NIEHS, 1986). However, a number of uncertainties exist with regard to the human health risk from exposure to these compounds; therefore, research is still needed to determine the effects of disinfectants and disinfectant byproducts on human health.

A second approach is the use of alternative disinfectants, including ultraviolet light (UV), ozone, bromide, chloride, and chlorine dioxide. To optimize inactivation of these viruses, most, if not all, of these alternative disinfectants may require reduction of suspended solids and/or organic loads beyond those obtained with conventional secondary treatment. Biotechnological approaches could be useful in this regard. Although ozone and chlorine dioxide have been used more extensively in Europe (Engineering News Record, 1985; SAIC, 1986), primarily for the disinfection of drinking water, the most widely used alternative disinfectant in the United States has been ultraviolet and gamma radiation, probably because the process does not require a chemical additive (OTA, 1987). These techniques, however, may be difficult and expensive to apply.

The third approach has been to improve the physical removal of the pathogens, especially the viruses. Historically, this has been accomplished (following secondary treatment) by sand filtration or the addition of flocculating agents such as alum, lime, or synthetic agents. Lime application has the additional advantage that viruses are inactivated at the high pH levels achieved. Practical and logistic problems, however, are associated with all of these alternatives.

Alternative treatment systems and methods need to be developed that are highly effective against these pathogens where present treatment processes have a limited impact. These methods should be developed using a multidisciplinary approach and coordinated with possible nutrient and toxic chemical removal efforts. Studies on the effectiveness and environmental implications of alternative treatment processes would be valuable, especially concerning the effectiveness against the release of hepatitis A and Norwalk viruses.

Septic waste systems are commonly used for domestic sewage treatment in many coastal communities adjacent to shellfish-growing areas. These systems commonly fail, or are subject to improper or faulty operation owing to poor soil drainage characteristics, seasonally high water tables, or owner bypass/modifications. The degree of disinfection provided by such marginal systems should be evaluated as a potential contributor to nonpoint source pollution in impacted shellfish-growing areas. Overboard discharges of wastes from pleasure craft also have had a significant impact on harbor areas and shellfish beds. These wastes must also be evaluated.

> *Recommendation: Develop methods to remove and/or inactivate the human pathogens such as Norwalk-like viruses found in municipal effluents and sewage sludge.*

Even with the best treatment technologies to reduce marine pollution, there is still the potential for seafood to be contaminated with pathogenic microorganisms and marine toxins. Self-cleaning of shellfish after transplanting from contaminated to cleaner waters (i.e., depuration) may not reduce levels of certain pathogenic microorganisms and marine toxins. Therefore, it is recommended that the effectiveness of techniques such as depuration for removing or reducing pathogenic microorganisms and marine toxins from shellfish be studied.

Several other methods have been proposed for reducing the levels of pathogens in fish. Low-dose gamma radiation has been shown to be effective in reducing the number of *Vibrio* species in shellfish (Giddings, 1984; NAS, 1991.) Various preprocessing methods such as refrigeration also can be effective in reducing the population growth of bacteria in seafood (Cook and Ruple, 1989). Freezing seafood before raw consumption or properly cooking seafood may significantly reduce the levels of pathogenic microorganisms (NAS, 1991). Changes in harvesting time also may reduce levels of pathogenic microorganisms in fish tissue. For example, there is evidence to suggest that harvesting shellfish when water temperatures are high may reduce the amount of *Vibrio* species in shellfish (NAS, 1991).

> *Recommendation:* *Conduct research to develop cost-effective means for removing, reducing, and/or inactivating chemical contaminants and/or pathogens in fish.*

Conclusions

A number of toxic substances and human pathogens that have the potential to cause adverse human health effects have been identified in the marine environment. Although the presence of these agents in the marine environment does not alone constitute a public health risk, it does suggest that some potential health risk may be present if humans are exposed to these agents. The likelihood of developing adverse health effects from these substances is a result of the toxicity or pathogenicity of the agent and the extent to which the population is exposed. The following conclusions concerning human health implications of marine pollution are based on the discussions of the priority issues and information needs presented in the previous sections:

- For evaluating the impact from exposure to chemical contaminants in fish, existing Federal and State monitoring programs provide limited data on the concentrations of chemical contaminants (including biocides used in aquaculture) in edible tissues of commercial and recreational fish species and the recommended analytical methods are not consistent. In addition, there is limited information on seafood consumption patterns suitable for risk assessment purposes relative to commercial, recreational, and subsistence fishermen. There is also a lack of consistent approaches for quantifying exposure and risk from ingestion of contaminated fish. Regulatory programs could be made more effective if these inadequacies were resolved and if a consistent approach for evaluating these impacts were adopted.

- Governmental programs, such as the National Shellfish Sanitation Program, have been largely effective in protecting the public from enteric diseases such as hepatitis, cholera, and typhoid, as well as from biotoxin poisoning associated with the consumption of molluscan shellfish. However, sporadic outbreaks of illness, primarily associated with free-living, opportunistic *Vibrio* species, gastroenteritis-causing viruses, and biotoxins still occur. Research is needed to determine whether microorganisms and marine toxins are actually associated with marine pollution. For the pathogens that are associated with marine pollution, more information is needed on the exposure and health risk from pathogenic microorganisms in the aquatic environment, as well as the survivability and transmission of these pathogens. There also is a need to develop and apply modern techniques for directly enumerating populations of pathogenic microorganisms such as *Vibrio* species and Norwalk-like viruses in surface water as well as fish. These methods can be used to establish water quality criteria specific to the pathogen of concern in order to make the advisories effective in reducing risk.

- The NAS (1991) concluded that the health risks associated with seafood should be handled by control of harvest or the point of harvest rather than by increased inspection of seafood. Thus, efforts should be focused on ensuring that the fish are grown in a cleaner marine environment. Current methods for the removal and inactivation of human pathogens are effective in controlling the input of most enteric bacteria to the marine environment but not for other important pathogens such as the Norwalk-like viruses. There is a need for effective methods to remove and/or inactivate human pathogens from municipal effluents and sewage sludge. In addition, there is a need for practical and cost-effective methods for reducing and/or inactivating human pathogens and marine toxins in fish.

Based on these conclusions, the recommendations below are made to improve our understanding of the implications of marine pollution to human health.

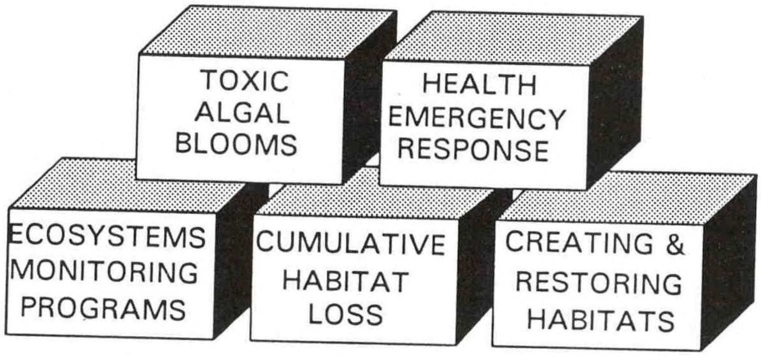
Recommendations

Chemical Contamination

- Develop consistent methods for sampling and analyzing fish tissue for chemical contaminants designed specifically for risk assessment purposes.
- Design and conduct appropriate surveys on seafood consumption patterns suitable for risk assessment purposes relative to commercial, recreational, and subsistence fisheries.
- Develop and recommend methods for assessing exposure and risk, particularly to high-risk groups, from seafood consumption.

Pathogenic Microorganisms and Marine Biotoxins

- Continue research to determine which marine pollution-related pathogens are causing human health effects.
- Continue efforts to improve our ability to monitor seafood and water quality for the human pathogens and marine biotoxins associated with marine pollution, including development of rapid detection methods.
- Continue research on the survivability and transmission of pathogenic microorganisms and biotoxins.
- Develop methods to remove and/or inactivate the human pathogens such as Norwalk-like viruses found in municipal effluents and sewage sludge.
- Conduct research to develop cost-effective means for removing, reducing, and/or inactivating chemical contaminants and/or pathogens in fish.



Chapter VIII

Priorities for Action

An Action Agenda will be undertaken by the National Ocean Pollution Policy Board over the next 3 years. As was described in Chapter I, the Policy Board is composed of senior-level representatives from those Federal agencies whose mandates cover ocean pollution. In each iteration of the 5-Year Federal Plan for Ocean Pollution Research, Development, and Monitoring, the Board outlines an agenda for itself for the period between Plans. This agenda is composed of priority activities that require and would benefit from an interagency task group approach.

For example, the 1988 Federal Plan identified a number of tasks for the Board to consider. From 1988 to 1991, some of the specific tasks that were supported by the Board were undertaken within the Federal agencies, such as EPA's workshop and report on the atmospheric deposition of nitrogen and toxics to estuaries and the FDA and EPA studies on seafood consumption patterns. The Board also established two ad hoc working groups to report on Monitoring Environmental Quality of Marine Ecosystems and Habitat Loss and Modification. Recommendations from the reports of these working groups appear below as action items for Board consideration during this upcoming interim.

The five action items that the Board has chosen to consider during the period beginning in 1992 relate to the Goals of the National Plan and to ongoing issues of coordination and cooperation and/or to issues that the Board has recognized as growing in significance over the next set of years. The action items listed below will be described individually; no ranking is implied.

Action Items

Toxic Algal Blooms

Need: The frequency, extent, and effects of toxic algal blooms seem to be increasing as is discussed in Chapter III on nutrients. These blooms are thought to be correlated with worsening coastal conditions on a global scale and are disruptive to fishery and tourist industries as well as posing human health problems.

Both national and international activities are under way. Currently within the Federal agencies, a NOAA Sea Grant Task Force is evaluating the state of knowledge regarding harmful blooms and recommending research priorities. The Nutrient Enhanced Productivity theme area of NOAA's Coastal Ocean Program is developing a research program on toxic algal blooms. The Program will focus on understanding the conditions that cause and exacerbate blooms with the objective of predicting blooms in order to take action to reduce damage to living marine resources.

The Board will consider convening an interagency committee to coordinate and complement ongoing Federal activities. The tasks the committee may undertake include:

- Report on the present problem and science;
- Identify related Federal programs and activities;
- Identify research and information gaps in current programs; and
- Develop recommendations for research, development, and monitoring.

Public Health Emergency Response Mechanism

Need: The human health risks from a toxic pollution-related event, whether natural or anthropogenic, are of growing concern to the regulatory community. Some of these issues were discussed in Chapter VII on human health. At the present time, there is no consistent emergency response mechanism to protect public health from contaminated marine waters or resources.

The Board will consider convening an ad hoc working group to address emergency response issues. The tasks the working group may undertake include:

- Inventory current Federal and State emergency response procedures;
- Develop surveillance and information reporting procedures for responding to emergency situations related to human health risks from marine pollution events; and
- Recommend research to:
  - Validate sublethal toxicological effects through laboratory and field tests of select chemicals and test organisms,
  - Develop indicators of unacceptable levels of contamination or infection of marine resources (from the perspective of risk to human health), and
  - Develop monitoring tools to assist in recognizing the presence and levels of toxicants and their sublethal effects.

Marine Ecosystems Monitoring Programs

Need: There is a need to improve coordination among existing Federal marine ecosystems monitoring programs in order to meet the following objectives:

- Enhance comparability of data;
- Facilitate exchange and synthesis of data;
- Avoid duplication of effort; and
- Ensure that national needs are met.

This issue and current Federal agencies' activities relating to coordination and comparability are discussed in Chapter VI on the status of marine ecosystems. A related recommendation is included in the report of the Working Group on Monitoring Environmental Quality of Marine Ecosystems (Kiraly et al., 1991) convened after the 1988 Plan was written.

The Board will consider convening a technical working group to:

- Provide specific recommendations for coordination;
- Develop ways to improve
  - Quality assurance/quality control,
  - Parameter selection procedures,
  - Data management, and

- The types of ancillary data collected; and

- Recommend research with regard to

  - Early indicators of marine ecosystem stress,

  - Population dynamics of indicator species,

  - Models correlating ecosystem change to population change,

  - Protocols for defining and measuring ecosystem change, and

  - Validation of predictive tools.

Cumulative Habitat Loss

Need: Coastal wetlands are of fundamental importance to the support of nearshore fisheries. At the present there is no comprehensive mechanism to document the cumulative conversion of wetlands through the construction permitting processes of Section 404 of the Clean Water Act and Section 10 of the River and Harbors Act. The absence of such a data base is compounded by the difference between what is actually lost due to a project versus what loss the permit allows.

The issue of wetland loss is discussed in Chapter V on habitats. The Working Group on Habitat Loss and Modification, convened after the 1988 Plan was written, recommended that the cumulative problem be addressed, perhaps using the Corps of Engineers' Regulatory Analysis Management System (RAMS) as the starting point for a national data base (Kiraly et al., 1990).

The Board will consider convening a working group consisting of the Corps of Engineers and other Federal agencies to explore opportunities for developing RAMS into a data base system that would be useful to all agencies involved in the permit reviewing and/or granting process in order to document the cumulative loss of wetlands.

Restoration and Creation of Coastal Habitats

Need: The restoration and creation of coastal habitats has emerged over the last few years as a priority concern. The concern stems from the realization of how critical habitats are to the productivity of living marine resources and to the environmental services provided such as buffering storm surges and enhancing water quality.

This issue is discussed in Chapter V on habitat and was also considered by the Working Group on Habitat Loss and Modification, which recommended coordination of Federal efforts (Kiraly et al., 1990).

The Board will consider convening a technical working group to provide specific recommendations for coordinating coastal habitat restoration and creation research among Federal agencies.

List of Acronyms

AGI	acute gastroenteritis
ANICA	Atmospheric Nutrient Input to Coastal Areas
APHIS	Animal and Plant Health Inspection Service
ARS	Agricultural Research Service
ATCC	American Type Culture Collection
BRS	Biotechnology Research Subcommittee
CEQ	Council on Environmental Quality
COE	U.S. Army Corps of Engineers
COP	Coastal Ocean Program
CSO	combined sewer overflow
CSRS	Cooperative State Research Service
DDT	p,p^{1} - Dichlorodiphenyltrichloroethane
DHHS	Department of Health and Human Services
DNA	deoxyribonucleic acid
DO	dissolved oxygen
DOC	Department of Commerce
DOE	Department of Energy
DOI	Department of the Interior
DOT	Department of Transportation
EHP	Estuarine Habitat Program
EMAP	Environmental Monitoring and Assessment Program
EMAP-NC	Environmental Monitoring and Assessment Program - Near Coastal Component
EPA or USEPA	Environmental Protection Agency (U.S.)
FAO	United Nations' Food and Agriculture Organization
FDA	Food and Drug Administration
FGDC	Federal Geographic Data Committee
FS	Forest Service
FWPCA	Federal Water Pollution Control Act
FWS	Fish and Wildlife Service
GEM	genetically engineered microorganism
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Pollution

GIS	Geographic Information System
GLERL	Great Lakes Environmental Research Laboratory
HAV	Hepatitis A virus
HC	hydrocarbon
HEAST	Health Effects Assessment Summary Tables
IHN	infectious hematopoietic necrosis
IMO	Intergovernmental Maritime Organization
IPN	infectious pancreatic necrosis
IRIS	Integrated Risk Information System
JOI	Joint Oceanographic Institutions
LMER	Land-Margin Ecosystem Research
LTER	Long-Term Ecological Research
LTMS	Long-Term Management Strategy
MFO	mixed function oxidate
MMS	Minerals Management Service
MPCA	Microbial Pest Control Agents
MPN	most probable number
MPRSA	Marine Protection, Research and Sanctuaries Act
NAPINet	National Animal Poison Information Network
NAS	National Academy of Sciences
NASQUAN	National Stream Quality Accounting Network
NAWQA	National Water Quality Assessment Program
NECOP	Nutrient-Enhanced Coastal Ocean Productivity
NEFC	Northeast Fisheries Center
NEP	National Estuary Program
NESDIS	National Environmental Satellite, Data, and Information Service
NIEHS	National Institute of Environmental Health Sciences
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NMFS	National Marine Fisheries Service
NMPIS	National Marine Pollution Information System
NOAA	National Oceanic and Atmospheric Administration
NOCN	NOAA's Ocean Communications Network
NODC	National Oceanographic Data Center
NOPP	National Ocean Pollution Program

NOPPA	National Ocean Pollution Planning Act
NOPPO	National Ocean Pollution Program Office
NOS	National Ocean Service
NRC	National Research Council
NSF	National Science Foundation
NSG	National Sea Grant Program
NSP	neurotoxic shellfish poisoning
NS&T	National Status and Trends
NWI	National Wetlands Inventory
OAD	Ocean Assessments Division
OAR	Office of Oceanic and Atmospheric Research
OCS	outer continental shelf
OMB	Office of Management and Budget
OPDIN	Ocean Pollution Data and Information Network
OPP	Office of Pesticide Programs
ORD	Office of Research and Development
OTA	Office of Technology Assessment
OWOW	Office of Wetlands, Oceans and Watersheds
PAH	polyaromatic hydrocarbon
PCB	polychlorinated biphenyls
PCR	polymerase chain reaction
PERL	Pacific Estuarine Research Laboratory
POES	Polar-orbiting Operational Environmental Satellites
POTW	Publicly-Owned Treatment Works
PSP	paralytic shellfish poisoning
QA	quality assurance
RAMS	Regulatory Analysis Management System
RNA	ribonucleic acid
ROMP	Registry for Marine Pathology
RTLA	Registry of Tumors in Lower Animals
SAV	submerged aquatic vegetation
TAS	Tolerance Assessment System
TOXICS	Toxic Substances Hydrology Program
USDA	United States Department of Agriculture
UV	ultraviolet light

VEN	viral erythrocytic necrosis
VHS	viral hemorrhagic septicemia

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Appendix A

Agency Funding Trends and Programs Under the National Ocean Pollution Program

FUNDING TRENDS

Funding for the National Ocean Pollution Program (NOPP) has shown a steady upward trend from fiscal year 1987 through the Presidential budget requests for 1992 (Figure 1 and Table 1). Over the 6-year period, the rise is 82 percent; for the 3 years starting in 1990, that number is 64 percent. Between 1991 and 1992 the projected rise in expenditures for marine pollution is $29 million. The major part of this rise is expected to go to programs that have a high priority on the national agenda. The distribution of funding under NOPP by agency for 1992 is shown in Figure 2. The U.S. Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce (DOC), and the U.S. Department of the Interior (DOI) together account for about 81 percent of the 1992 NOPP requested funding.

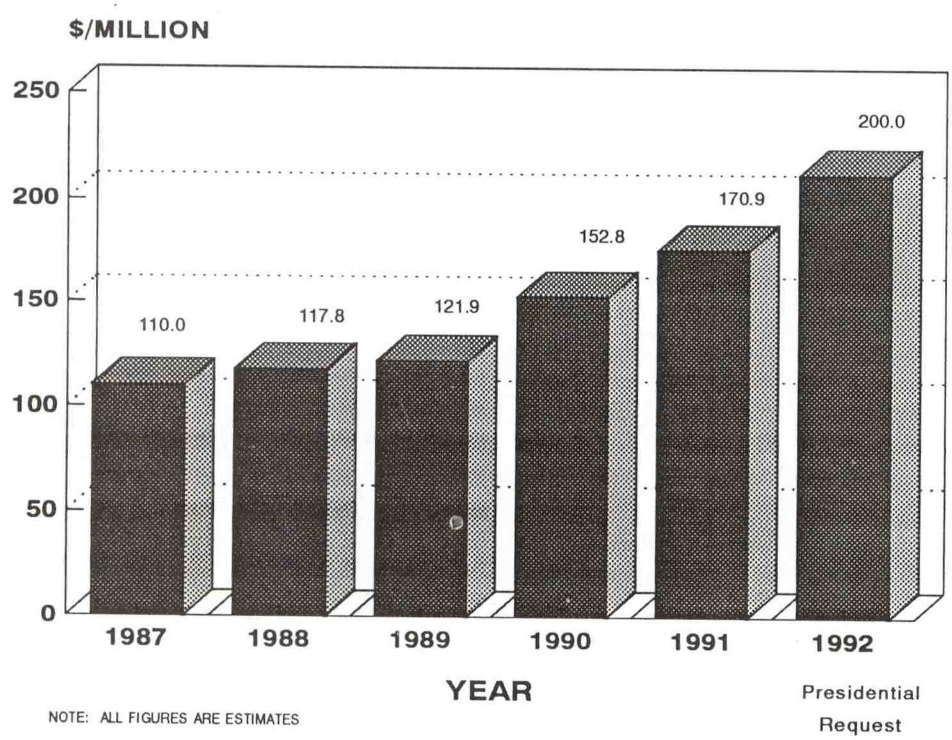

Figure 1. Funding trends under NOPP

Table 1. National Ocean Pollution Program Funding Levels: FY 1987 - 1992 (funding in thousands of dollars)[a]

Agency	FY1987 Estimates	FY1988 Estimates	FY 1989 Estimates	FY 1990 Estimates	FY 1991 Estimates	FY 1992 Presidential Budget
CEQ	0	9	5	9	15	30
USDA	3,395	3,261	3,667	3,848	3,910	3,688
DOC						
NIST [b]	0	0	0	0	0	0
NOAA	30,400	28,953	32,639	46,776	46,365	53,116
DOD						
COE	8,996	8,500	10,190	11,463	10,720	15,177
Navy	1,575	1,235	720	900	600	650
DOE	6,895	6,095	5,950	5,847	5,504	5,587
DHHS						
NIEHS	350	3,349	3,457	3,240	3,370	3,488
FDA	2,840	4,332	4,648	4,728	4,974	6,600
DOI						
MMS	17,387	19,758	15,299	18,500	20,439	32,439
FWS	5,546	5,493	4,516	6,620	7,120	6,300
USGS	2,583	2,783	2,452	950	7,770	7,750
DOT						
USCG	600	1,744	1,530	3,080	2,350	2,470
EPA	28,625	31,715	36,269	46,290	57,235	62,110
NASA	480	480	536	536	563	585
NSF	690	142	50	0	0	0
TOTAL	110,011	117,849	121,928	152,787	170,935	199,990

a Information from NOPPB, 1991.

b All marine pollution-related activities at NIST are carried out on a reimbursable basis; therefore, no funding is listed.

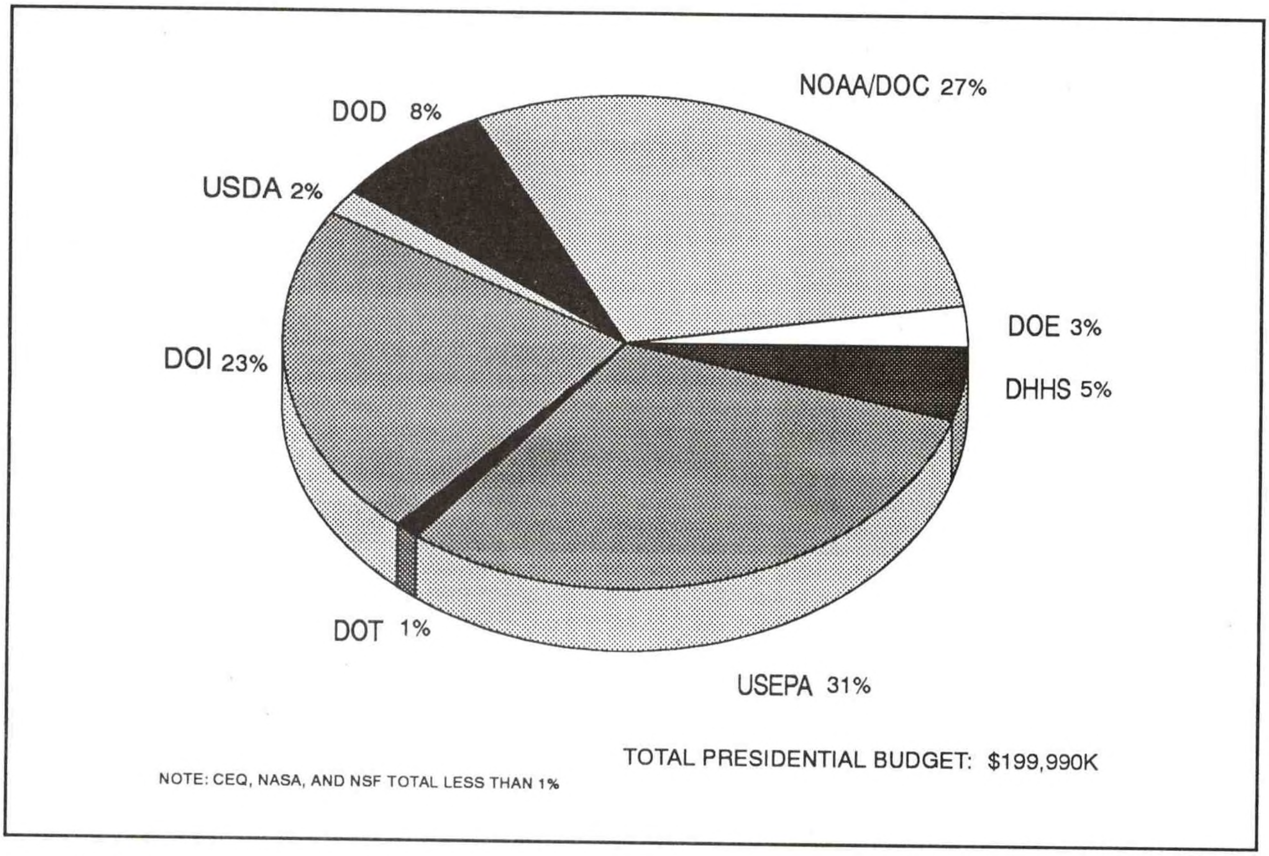

Figure 2. Distribution of FY 1992 funding requests by agency

Programs with Major Funding Increases. The following discussion is based on the FY 1992 Presidential submission to Congress (NOPPB, 1991). For fiscal 1992, NOAA has requested an additional $6.2 million for the Coastal Ocean Program and $2 million for studies in Prince William Sound, the site of the *Exxon Valdez* oil spill. NOAA's Coastal Ocean Program is a multifaceted NOAA effort addressing three themes: 1) coastal ocean pollution and habitat degradation, 2) coastal fisheries productivity, and 3) protection of life and property. The Program focuses on five critical areas within these themes including nutrient overenrichment, estuarine habitat alterations, coastal fishery ecosystems, toxic chemical contamination, and coastal hazards. NOAA's Prince William Sound studies will evaluate the impacts of the oil spill on the living marine resources of the Sound.

EPA has asked for a $4.1 million increase in its Great Lakes Research Program and a $4.3 million increase in its Environmental Monitoring and Assessment Program (EMAP). The Great Lakes Program focuses on the development and testing of methods, models, and data bases to predict the fate and effects of toxic substances on the Great Lakes ecosystem. The additional funding in 1992 would be used to support research into zebra mussel impacts, modeling of toxic chemical dynamics, and the study of contaminated sediments. EPA's EMAP is both a terrestrial and marine monitoring program. The additional funding under NOPP in FY 1992 will be used to study ecological conditions in coastal waters and to expand research and monitoring programs for measuring a wide spectrum of contaminants.

Responding to an effort to increase domestic oil and gas production, the Minerals Management Service (MMS/DOI) has asked for an additional $12 million to support its Headquarters and its Regional Studies Program, which develops environmental analyses of outer continental shelf areas to determine their suitability for marine mining. The Army Corps of Engineers (COE) of the U.S. Department of Defense is to receive an additional $4 million under its Environmental Analysis Research and Development Program to expand its wetlands research in response to the President's policy for "no net loss" in these important coastal areas. Mirroring a heightened public concern about the human health aspects of marine pollution, the Food and Drug Administration (FDA) of the U.S. Department of Health and Human Services (DHHS) has requested a $1.6 million increase for its Seafood Safety and Contamination Program. More detailed descriptions of these programs appear below in the section entitled "Agency Programs."

Project Trends Analyses. The National Marine Pollution Information System (NMPIS) tracks funding for projects in the NOPP. Using the base period 1984 to 1989 (the most recent year for which funding breakdowns are currently available), it is possible to identify some changes that have taken place in the emphasis of projects under NOPP.

Region and Zone. Figure 3(a) shows trends in funding by geographic region. The Atlantic Coast continues to draw a major share of funding for pollution projects with approximately 35 percent of the region-specific funding in 1989. Over the period, the regions, with minor fluctuations, tended to maintain their percentage of funded studies. On the other hand, Figure 3(b) indicates a clear shift away from projects that study the oceans and the outer continental shelf (OCS) to those studying coastal and estuarine areas. This reflects a decline in funding of projects related to dumping in the ocean and a decline in the study of impacts of marine mining and radionuclide fates and effects on the outer continental shelf. Increasing support is being given to projects identified with pollution related to nearshore development.

Pollutants. Trends in funding for major pollutant groups receiving monies identified as specific to that pollutant are shown in Figures 4(a) and 4(b). Figure 4(a) indicates that funding for projects concerned with petroleum have shown a decline between 1984 and 1989 of about 37 percent. This coincides with the drop in the study of marine mining as a cause of pollution. In 1984 over 26 percent of NMPIS projects that identified the study of a specific cause of pollution listed marine mining as that cause; in 1989 that number dropped to 9 percent. A period of re-evaluation on nuclear power development has resulted in a downturn in the amount of funding under NOPP for the study of radionuclides in the marine environment. As Figure 4(b) shows, projects involved with radionuclides received over $8 million of funding in 1984, but by 1989 that figure was under $1 million, a drop of 91 percent. On the other hand, there has been a significant upturn in projects identified with habitat modification and sediment disposal, rising some 35 percent from 1984 to 1989.

Project Activity. An analysis to be drawn from comparing funding for projects from 1984 through 1989 is that there is a decline in those which identify their major activity as "research." Research is defined to include projects that develop new knowledge concerning the characteristics of the marine environment, pollutant effects, pollutant concentrations, transport and transformation, or pollutant origin. The decline in the funding for such research has been 44 percent. On the other hand, funding for projects identifying their major activity as monitoring rose almost 45 percent, and those identifying data interpretation/application as a project activity rose nearly 300 percent (Figure 5).

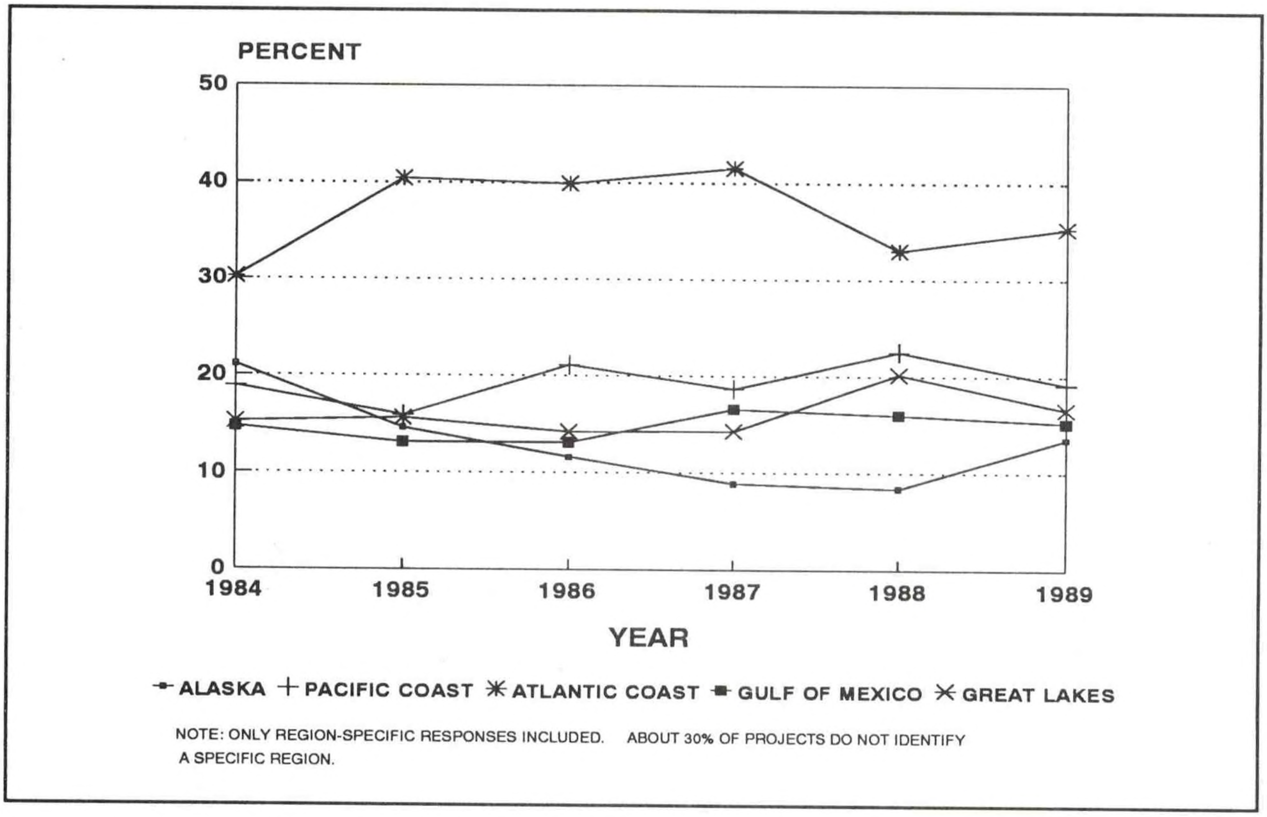

Figure 3(a). Trends in percent of funding by region 1984-1989

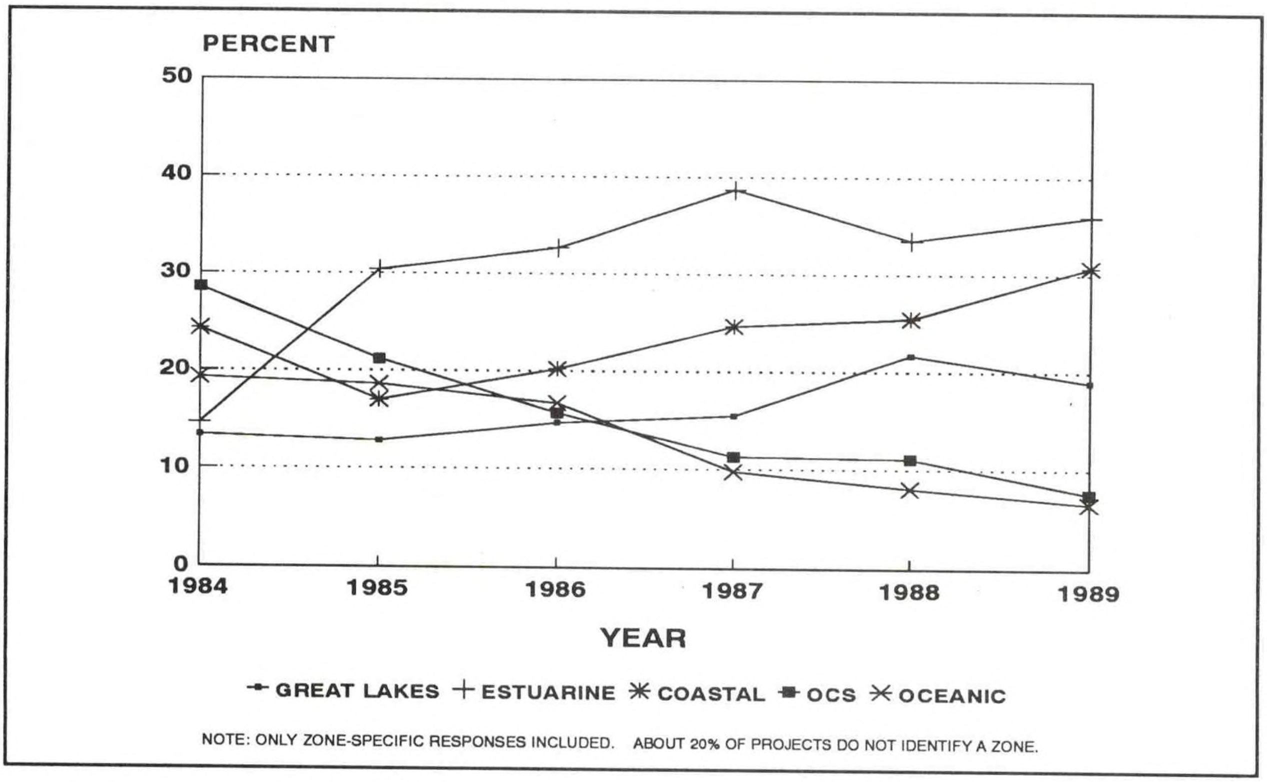

Figure 3(b). Trends in percent of funding by zone 1984-1989

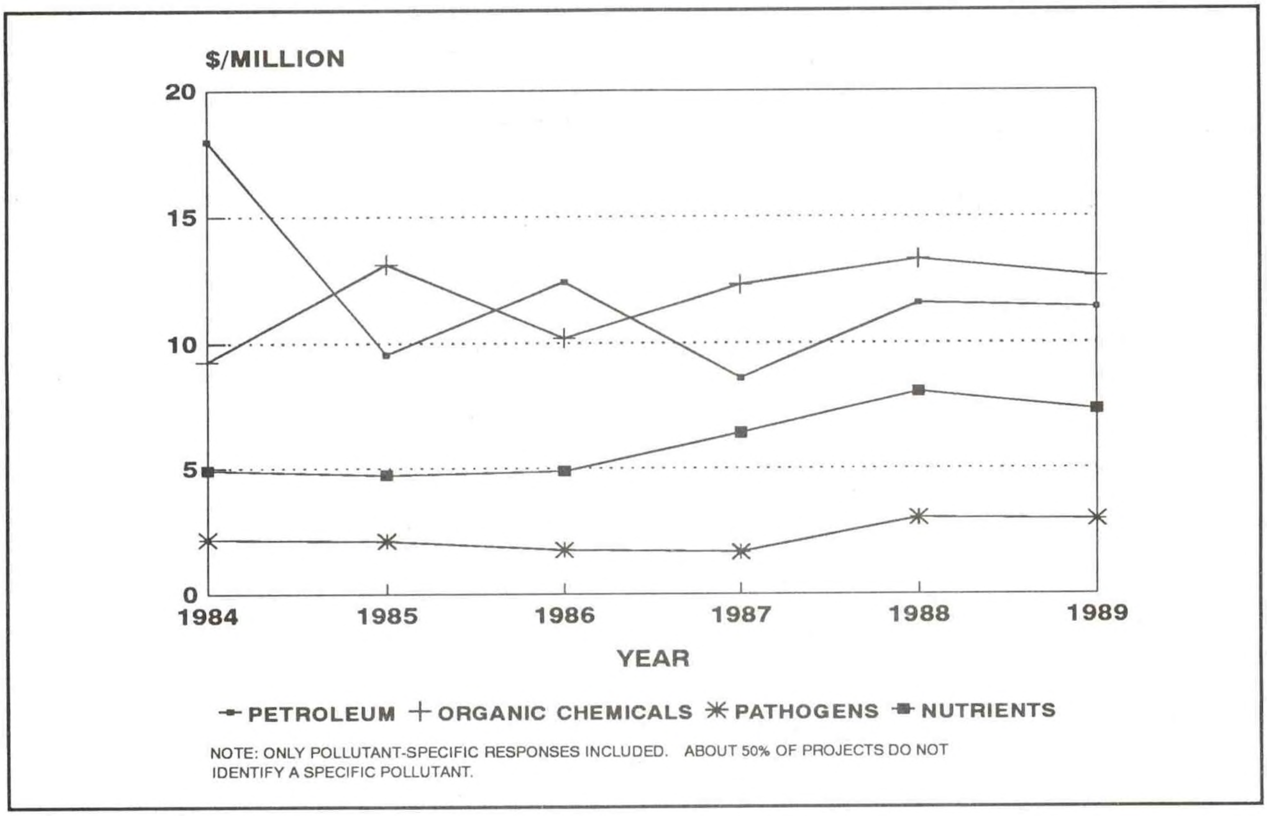

Figure 4(a). Trends in funding for pollutants 1984-1989

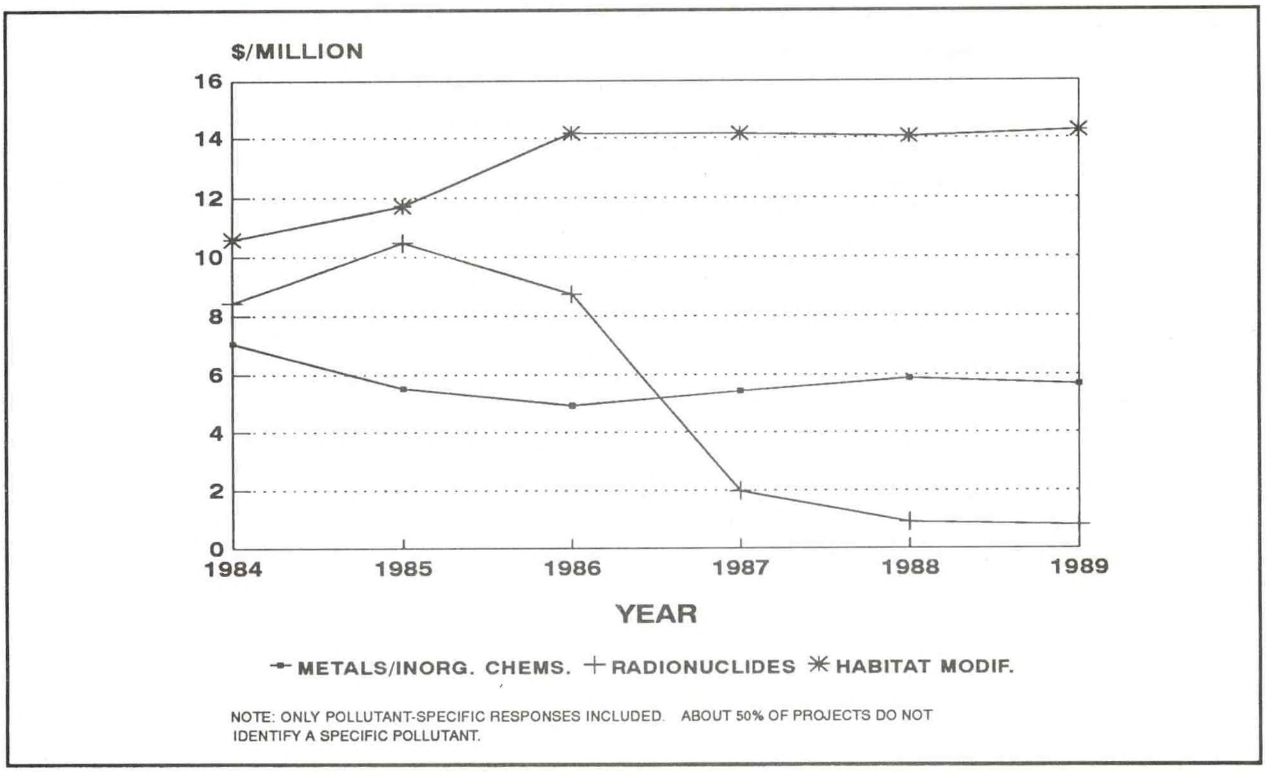

Figure 4(b). Trends in funding for pollutants 1984-1989

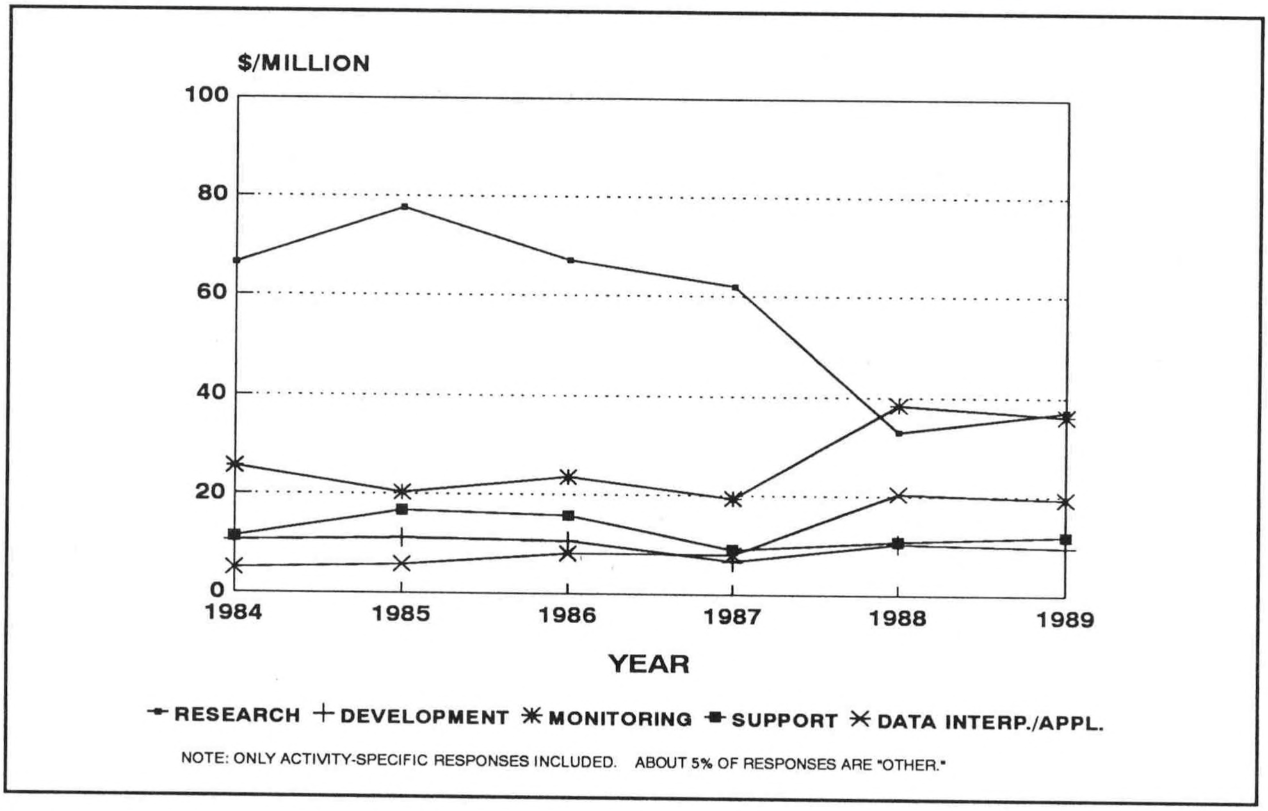

Figure 5. Funding trends by project activity 1984-1989

Funding by Goals. In the last Federal Plan, six goal areas were identified and the supporting Federal effort was evaluated. The results of analysis of the NMPIS data base as to the division of funds in FY 1989 among these goal areas were as follows:

Goal	$/K
Understanding the Sources, Fates, and Effects of Toxic Substances	41,738
Understanding the Sources, Fates, and Effects of Nutrients	13,738
Understanding the Sources, Fates, and Effects on Marine Organisms of Biological Agents	6,898
Understanding the Effects of Losing or Modifying Marine Habitats	19,791
Documenting Trends in the Status of Marine Ecosystems	22,532
Understanding the Implications of Marine Pollution to Human Health	4,258
Other Activity	12,973
TOTAL	121,928

AGENCY PROGRAMS

The following discussion presents an overview of the major responsibilities and activities of the Federal agencies involved in ocean pollution research, development, and monitoring under the National Ocean Pollution Program (NOPP). Included are discussions of major marine pollution programs within each agency and the estimated FY 1991 funding levels of these programs. More specific information as to funding as well as other pertinent data on these programs will be reported in future editions of the *National Ocean Pollution Program: Summary of Federal Programs and Projects.* Agency funding discussions are based on information submitted with the FY 1992 Presidential budget submission to Congress (NOPPB, 1991).

Council on Environmental Quality (CEQ)

CEQ is required by the National Environmental Policy Act of 1969 to report to Congress annually on the status and condition of the environment; the current and foreseeable trends in the quality, management, and utilization of the environment; and the effects of environmental trends. In an effort to fulfill this Congressional mandate, CEQ has enjoined other Federal agencies to develop a sourcebook of environmental statistics that are indicative of current conditions and historic trends in the quality of the environment of the United States. The proposed FY 1991 ocean pollution-related funding provided by CEQ for this effort is approximately $15,000. This amount is augmented by funding from other Federal agencies.

U.S. Department of Agriculture (USDA)

USDA supports research, development, and education programs on problems related to agricultural production and to the protection of the environment. A portion of the USDA research effort addresses the effects of agricultural and resource development practices on the quality of the marine environment. The overall goals of this research are to aid in the effective management and use of the Nation's soil, water, and air resources and to reduce pollutants in receiving streams, lakes, estuaries, and oceans. Research projects of the Agricultural Research Service (ARS), Cooperative State Research Service (CSRS), and Forest Service (FS) are included in the National Ocean Pollution Program.

The USDA's estimated FY 1991 budget was $3.9 million for ocean pollution research, development, and monitoring activities for FY 1991. These funds were to be used to support research examining the effects of soil erosion, agricultural runoff, agricultural waste disposal, sedimentation, nutrients, and pesticides on marine organisms and ecosystems and the transport and transformation of pollutants. The projects are conducted through mechanisms of direct Federal research as well as support of cooperative efforts and grants. An important aspect of the total research effort is the contribution made by the States in matching the Federal USDA funds. The State-to-Federal match is 4 to 1, although only 1 to 1 is required. This leads to a significant expansion of the Federal investment.

All relevant USDA projects have been grouped into the following three areas, which are listed as programs:

- Nonpoint Source Contaminants Program ($2.8 million) — Conducted by ARS, CSRS, and the FS to do research on pollution problems caused by soil erosion, estuarine sedimentation, slope stability in agricultural and forested watersheds, stream bank and shoreline stability, organic debris and turbidity, and on-land studies to prevent erosion from occurring.

- Habitat Modification Program ($1.0 million) — Conducts research on improving the ability to evaluate the effects of watershed development projects on resource conservation and conducts investigations of the influence of landscape and channel modifications on ambient concentrations of sediments and agricultural chemicals in streams.

- Point Source Contaminants Program (less than $0.1 million) — Conducts studies to investigate chemicals in bottom mud originating from dump sites and chemical plants, oil spills, and contaminants from other point sources. This research is conducted by cooperating State Agricultural Experiment Stations.

U.S. Department of Commerce (DOC)

National Institute of Standards and Technology (NIST)

NIST has responsibility for the custody, maintenance, and development of the national standards of measurement and the provision of means and methods for making measurements consistent with those standards. NIST cooperates with other Federal agencies for the development of standard practices and the establishment of reference bases in support of national programs. Within NIST, the National Measurement Laboratory's Center for Analytical Chemistry performs research in analytical methods and standard reference materials, and provides quality assurance and other services to other agencies of the government. Many of the Center's services are applicable to ocean pollution research and monitoring as well as other programs and are conducted for Federal and State governments. These include measurement of hazardous wastes, organic and inorganic species in water, organic and inorganic species in marine organisms and sediments, research in sampling, analytical design, and long-term storage of samples. Additional services include the development of measurement technologies to improve the accuracy of measurements and comparability among laboratories, the development and distribution of standard reference samples, and the provision of advisory and research services in analytical chemistry.

All ocean pollution-related activities at NIST are carried out on a reimbursable basis and thus no funding is listed in the National Ocean Pollution Program for NIST's related activities.

National Oceanic and Atmospheric Administration (NOAA)

NOAA has legislative responsibilities for conducting research on the effects caused by polluting activities in the oceans and the Great Lakes. During the past 10 years, NOAA's responsibilities have grown so that now an important part of NOAA's mission relates to marine pollution and the balanced management of the marine environment. NOAA programs in support of this mission work toward the development of an information base designed to contribute to the national, efficient, and equitable utilization, conservation, and development of oceanic and coastal resources.

Under the FY 1991 budget, NOAA's estimated funding was $46.4 million for marine pollution, research, development, and monitoring studies under the Office of the Chief Scientist; the National Ocean Service; Oceanic and Atmospheric Research; the National Marine Fisheries Services; and the National Environmental Satellite, Data, and Information Services. The ocean pollution programs of these organizations and their specific research responsibilities are as follows:

- Office of the Deputy Under Secretary

  - NOAA Coastal Ocean Program ($9.4 million) — A major cross-cutting NOAA effort with the goal of providing information to decision makers that will help develop the full potential of coastal resources and protect them for the future. The basis of this information is an improved understanding and development of predictive capabilities to address three themes: 1) coastal ocean pollution and habitat degradation; 2) coastal fisheries productivity, and 3) protection of life and property. The Program focuses on five critical areas within these themes including nutrient overenrichment, estuarine habitat alterations, coastal fishery ecosystems, toxic chemical contamination, and coastal hazards.

– Office of the Chief Scientist

- National Marine Pollution Coordination Program ($1.1 million) — Coordinates ocean pollution research, development, and monitoring programs supported by all Federal departments and agencies.

– National Ocean Service

- National Status and Trends Program ($5.7 million) — Quantifies the present concentrations of toxicants in U.S. coastal and estuarine waters, sediments, and tissues of key organisms; determines the temporal trends and spatial distributions of these concentrations; and monitors the biological response of indigenous organisms to contamination by subjecting them to bioassay analysis. Results are used to assess the potential impact of contaminants on protected, commercially important, and ecologically valuable living marine resources.

- Strategic Assessments Program ($4.2 million) — Conducts assessments of multiple ocean resource uses for the Nation and its major coastal and ocean regions to determine marine resource development strategies, which will result in maximum benefit to the Nation with minimum environmental damage or conflicts among uses.

- Hazardous Materials Response Program ($2.7 million) — Develops scientific plans and coordinates scientific input related to spills of hazardous substances occurring in coastal waters, the 197-mile Exclusive Economic Zone, and the Great Lakes.

- Damage Assessment Program ($2.5 million). The Under Secretary for Oceans and Atmosphere (NOAA Administrator) acts on behalf of the Secretary of Commerce as a Federal trustee for natural resources provided by the Comprehensive Environmental Response, Compensation, and Liability Act; the Clean Water Act; the Marine Protection, Research and Sanctuaries Act; and the Oil Pollution Act. The natural resources for which the Under Secretary serves as trustee include all life stages, wherever they occur, of fishery resources of the Exclusive Economic Zone and continental shelf: anadromous and catadromous species throughout their ranges; endangered and threatened species and marine mammals for which NOAA is responsible; tidal wetlands and other habitats supporting these living marine resources; and the resources of the National Marine Sanctuaries. For resources in coastal waters and anadromous fish streams, the Under Secretary may be a co-trustee with the Secretary of the Interior, with the Secretaries of other Federal land-managing agencies, and with designated State and possibly Indian tribal trustees. To implement the trustee responsibilities, the Under Secretary has established the Damage Assessment and Restoration Center with the National Ocean Service to work to conduct damage assessments and bring claims against potentially responsible parties.

- Prince William Sound Oil Spill ($2.0 million) — Along with the National Forest Service, Fish and Wildlife Service, and Alaska's Department of Fish and Game, conducts assessment of damages to determine injury from the March 24, 1989, grounding of the tanker *Exxon Valdez* in Alaska's Prince William Sound. NOAA is conducting studies to determine the distribution and composition of petroleum hydrocarbons and their conversion products in water, sediments, and living resources. Additional studies are being conducted to assess the impact to fish, shellfish, and marine mammal populations.

Technical services are also supplied to support all studies in the areas of analytical chemistry, quality assurance/quality control, histopathology, and data management and information.

- Ship Support ($1.4 million) — Provides ship support for NOAA's marine pollution research and monitoring activities.
- Deep Seabed Mining Environmental Research Program ($0.6 million) — Provides scientific information to predict potential adverse impacts from the mining of hard mineral resources in the deep ocean and to enable government decisions to be made regarding the mining of these resources in an environmentally sound matter.
- National Marine Sanctuaries Program ($0.4 million) — Promotes and coordinates research to expand the scientific knowledge of marine sanctuaries and to improve management decision-making for the purpose of preserving or restoring their conservation, recreational, ecological, or aesthetic values.
- International Mussel Watch Program ($0.1 million) — An international extension and coordination of national mussel watch programs.

– Office of Oceanic and Atmospheric Research

- Sea Grant Ocean Pollution Studies ($3.1 million) — Provides funding to selected colleges and universities throughout the Nation to solve pollution problems related to State and local activities in fisheries, recreation, and overall marine and estuarine resource management.
- Environmental Research Laboratories Great Lakes Pollution Studies ($3.0 million) — Conducts process studies to improve our understanding and prediction of the impact of pollutants on the Great Lakes and problem-oriented research to develop improved engineering prediction models.
- National Undersea Research Program ($2.0 million) — An integrated program focusing on research relating to processes in the world's oceans and great lakes in order to understand the global ecosystem, which will then lead to predicting changes in that system. The program promotes studies relating the use of ocean and lake resources to the ecosystem. Three important aspects of the program that relate to ocean pollution are the study of pathways and fate of materials in the ocean, the study of coastal oceanic processes, and the study of productivity and habitat characteristics.
- Environmental Research Laboratories Ocean Pollution Studies ($0.5 million) — Conducts process-oriented research to improve our understanding of natural oceanic systems and the ecological impacts of human-induced stress on these systems; problem-oriented research is also conducted to develop improved assessment capabilities.

– National Marine Fisheries Service

- National Fishery Ecology Program ($7.5 million) — Conducts research directed toward understanding the effects of human-induced and natural changes on the abundance, distribution, and health of living marine resources of commercial and recreational importance and their habitats.
- Other NMFS ocean pollution-related programs include:
  - Restoration Center — Develops and directs national expertise and provides the institutional focus required to identify and evaluate restoration methodologies for specific cases during the damage assessment process, to use recovered damages to restore the injured resources, and to address research and development priorities

necessary for successful resource habitat restoration. This includes conducting a scientific program under a memorandum of agreement with the U.S. Army Corps of Engineers designed to create, enhance, and restore fishery habitats at Corps construction sites.

- Habitat Conservation — Provides Federal agencies with information and recommendations on the ecological impacts of proposed actions that would affect the habitats of anadromous, estuarine and marine resources. NOAA also evaluates and provides technical assistance on fisheries and proposed marine and estuarine sanctuaries. These consultations help to minimize or eliminate adverse effects on marine fish populations by recommending appropriate alternatives and mitigation efforts in order to maintain the Nation's coastal environment.
- Product Safety, Quality and Identity Research Program — Conducts safety research that addresses the continuing concern regarding the impact of environmentally and process-induced contamination of seafood on consumers. Activities include the collection, interpretation, publication, and dissemination of information and research results.
- The National Seafood Inspection Program — Administered by the National Marine Fisheries Service. The program conducts a voluntary seafood inspection program on a fee-for-service basis and provides a wide range of services to any interested party including harvester, processor, food service distributor, importer, and exporter. NOAA and FDA recently announced plans for a joint, enhanced voluntary fee-for-service program based on Hazard Analysis Critical Control Point principles to provide additional assurance to consumers at home and abroad that fish products are safe, wholesome, and properly labeled.

– National Environmental Satellite, Data, and Information Service

- Marine Pollution Data Support Program (less than $0.1 million)
  - National Oceanographic Data Center — NODC provides a variety of marine pollution data management activities as part of its mission to maintain a national ocean data archive. These activities include data identification and acquisition, data processing and quality control, data and information products and services, and project data management.
  - Ocean Pollution Data and Information Network (funding under National Marine Pollution Coordination Program) — OPDIN maintains data bases and facilitates access to data and information generated by Federally funded activities on marine and Great Lakes pollution, and enhances interagency coordination and communication regarding these activities. A new user-friendly system, AESOP (Automated Environmental System for Ocean Pollution), links together these data and information bases:

    Handbook of Federal Systems and Services for Marine Pollution Data and Information. This data base profiles systems and services within the Federal government that contain marine or Great Lakes pollution data and information.

    National Marine Pollution Information System (NMPIS). This PC-based data base includes descriptions of marine and Great Lakes pollution projects conducted or funded by Federal agencies.

    Guide to Marine Pollution Related Data. The guide identifies projects from the NMPIS data base that have generated oceanographic field data.

Marine and Great Lakes Pollution Literature. OPDIN worked with the central NOAA Library to develop a data base of marine and Great Lakes pollution literature.

Directory. The Directory identifies Federal marine and Great Lakes pollution scientists and managers.

Customer Services Reporting System. This data base serves a record of user requests and tracks staff activities in this area.

U.S. Department of Defense (DOD)

U.S. Army Corps of Engineers (COE)

The COE has responsibility for conducting studies on the environmental effects of water use, water diversion, and construction projects it undertakes in the ocean environment. Estimated FY 1991 COE funding was $10.7 million for ocean pollution research, development, and monitoring studies. The COE's marine pollution projects are divided into two major programs: the Environmental Quality Research and Development Program and the Navigation Project Environmental Operations and Maintenance Program.

- Environmental Quality Research and Development Program ($2.6 million) — Concerned with the development of techniques and procedures for assessing, evaluating, and controlling the impact of COE and other coastal construction activities on the environment, including effects on wetlands. Wetlands research is becoming an increasingly significant part of the program.

- Navigation Project Environmental Operations and Maintenance Program ($8.1 million) — Composed of the Long-Term Monitoring Project and the Long-Term Management Strategy Programs. The Long-Term Monitoring Project involves the continued evaluation of nine existing habitat development field sites, low-cost breakwater tests to determine rapid development and survival benefits in marsh development and shoreline stabilization, and dissemination of information on beneficial uses of dredged materials. The principal objective of the Long-Term Management Strategy (LTMS) Program is to provide the field with protocols for developing LTMSs for disposing of dredged materials in an economically and environmentally sound manner.

U.S. Navy

The U.S. Navy's estimated FY 1991 budget was used to conduct research, development, and monitoring programs related to ocean pollution. The ocean pollution programs of the Navy are carried out within the following program:

- Environmental Protection Technology Program ($0.6 million) — Goal of the program is to develop pollution reduction, abatement, or treatment techniques and permit the Navy to meet present and future environmental regulations. The program involves the development of onboard systems for pollution source reduction and control and the investigation of environmental aspects of treatment technology. This includes establishment and maintenance of a data base on quality and generation rates of all shipboard wastes including expended ordnance. The remainder of the program addresses short- and long-term environmental effects of antifouling paints applied to ship hulls. This research includes investigations of the environmental fates and effects of synthetic organic compounds released from antifouling paints during drydock removal and routine service.

U.S. Department of Energy (DOE)

A major DOE objective is to carry out research and monitoring to ensure that energy programs are consistent with environmental legislation and policies. To fulfill this objective within oceanic systems, DOE has conducted a marine research program to gain an understanding of the effects of energy-related pollutants on the marine environment. This research program is a small part of a broader, integrated program of health and environmental research designed to identify, measure, and characterize energy-related releases of pollution into the terrestrial, freshwater, and marine environment; understand their transport, conversion, and ultimate fate; determine their ecological impacts; and define their potential effects on human health.

During FY 1991, the DOE marine pollution research was coordinated under the following program:

- Regional Marine Program ($5.5 million) — Supports research on natural physicochemical and biological processes to help determine the pathways and fates of energy-related materials in marine systems and food chains.

In FY 1992, DOE will be restructuring its Regional Marine Program into an Ocean Margins Program to quantify the role of the coastal ocean in the global flux of carbon. The central goal of this program will be to determine whether continental shelves are quantitatively significant in removing carbon dioxide from the atmosphere and isolating it via burial in sediments or export to the interior ocean. The secondary goals of the program are to quantify the mechanisms and processes by which carbon dioxide and nutrients are assimilated, transported, and transformed in the coastal ocean and to define ocean-margin sources and sinks in global biogeochemical cycles.

U.S. Department of Health and Human Services (DHHS)

U.S. Food and Drug Administration (FDA)

The FDA is responsible for the safety and the regulation of the Nation's foods, cosmetics, drugs, medical devices, biologics, and electronic radiological products. The FDA applies the regulation through a strategy consisting of policies and procedures that are intended to be preventive rather than corrective. The purpose of this strategy is to ensure the safety of seafood products prior to consumption.

The current FDA ocean pollution research and monitoring effort is coordinated under the following program:

- Seafood Safety and Contamination Program ($5.0 million) — This program operates the National Shellfish Sanitation Program to ensure that the Nation's shellfish supply is free from contamination from polluted waters. Projects include developing and maintaining current procedures and guidelines to ensure sanitary control of growing waters and sanitary harvesting, processing, and marketing practices; promoting sanitary controls in domestic and foreign laws and regulations; evaluating the effectiveness of seafood sanitation programs and seeking necessary corrective measures where required; and conducting research and providing technical assistance and training to ensure the safety and quality of seafood products.

National Institute of Environmental Health Sciences (NIEHS)

The NIEHS is responsible for the support of research in the areas of the effects of chemical and physical environmental agents on human health. This includes basic research as well as research on the causes of environmentally related diseases and how they develop. While the focus of NIEHS-supported research is primarily on human health, one of its projects supports ocean pollution-related research:

- Extramural Program ($3.4 million) — Supports research on the distribution and alteration of environmental compounds in the marine environment and their accumulation and biological effects in marine biota. Emphasis is placed on understanding known or toxic effects in the human population.

U. S. Department of the Interior (DOI)

Minerals Management Service (MMS)

The MMS research program supports one of the mandates of the Outer Continental Shelf (OCS) Lands Act Amendments of 1978, which is to provide for the protection of the human, marine, and coastal environments concomitant with mineral resource development of the OCS. To meet this goal and to meet information and administrative requirements of the National Environmental Policy Act of 1969, the following national program was inaugurated:

- OCS Environmental Studies Program ($20.4 million) — Initiated by the Bureau of Land Management (now MMS) in 1974 to provide environmental information and analyses on marine and coastal ecosystems and to establish benchmark environmental conditions in all OCS areas for future identification of alterations caused by OCS activities. The program has since evolved from the benchmark environmental characterization approach to the monitoring of effects on marine ecosystems as oil and gas development occurs. This diverse program includes studies on the following topics: air quality, ecology, fisheries, protected species, fates and effects, and physical oceanography. Studies range in scope from literature synthesis to field tagging and monitoring and development of computer models. The OCS Environmental Studies Program is managed in the MMS Headquarters Office by the Environmental Studies Branch located within the Environmental Policy and Programs Division.

U.S. Fish and Wildlife Service (FWS)

The FWS has general responsibility for perpetuating and providing public use and enjoyment of the fish and wildlife resources of the United States. Its functions include responsibility for the fish and wildlife resources and habitats of national interest through research, management, and provision of technical assistance to other Federal and nongovernment agencies and States. The FWS conducts operations in the entire coastal zone, the contiguous lands, and the waters that flow into the zone. Through the Assistant Secretary for Fish and Wildlife and Parks, FWS acts as the principal environmental advisor in reviewing various departmental policy and opinion documents for energy development programs, including those in the coastal zone. Portions of its component programs with marine pollution-related goals, objectives, and activities constitute important factors in the protection, conservation, and enhancement of estuarine and coastal fish and wildlife resources and their habitats.

The FWS funded $7.1 million for ocean pollution-related research in FY 1991 under the Research and Development Program and the National Wetlands Inventory. The ocean pollution-related research activities of these programs are presented below.

- Research and Development Program ($4.1 million) — Collects, collates, and interprets diverse information on fish species populations and habitats to provide information, methodology, and materials to assist fishery managers in decisions about the protection, enhancement, and utilization of fishery resources. Research addresses specific needs of the Service and, when feasible, responds to the needs of other Federal agencies, Indian tribes, State agencies, and international groups.

- National Wetlands Inventory ($3.0 million) — Prepares a wetland data base in map form, conducts trend analyses for wetland change, maintains standardized mapping procedures, correlates known wetland values, and upgrades and makes available the collected information. Wetland maps have been completed for the coastal zone of the lower 48 United States (including the Great Lakes) and Hawaii.

U.S. Geological Survey (USGS)

The USGS is responsible for the classification of public lands and examination of the geological structure, mineral resources, and products of the national domain. Over the years, the USGS's mission has expanded to include topographic mapping and hydrologic investigations of water in streams and underground. In compliance with its broad mission for earth science research and application, the USGS conducts a few ocean pollution-related programs.

For FY 1991, the USGS proposed $7.8 million for ocean pollution-related studies under two programs. These programs and their ocean pollution-related responsibilities are presented below.

- Geologic Division Program ($4.0 million) — Conducts research on the physical and geological processes on the seafloor, specifically on sediment transport processes, marine deposits, and sedimentary dynamics.

- Water Resources Division Program ($3.8 million) — Responsible for providing hydrologic data on surface and groundwater, including the long-term operation of downstream gauges on major rivers and streams (yielding both quantity and quality data) and site-specific investigations of estuarine circulation, geochemistry, and ecology.

U.S. Department of Transportation (DOT)

U.S. Coast Guard

The majority of U.S. Coast Guard marine pollution activities focus on reducing the impact from oil pollution incidents and, as the Federal On-Scene Coordinator, ensuring that effective countermeasures and cleanup operations are conducted for accidental discharges. In performing these functions, the Coast Guard utilizes HU-25 aircraft equipped with AIREYE Sensors for locating oil spills and monitoring drift behavior, operates a Central Oil Identification Lab (COIL) for performing oil fingerprinting to identify the sources of discharges, and works in concert with industry and other Federal agencies to coordinate the response effort. In addition, the Coast Guard is the United States' representative to the Intergovernmental Maritime Organization (IMO), which promotes improved safety and pollution prevention at sea. The major goals and responsibilities involving research and development and monitoring are contained in the following program:

- Marine Environmental Response Program ($2.4 million) — Supports research on monitoring behavior and movements of spilled oil and hazardous substances, developing systems for more precise detection, sampling, identification, and quantification of discharged chemicals, and improving techniques for spill mitigation and the removal, storage and disposal of spilled oil and chemicals.

U.S. Environmental Protection Agency (EPA)

The EPA programs funding for research, development, and monitoring programs related to ocean pollution for FY 1991 is estimated to be $57.2 million. The EPA assumes lead responsibility in the Federal Government for identifying, evaluating, and controlling environmental pollutants. The purview of EPA includes freshwater, estuarine, coastal, and oceanic pollution. Ocean pollution research activities range from specific mission-oriented endeavors to basic research concerned with achieving a general understanding of marine ecosystem structure and function.

The major responsibilities of EPA include review of permits, setting standards, and overall regulatory activities. The EPA mandate includes the following areas of ocean pollution research and monitoring:

- National Estuary Program ($13.7 million) — Designed to develop a series of comprehensive master environmental plans to protect and restore water quality and living resources for various estuaries throughout the Nation, using resources available from a variety of Federal agencies as well as State and local governments.
- Water Quality Research ($11.1 million) — Relates to establishing limits on substances such as priority pollutants, toxic substances, pesticides, and carcinogens released into the marine environment.
- Great Lakes Research ($10.0 million) — Addresses the pollution problems of the Great Lakes. Objectives include research on water quality and eutrophication and monitoring of contaminants and discharges from tributaries and point sources. Great Lakes Research focuses on the development and testing of methods, models, and databases to predict the fate and effects of toxic substances on the Great Lakes ecosystem.
- Environmental Monitoring and Assessment Program ($7.2 million) — Using a regional design, conducts quantitative evaluations on available monitoring data for pollutant exposure in air, water, and soils to identify critical information gaps. Research is carried out on ecosystem classification, monitoring network design and optimization, indicator methods for ecological condition, and quality assurance and data management techniques for multi-operator, multi-objective environmental monitoring networks.
- Marine Disposal Program ($6.1 million) — Addresses the short- and long-term environmental effects of the disposal of municipal waste, industrial waste, and low-level radioactive waste in the marine environment.
- Reducing Uncertainties in Risk Assessment for Ecological Systems Program ($3.0 million) — Develops ecological monitoring systems that match available and/or augment current data collection efforts with the measures required for effective systems monitoring.
- Energy-related Research ($4.1 million) — Includes environmental studies on the impacts of waste materials produced from offshore oil and gas drilling and production platforms. Also includes permitting activity for waste discharge from offshore oil and gas platforms.
- Chesapeake Bay Program ($1.7 million) — Coordinates pollution research in Chesapeake Bay. These efforts include research on sources, transport, fate, and physical properties of pollutants and on pollution control alternatives and data management.
- Exploratory Research ($0.5 million) — Involves long-term research conducted through cooperative agreements with universities. This research provides a link between basic and applied research on fates and effects of marine pollutants.

National Aeronautics and Space Administration (NASA)

NASA does not have any direct statutory responsibilities for ocean pollution research, development, and monitoring, but does conduct studies indirectly related to marine pollutants. Those projects indirectly related to the National Ocean Pollution Program fall under two categories. The first includes the development of space-borne techniques and the evaluation and application of these techniques to advance our understanding of the fundamental behavior of the oceans. These elements are conducted by the Earth Science and Applications Division of the Office of Space Science and Applications. The second includes programs that make possible the utilization of proven technologies and methodologies to other government agencies and industries for use in ongoing programs. These efforts are conducted by the Division of Technology Utilization in the Office of External Relations. The following describes the ocean pollution-related activities conducted by NASA:

- Ocean Productivity Program ($0.6 million) — Conducts research to improve the understanding of global oceanic primary productivity and phytoplankton distribution, reasons for observed spatial and temporal variability, how these distributions are influenced by ocean physics and circulation, and the impacts on living marine resources and global carbon and nitrogen cycles.

National Science Foundation (NSF)

Although NSF identified no funding for FY 1991 under the National Ocean Pollution Program, the agency has the mission to support scientific research to maintain and increase the Nation's ability to advance in scientific and technological areas. The NSF does not itself conduct research but provides funding for scientists in the public sector, mostly in academic institutions.

The Division of Ocean Sciences is the principal administrative unit within NSF that supports research relevant to ocean pollution. Most of this research can be categorized as basic research, since it is not narrowly focused by mandates or policy. However, because many of the findings from NSF-supported basic research make a contribution to other applied studies of ocean pollution problems, the agency is included in this section.

Appendix B

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APPENDIX D

THE NATIONAL OCEAN POLLUTION PLANNING ACT
(Public Law 95-273)

§ 1701. Findings and purposes

(a) The Congress finds and declares the following:

(1) Man's activities in the marine environment can have a profound short-term and long-term impact on such environment and greatly affect ocean and coastal resources therein.

(2) There is a need to establish a comprehensive Federal plan for ocean pollution research and development and monitoring, with particular attention being given to the inputs, fates, and effects of pollutants in the marine environment.

(3) Man will increasingly be forced to rely on ocean and coastal resources as other resources are depleted. Our ability to protect, preserve, develop, and utilize these ocean and coastal resources is directly related to our understanding of the effects which ocean pollution has upon such resources.

(4) Numerous departments, agencies, and instrumentalities of the Federal Government sponsor, support, or fund activities relating to ocean pollution research and development and monitoring. However, such activities are often uncoordinated and can result in unnecessary duplication.

(5) Better planning and more effective use of available funds, personnel, vessels, facilities, and equipment is the key to effective Federal action regarding ocean pollution research and development and monitoring.

(6) Numerous Federal agencies have initiated and supported research projects to study, enhance, manage, preserve, protect, or restore the resources of the Great Lakes, the Chesapeake Bay, Puget Sound, and other estuaries of national significance.

(7) Various research projects relating to the Great Lakes, the Chesapeake Bay, Puget Sound, and other estuaries of national significance, including those conducted at the college and university level and those conducted at the State and local governmental level, can be more effectively coordinated in order to obtain maximum benefits.

(b) It is therefore the purpose of the Congress in this chapter—

(1) to establish a comprehensive 5-year plan for Federal ocean pollution research and development and monitoring programs in order to provide planning for, coordination of, and dissemination of information with respect to such programs within the Federal Government;

(2) to develop the necessary base of information to support, and to provide for, the rational, efficient, and equitable utilization, conservation, and development of ocean and coastal resources;

(3) to provide for the effective coordination of research conducted to support the preservation and protection of the environmental quality of the Great Lakes, the Chesapeake Bay, Puget Sound, and other estuaries of national significance, and to encourage the use of such research in determinations that affect the environmental quality of the Great Lakes, the Chesapeake Bay, Puget Sound, and other estuaries of national significance; and

(4) to designate the National Oceanic and Atmospheric Administration as the lead Federal agency for preparing the plan referred to in paragraph (1) and to require the Administration to carry out a comprehensive program of ocean pollution research and development and monitoring under the plan.

§ 1702. Definitions

As used in this chapter, unless the context otherwise requires—

(1) The term "Administration" means the National Oceanic and Atmospheric Administration of the United States Department of Commerce.

(2) The term "Board" means the National Ocean Pollution Policy Board established under section 1702a(b) of this title.

(3) The term "Director" means the Director of the Office of Science and Technology Policy in the Executive Office of the President.

(4) The term "marine environment" means the coastal zone (as defined in section 1453(1) of Title 16); the seabed, subsoil, and waters of the territorial sea of the United States; the waters of any zone over which the United States asserts exclusive fishery management authority; the waters of the high seas; and the seabed and subsoil of and beyond the Outer Continental Shelf.

(5) The term "ocean and coastal resource" has the same meaning as is given such term in section 1122(7) of this title.

(6) The term "ocean pollution" means any short-term or long-term change in the marine environment.

(7) The term "Office" means the National Ocean Pollution Program Office established under section 1702a(a) of this title.

(8) The term "Under Secretary" means the Under Secretary for Oceans and Atmosphere, United States Department of Commerce.

§ 1702a. National Ocean Pollution Program Office and Policy Board

(a) Program Office

(1) The Under Secretary shall establish within the Administration the National Ocean Pollution Program Office.

(2) The Office shall—

(A) serve as the lead entity responsible for administering the program established under section 1703 of this title;

(B) be headed by a director who shall—

(i) be appointed by the Under Secretary, and
(ii) be the official responsible for the administration of the program;
(iii) be the spokesperson for the program;

(C) serve as the staff for the Board and its supporting committees and working groups; and

(D) review each department and agency budget request transmitted under section 1703(d) of this title and submit an analysis of the request to the Board for its review.

The analysis described in subparagraph (D) shall include an analysis of how each departmental or agency budget request relates to the priorities and goals of the Plan established under section 1703 of this title.

(b) Policy Board

(1) The Under Secretary, with the cooperation of the Federal departments and agencies referred to in section 1706 of this title, shall establish a National Ocean Pollution Policy Board consisting of representatives of those departments and agencies:

(2) The Board shall—

(A) be responsible for coordinated planning and progress review for the program established under section 1703 of this title;

(B) review all department and agency budget requests transmitted to it under section 1703 of this title and submit a report simultaneously to the Office of Management and Budget and to the Congress concerning those budget requests;

(C) establish and maintain such interagency groups as the Board determines to be necessary to carry out its activities; and

(D) consult with and seek the advice of users and producers of ocean pollution data, information, and services to guide the Board's efforts, keeping the Director and the Congress advised of such consultations.

§ 1703. Comprehensive Federal Plan relating to ocean pollution

(a) Lead agency for plan

The Under Secretary, in consultation with the Director and other appropriate Federal officials having authority over ocean pollution research and development and monitoring programs, shall prepare, in accordance with this section, a comprehensive 5-year plan (hereinafter in this chapter referred to as the "Plan") for the overall Federal effort in ocean pollution research and development and monitoring. The Plan shall be prepared and submitted to Congress and the President on or before February 15, 1979, and a revision of the plan shall be prepared and so submitted by September 15 every three years after 1979.

(b) Content of Plan

The Plan shall contain, but need not be limited to, the following elements:

(1) Assessment and ordering of national needs and problems

The plan shall—

(A) identify those national needs and problems, which relate to specific aspects of ocean pollution (including, but not limited to, the effects of ocean pollution on the economic, social, and environmental values of ocean and coastal resources), which exist and will arise during the Plan period;

(B) establish the priority, based upon the value and cost of information which can be obtained from specific ocean pollution research and development and monitoring programs and projects, in which such needs should be met, and such problems should be solved, during the Plan period; and

(C) contain, if pursuant to the preparation of any revision of the Plan required under subsection (a) of this section it is determined that any national need or problem or priority set forth in the preceding version of the Plan should be changed, a detailed explanation of the reasons for the change.

(2) Existing Federal capability

The plan shall contain—

(A) a detailed listing of all existing Federal programs relating to ocean pollution research and development and monitoring (including, but not limited to, general research on marine ecosystems, including the Great Lakes, the Chesapeake Bay, Puget Sound, and other estuaries of national significance,) which listing shall include, with respect to each such program—

(i) a catalogue of the Federal personnel, facilities, vessels and other equipment currently assigned to, or used for, the program, and
(ii) detailed description of the existing goals and costs of the program, including, but not limited to, a categorical breakdown of the funds currently being expended, and planned to be expended, to conduct the program; and

(B) an analysis of the extent to which each such program, if continued on the basis and at the funding level described pursuant to subparagraph (A)(ii), will assist in meeting the priorities set forth pursuant to paragraph (1)(B) during the Plan period.

(3) Policy recommendations

If it is determined, as a result of the analysis required to be made under paragraph (2)(B), that the priorities set forth pursuant to paragraph (1)(B) will not be adequately met during the Plan period using the existing Federal capability described pursuant to paragraph (2)(A), the Plan shall contain those recommendations for changes in the overall Federal effort in ocean pollution research and development and monitoring which would ensure that those priorities are adequately met during the Plan period. Such recommendations may include, but need not be limited to—

(A) changes in the goals to be achieved under various existing Federal ocean pollution research and development and monitoring programs;

(B) suggested increases and decreases in the funding for any such existing program consistent with the extent to which such program contributes to the meeting of such priorities;

(C) specific proposals for interagency cooperation in cases in which the pooling of the resources of two or more Federal departments, agencies, or instrumentalities under existing programs could further efforts to meet such priorities or would eliminate duplication of effort; and

(D) suggested legislation to establish new Federal programs considered to be necessary if such priorities are to be met.

(4) Plan review

The Plan shall contain a description of actions taken by the Under Secretary and the Director for the purpose of ensuring interagency coordination and cooperation in (A) the carrying out of Federal ocean pollution research and development and monitoring programs; and (B) eliminating unnecessary duplication of effort among such programs.

(c) Plan period

For purposes of this section, the term "Plan period" means—

(1) with respect to the Plan as required to be submitted on February 15, 1979, the period of 5 fiscal years beginning on October 1, 1978; and

(2) with respect to each revision of the Plan, the period of 5 fiscal years beginning on October 1 of the year before the year in which the revision is required to be prepared under subsection (a) of this section.

(d) Budgeting

Each Federal Agency and department included under the Plan shall prepare and submit to the Office of Management and Budget, the Office, and the Board on or before the date of submission of department requests for appropriations to the Office of Management and Budget, an annual request for appropriations to carry out the activities of that agency or department under the Plan during the subsequent fiscal year. The Office of Management and Budget shall review the request for appropriations as an integrated, coherent, and multiagency request, taking into account the review by the Board of those requests under section 1702a(b) of this title.

§ 1704. Comprehensive ocean pollution program in the Administration

(a) Establishment of program

The Under Secretary shall establish within the Administration a comprehensive, coordinated, and effective ocean pollution research and development and monitoring program. The Under Secretary shall carry out all projects and activities under the program in a manner consistent with the Plan.

(b) Content of the program

The program required to be established under subsection (a) of this section shall include, but not be limited to—

(1) all projects and activities related to ocean pollution research and development and monitoring for which the Under Secretary has responsibility under provisions of law (including, but not limited to, title II of the Marine Protection, Research, and Sanctuaries Act of 1972 (33 U.S.C. 1441-1444)) other than paragraph (2);

(2) such projects and activities addressed to the priorities set forth in the Plan pursuant to section 1703(b)(1)(B) of this title that can be appropriately conducted within the Administration; and

(3) the provision of financial assistance under section 1705 of this title.

§ 1705. Financial assistance

(a) Grants and contracts

The Under Secretary may provide financial assistance in the form of grants or contracts for research and development and monitoring projects or activities which are needed to meet priorities set forth in the Plan pursuant to section 1703(b)(1)(B) of this title, if such priorities are not being adequately addressed by any Federal department, agency, or instrumentality.

(b) Applications for assistance

Any person, including institutions of higher education and departments, agencies, and instrumentalities of the Federal Government or of any State or political subdivision thereof, may apply for financial assistance under this section for the conduct of projects and activities described in subsection (a) of this section, and, in addition, specific proposals may be invited. Each application for financial assistance shall be made in writing in such form and manner, and contain such information, as the Under Secretary may require. The Under Secretary may enter into contracts under this section without regard to section 5 of Title 41.

(c) Existing programs

The projects and activities supported by grants or contracts made or entered into under this section shall, to the maximum extent practicable, be administered through existing Federal programs (including, but not limited to, the National Sea Grant Program) concerned with ocean pollution research and development and monitoring.

(d) Action by Under Secretary

The Under Secretary shall act upon each application for a grant or contract under this section within six months after the date on which all required information is received by the Under Secretary from the applicant. Each grant made or contract entered into under this section shall be subject to such terms and conditions as the Secretary deems necessary in order to protect the interests of the United States. The total amount paid pursuant to any such grant or contract may, in the discretion of the Under Secretary, be up to 100 percent of the total cost of the project or activity involved.

(e) Records

Each recipient of financial assistance under this section shall keep such records as the Under Secretary shall prescribe, including records which fully disclose the amount and disposition by such recipient of the proceeds of such assistance, the total cost of the project or activity in connection with which such assistance was given or used, the amount of that portion of the cost of the project or activity which was supplied by other sources, and such other records as will facilitate an effective audit. Such records shall be maintained for three years after the completion of such project or activity. The Under Secretary and the Comptroller General of the United States, or any of their duly authorized representatives, shall have access, for the purpose of audit and examination, to any books, documents, papers, and records of receipts which, in the opinion of the Under Secretary or of the Comptroller General may be related or pertinent to such financial assistance.

§ 1706. Interagency cooperation

The head of each department, agency, or other instrumentality of the Federal Government which is engaged in or concerned with, or which has authority over, programs relating to ocean pollution research and development and monitoring—

(1) shall cooperate with the Under Secretary in carrying out the purposes of this chapter;

(2) may, upon written request from the Under Secretary or Director, make available to the Under Secretary or Director, on a reimbursable basis or otherwise, such personnel (with their consent and without prejudice to their position and rating), services, or facilities as may be necessary to assist the Under Secretary or the Director to achieve the purposes of this chapter; and

(3) shall, upon a written request from the Under Secretary or Director, furnish such data or other information as the Under Secretary or Director deems necessary to fulfill the purposes of this chapter.

§ 1707. Dissemination of information on ocean and Great Lakes pollution research activities

(a) The Under Secretary shall ensure that the results, findings, and information regarding ocean pollution research and development and monitoring programs conducted or sponsored by the Federal Government be disseminated in a timely manner, and in useful forms, to relevant departments, agencies, and instrumentalities of the Federal Government, and to other persons having an interest in ocean pollution research and development and monitoring.

(b) The Under Secretary shall ensure that the findings and information regarding ocean pollution research activities associated with the Great Lakes identified pursuant to section 1703(b) of this title be disseminated in a timely manner and in useful forms to relevant departments of the Federal Government, State governments, and other persons with an interest in such information.

§ 1708. Effect on other laws

Nothing in this chapter shall be construed to amend, restrict, or otherwise alter the authority of any Federal department, agency, or instrumentality, under any law, to undertake research and development and monitoring relating to ocean pollution.

§ 1709. Authorization of appropriations

There are authorized to be appropriated to the Administration for the purposes of carrying out this chapter not to exceed $5,000,000 for the fiscal year ending September 30, 1979, not to exceed $4,300,000 for the fiscal year ending September 30, 1980, not to exceed $3,000,000 for the fiscal year ending September 30, 1981, not to exceed $4,000,000 for the fiscal year ending September 30, 1982, and not to exceed $3,571,000 for fiscal year 1986, not to exceed $3,732,000 for fiscal year 1987, not to exceed $3,750,000 for fiscal year 1989, and not to exceed $4,000,000 for fiscal year 1990.

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