Restoring & Protecting America's Waters

CLEAN WATER ACTION PLAN

CLEAN WATER ACTION PLAN: COASTAL RESEARCH AND MONITORING STRATEGY

BY

THE COASTAL RESEARCH AND MONITORING STRATEGY WORKGROUP

SEPTEMBER 2000

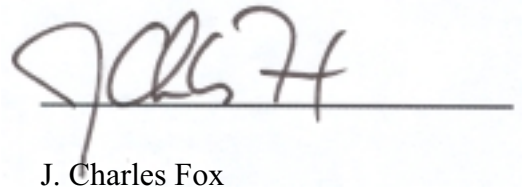
EPA NOAA USDA USGS science for a changing world

http://www.cleanwater.gov

Preface

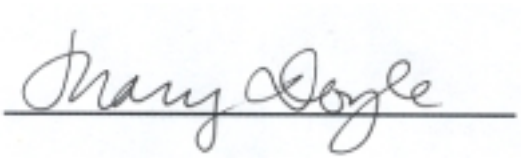
We are pleased to announce the *Coastal Research and Monitoring Strategy.* The *Strategy* presents a basic assessment of the Nation's coastal research and monitoring needs, and recommends an integrated framework to address the needs of the Nation and the coastal States and Tribes in order to protect vital coastal resources. This work was identified in the *Clean Water Action Plan,* as part of a renewed effort by the Federal agencies, in partnership with States and Tribes to restore and protect the Nation's estuarine and coastal areas.

The *Action Plan* outlined several key directions for reorienting the Nation's water programs to enhance stewardship of critical coastal resources. The most fundamental of these commitments is a focus on enhancing coastal research and monitoring activities. Current responsibilities for coastal research and monitoring are often distributed among a variety of agencies. The wide distribution of these responsibilities can result in duplication of effort, informational gaps, and an incomplete understanding of resource conditions. In recognition of this fact, the *Strategy* was built upon input from a wide range of groups and individuals including non-government organizations, State and local governments, Tribes, the research community and other interests and thus, we believe, will be workable and sustainable.

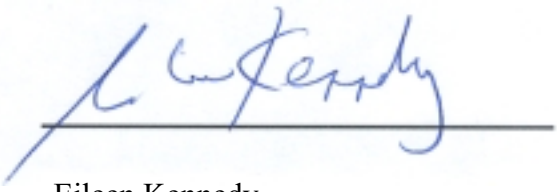


J. Charles Fox
Assistant Administrator for Water
U.S. Environmental Protection Agency

D. James Baker
Under Secretary
for Oceans and Atmosphere
National Oceanic and Atmospheric Administration



Mary Doyle
Acting Assistant Secretary
for Water and Science
U.S. Department of the Interior



Eileen Kennedy
Acting Under Secretary
Research, Education, and Economics
U.S. Department of Agriculture

Coastal Research and Monitoring Strategy Workgroup

The Coastal Research and Monitoring Strategy Workgroup was formed in 1999 with representatives from the following Federal, State, Tribes, and Non-Governmental Organizations (NGO) to prepare the *Coastal Research and Monitoring Strategy*. Simply stated, the intent of the *Strategy* is to replace traditional single-issue, single-agency, single-discipline problem solving with a coordinated, multi-agency, interdisciplinary approach to address problems of coastal water quality and coastal resources.

As directed in the Clean Water Action Plan, EPA, NOAA, USGS, and the USDA led the development of this *Coastal Research and Monitoring Strategy* and provided leadership for strategic planning, coordination, and prioritization of research and monitoring objectives. The co-chairs of the workgroup include:

Darrell Brown, EPA	brown.darrell@epamail.epa.gov
Andrew Robertson, NOAA	andrew.robertson@noaa.gov
Don Scavia, NOAA	don.scavia@noaa.gov
Timothy Strickland, USDA	tstrickland@reeusda.gov
Richard Hooper, USGS	rphooper@usgs.gov

Federal Agencies
Army Corps of Engineers
Bureau of Reclamation
Coast Guard
Department of Agriculture
Department of Interior
U.S. Fish and Wildlife Service
U.S. Geological Survey
Environmental Protection Agency
National Atmospheric and Space Administration
National Institutes of Health
National Oceanic and Atmospheric Administration
National Science Foundation
Office of Science and Technology Policy
Smithsonian Institution
Tennessee Valley Authority

States/Local Agencies
Florida Sea Grant
Georgia
Maine
Massachusetts
Minnesota
Oregon
South Carolina
Washington
Hampton Roads Sanitation District
Puget Sound Ambient Monitoring Program

Tribes
Alaska Inter-Tribal Council
Columbia River Inter-Tribal Council
Great Lakes Inter-Tribal Council
Inter-Tribal Council of Arizona
National Tribal Environmental Council
Northwest Indian Fisheries Commission
Penobscot Nation
Quinalt Nation
United South and Eastern Tribes
Yurok Tribe

Non-Governmental Organizations
Association of National Estuary Programs
Association of State and Interstate Water Pollution Control Agencies
Center for Marine Conservation
Coastal Alliance
Coastal States Organization
Consortium for Oceanographic Research and Education
National Estuarine Research Reserves Associations

TABLE OF CONTENTS

Availability of this document was announced on the following homepages and list servers to solicit review and comment.

Association of National Estuary Programs List Server
Chesapeake Bay Homepage
Clean Water Action Plan Homepage
EPA, Office of Water, Office of Wetlands, Oceans and Watersheds Homepage
Gulf of Mexico Program Homepage
National Association of Marine Laboratories Homepage
NOAA Homepage
Ocean Studies Board of the National Research Council Homepage
Pacific Ballast Water Group List Server
Sea Grant Homepage
Western Regional Panel of Aquatic Nuisance Species Task Force List Server

To obtain additional information about the Coastal Research and Monitoring Strategy or the Workgroup, please contact:

Barry Burgan, Workgroup Coordinator
U.S. Environmental Protection Agency
Oceans and Coastal Protection Division
Washington, DC
burgan.barry@epa.gov

EXECUTIVE SUMMARY

The Clean Water Action Plan: Coastal Research and Monitoring Strategy is a product of the Coastal Research and Monitoring Strategy Workgroup, which was formed in 1999 with representatives from Federal agencies, States, Tribes, and NGOs. The *Coastal Research and Monitoring Strategy* presents current deliberations on proposed implementation of the *Clean Water Action Plan* in the coastal zone.

In terms of surface area, coastal waters of the United States represent the largest economic and environmental zone of the Nation. Because a disproportionate percentage of the Nation's population lives in coastal areas, the activities of municipalities, commerce, industry, and tourism have created environmental pressures that threaten the very resources that make the coast desirable.

To address these pressures, the Clinton Administration has called for a renewed effort to restore and protect our Nation's estuarine and coastal areas. The *Clean Water Action Plan*, announced by President Clinton and Vice President Gore on February 19, 1998, is intended to redirect the Nation's water programs to "protect public health and restore our Nation's waterways". The *Clean Water Action Plan* specifically calls for the development of a strategy for coastal research (Action Item 59) and a plan for coastal monitoring (Action Item 60) including a comprehensive review of existing programs related to the generation, transport, and effect of pollutants on coastal waters, habitats, and living and economic resources. This document addresses both Action Items because they are intrinsically linked for the purposes of assessing regional and national trends, determining cause and effect relationships, and implementing adaptive management principles.

While the national investments made as a result of environmental legislation have had a dramatic effect on improving the Nation's coastal water quality, there are still environmental problems in the coastal zone. Examples of environmental issues common to most coastal States include nutrient enrichment, habitat change, protection of living aquatic resources, invasive species, pathogens, toxic contaminants, and harmful algal blooms.

The Federal government invests annually about $225 million conducting research and monitoring programs addressing these and other specific environmental issues in the coastal zone. Despite these investments, the importance of the coastal region to the Nation's economy, and the high potential for human use to adversely impact coastal resources and ecosystems, information about the status and trends of critical environmental variables in coastal regions is often lacking. Other than programs for coastal weather, water levels, commercial fisheries, and point source discharges, there are currently no nationally consistent, comprehensive monitoring programs to provide the information necessary for effective management of coastal systems.

The *Coastal Research and Monitoring Strategy* employs a monitoring-research-assessment-management cycle that integrates coastal monitoring and research objectives to enable cross-cutting and comprehensive assessments of the Nation's coastal resources. The objectives of the *Strategy* are to:

- Document the status and assess trends in environmental conditions at the scales necessary for scientific investigation and policy development;
- Evaluate the causes and consequences of changes in environmental status and trends;
- Assess environmental, economic, and sociological impacts of alternative policies for dealing with these changes; and
- Implement programs and policies to correct observed environmental problems.

The key attributes of the proposed *Coastal Research and Monitoring Strategy* include co-funding by Federal and State programs; nested designs to allow State-specific issues to be addressed in a national context; collective reporting; and cross-system comparisons.

The strategy for a national coastal monitoring design is based on the three-tiered approach developed by the U.S. Environmental Protection Agency (Messer et al. 1991) and a similar version was recommended by NSTC (1997) and has the following components:

- Characterization of Problem (Tier 1) Broad-scale ecological response properties as a base determined by survey, automated collection, and/or remote sensing;
- Diagnosis of Causes (Tier 2) - Issue- or resource-specific surveys and observations concentrating on cause-effect interactions; and
- Diagnosis of Interaction and Forecasting (Tier 3) - Intensive monitoring and research index sites with higher spatial and temporal resolution to determine specific mechanisms of interaction needed to build cause-effect models.

Data and information generated at each tier help interpretation of results from the other tiers. For example, Tier 1 (Characterization) data provide geographic context for data collected at Tiers 2 and 3 (e.g., how widespread is the problem and how much of the nation's resources are affected by its occurrence). Likewise, Tiers 2 (Diagnosis of Causes) and 3 (Diagnosis of Interactions and Forecasting) aid in understanding how serious a particular relationship or issue is.

The focus of the *Strategy* and conceptual framework is monitoring in the coastal zone. However, important research activities must occur concurrently at each level of the monitoring framework. Research plays a vital role in increasing our ability to interpret data from our monitoring programs and enhance our monitoring tools and methods. Research is the foundation underlying all tiers of the monitoring framework, and is critical to achieving the objectives of integrated assessments.

The objectives and the conceptual framework for a *Coastal Research and Monitoring Strategy* have been defined by the Workgroup and are included in this document. However, the Workgroup recognizes that further development of an implementation strategy which contains specific action plans for each of the following recommendations is necessary to execute the concepts of this *Strategy*. The final section of this document suggests issues that should be considered during implementation. However, development of an implementation plan is beyond the scope of this Workgroup.

The following six recommendations are offered:

1. *Enhance and adapt existing programs to support an integrated and effective national coastal monitoring program.* A high priority is placed on the development of a national coastal survey based on State-level coastal monitoring programs. The data collected from coastal States could provide a comprehensive and consistent picture of the "coastal health" of each State which would complement the partial requirements of Section 305(b) of the Clean Water Act. The data generated as a result of these monitoring activities could be used to support States' 303(d) listing processes.

2. *Enhance and integrate interagency research efforts to fill data gaps, to increase the understanding of physical and ecological processes in the coastal zone, and to improve monitoring and assessment tools.* Opportunities must be developed to foster interagency solicitation, review, and support of research proposals. Appropriate methods include both competitive and external grant processes, and internal Federal competition and interagency agreements.

3. *Conduct periodic national and regional coastal assessments*. These would include national summary assessments, national habitat assessments, national issue-specific assessments, and regional assessments.

4. *Improve data management in support of the periodic assessments*. These activities include development and maintenance of an Internet-based coastal environmental data clearinghouse and directory of meta-data resources, development of performance-based standards for data management and data submission, and development of national data quality standards.

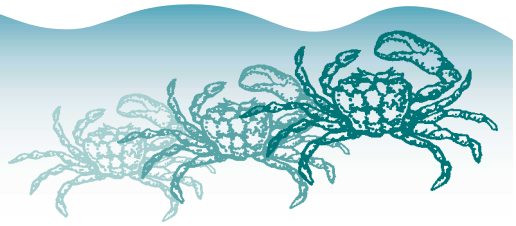
5. *Establish mechanisms to assess and adjust monitoring and research with changing national coastal priorities.* User-advisory and technical committees, composed of representatives from Federal, State, and local governments; academia; not-for-profit organizations; and the private sector would be established to ensure that the products and services of the system are relevant and stay on track and to ensure that development and implementation of the system uses the best available scientific methods and technologies.

6. *Establish a mechanism to define and develop an implementation plan for each of the Recommendations 1 - 5 and to oversee efficient execution of a national program.* To carry out the above recommendations and develop an implementation plan for a national strategy, the formulation of an interagency oversight committee is recommended. Long-term viability of the committee is essential.

List of Acronyms

ANICA	Atmospheric Nutrient Input to Coastal Areas
ARL	Air Resources Laboratory
ASP	Amnesic Shellfish Poisoning
BLM	Bureau of Land Management
CENR	Committee on Environment and Natural Resources
CISNet	Coastal Intensive Site Network
DDT	Dicholoro Diphenyl Tricholoroethane
DOI	Department of the Interior
DSP	Diarrhetic Shellfish Poisoning
ECOHAB	Ecology and Oceanography of Harmful Algal Blooms
EEZ	Exclusive Economic Zone
EPA	Environmental Protection Agency
EMAP	Environmental Monitoring and Assessment Program
FGDC	Federal Geographic Data Committee
GIS	Geographic Information System
GNP	Gross National Product
HAB	Harmful Algal Bloom
HAP	Hazardous Air Pollutants
LMER	Land-Margin Ecological Research
LTER	Long Term Ecological Research
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NCSL	National Conference of State Legislatures
NEP	National Estuary Program
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Administration
NOPP	National Ocean Pollution Program
NPS	National Park Service
NSF	National Science Foundation
NSP	Neurotoxic Shellfish Poisoning
NSTC	National Science and Technology Council
NWQMC	National Water Quality Monitoring Council
PCB	Polychlorinated Biphenyls
PSP	Paralytic Shellfish Poisoning
RMRP	Regional Marine Research Program
SAV	Submerged Aquatic Vegetation
SST	Sea Surface Temperature
TVA	Tennessee Valley Authority
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

INTRODUCTION



The *Clean Water Action Plan,* announced by the Clinton Administration on February 19, 1998, is intended to direct the Nation's water programs to "protect public health and restore our Nation's waterways" by setting strong goals and providing States, Tribes, communities, and individual landowners with the tools and resources to meet those goals. The *Plan* builds on the foundation of existing programs and proposes new steps to strengthen them. Its goals include:

- Strengthening and enhancing core programs that have been designed to protect public health, safeguard the sources of our drinking water, prevent polluted runoff, enhance natural resources (*e.g.,* wetlands and stream corridors), and improve citizens' access and right-to-know to water quality information;
- Promoting State-led, watershed approaches to pollution prevention, including restoration and preservation of watershed health through the coordination of government programs across Federal agencies, as well as across organizations within those agencies; and
- Developing a systematic program to monitor the effects of land use and modifications to coastal systems on the hydrology of estuaries and coastal areas and subsequent impacts on hypoxia, sedimentation and species composition and biodiversity.

For coastal systems, the *Plan* provides specific directions for reorienting programs that enhance stewardship of critical coastal resources.

It commits to:

- Coordinate coastal research and monitoring activities to provide useful information upon which to base coastal management decisions now and in the future;
- Expand Federal coastal programs to focus on urgent issues, such as harmful algal blooms, fisheries management, and habitat restoration;
- Build and expand partnerships among Federal, State, Tribal, local, and business stakeholders to achieve clean water and public health goals in the coastal zone; and
- Approve and implement State and Tribal polluted runoff control programs developed under Section 6217 of the Coastal Zone Act Reauthorization Amendments.

The *Plan's* guidance and directives for future coastal water research and monitoring provide an outline for the *Coastal Research and Monitoring Strategy* presented in this document. These directives are consistent with two important documents of the National Science and Technology Council (NSTC) which reviewed the status of U.S. environmental and coastal research and monitoring. In *Integrating the Nation's Environmental Monitoring and Research Networks and Programs* (NSTC 1997), guidance is proposed for synthesizing information into integrated assessments. *Setting a New Course for Coastal Ocean Science* (NSTC 1995) provides a framework and goal for research and relates it to monitoring, or observation, programs. Both recognize the importance of basing policy and management on good science, and recognize the current gaps in our understanding of pressing environmental issues, often resulting from inefficient coordination of Federal research and monitoring programs.

Key actions for coastal waters specifically called out in the *Plan* are the development of a multi-agency coastal research and monitoring strategy, to be lead by NOAA, EPA, DOI, and USDA. This *Coastal Research and Monitoring Strategy* has been developed in response to these actions, building on the work of the previous NSTC efforts. This document presents an assessment of the Nation's coastal research and monitoring needs, and recommends an integrated research and monitoring framework to guide future Federal programs in the coastal zone. Coastal information needs have been summarized in recent analyses by government, academia, the environmental community, and industry. A compendium of these assessments is included in Appendix A of this document. Appendix B of this document presents case studies demonstrating how this *Strategy* can be implemented to address selected coastal issues.

The Clean Water Action Plan strategically outlines actions that are co-dependent and beneficial to the implementation of one another. Therefore, successful implementation of the recommendations in this *Strategy* will require coordination with programs established under relevant actions in the *Plan*. For example, though this *Strategy* focuses primarily on the environmental conditions of the coast, to accurately assess coastal health, it will be necessary to consider pollution impacts to human health. This should be accomplished by integrating results from Clean Water Action Plan items developed to ensure that fish and shellfish are safe to eat (Action Items 1–10) and that beaches are safe for swimming (EPA's Beaches Program, Action Items 11–14). Similarly, though the monitoring and research that results from this *Strategy* will focus on the coastal geographic area, it will be essential to integrate coastal watershed data (*e.g.*, hydrology, land-use changes, point and nonpoint sources of pollutants, and socio-economic changes) to fully assess coastal trends and implement appropriate management actions. Though cross-communication will be crucial, it is not within the scope of this Workgroup to develop a strategy that addresses the *Clean Water Action Plan's* directives beyond the environmental health of the coastal zone. It is key that a plan for integrating with other initiatives and programs beyond the scope of this *Strategy* be developed as part of the recommended implementation plan.

The *Strategy* described herein proposes a multi-tier system to cover all appropriate spatial and temporal scales embedded within a monitoring-research-assessment-management cycle. This cycle maximizes the use of information from each of the activity areas (*e.g.*, monitoring) to enhance each of the remaining activities.

COAST-RELATED ACTION ITEMS FROM THE CLEAN WATER ACTION PLAN

- *EPA and NOAA will lead development of a multi-agency coastal research strategy to be issued in 1999.*
- *EPA, NOAA, DOI, and USDA — in cooperation with other Federal agencies, States, and Tribes — will develop a plan by the end of 1999 for coordinated monitoring of coastal waters and will, by the end of 2000, develop a comprehensive report to the public on the condition of the Nation's coastal waters.*

COASTAL RESOURCE ISSUES

The coastal ocean extends from shore to the seaward limit of the Exclusive Economic Zone (EEZ), and includes estuaries and embayments. The Great Lakes are also included because they represent similar resources and problems as those associated with marine coasts. The coastal ocean is the largest of the Nation's environmental components — exceeding the land area of the United States and its territories.

Coastal water resources represent enormous natural and economic importance to the Nation. Coastal ecosystems are among the most productive and diverse areas including estuaries, coastal wetlands, coral reefs, mangrove forests, and upwelling areas. Marine mammals, waterfowl, commercial fish species, and a multitude of other species inhabit or migrate through our coastal waters. In addition, a large number of Americans depend on coastal waters for their livelihood, food, recreation, and enjoyment. The coastal ocean also supports waterborne commerce, which is increasingly important in our global economy.

The health and welfare of the United States is intrinsically dependent on our ability to wisely use and conserve the resources of our coastal region. Unfortunately, our populations' preference for the coast has created environmental pressures that threaten the very resources that make the coast desirable. Since 1960, the population growth in the 672 counties now defined as coastal by the U.S. Census Bureau has been more rapid than in the interior. This trend is expected to continue, increasing pressures on the coastal zone. These stressors include increased loading of nutrients, toxic chemicals, and pathogens from municipal and industrial discharges; and alteration of the coastline and coastal currents. These stressors all converge on the coasts and tax their assimilative capacity, ultimately leading to degradation and loss of critical coastal habitats upon which healthy and diverse living resources depend.

The Nation has many success stories related to improving the quality of coastal waters resulting from 25 years of cooperative effort among Federal, State, Tribal, and local government and the public and business. These efforts have dramatically reduced the levels of nutrients and other pollutants entering coastal waters by implementing measures to manage multiple uses of the coastal zone. These measures have restored the environmental, recreational, and economic value of

U. S. COASTAL FACTS

- *More than one half of the population lives in the coastal region.*
- *U.S. commercial fisheries resulted in $3.9 billion in revenue to fishermen in U.S. ports in 1991.*
- *About one-third of the nation's GNP originates in the coastal zone.*
- *The coasts annually attract about 180 million recreational visitors.*
- *Most international commerce is shipped through coastal waters; greater than 99 percent by weight and 80 percent by value.*
- *The Nation's coastal population is growing by 3600 people per day.*

large areas of the coastal zone. However, serious problems still exist. For example, of the Nation's estuaries, 39 percent are partially or fully impaired, with water quality threatened in another 4 percent (EPA 1998). Of the miles of Great Lakes waters surveyed, 97 percent reported partially or fully impaired water quality (EPA 1998).

While specific coastal water quality problems differ in various regions of the country, there are common issues. The most common environmental issues in coastal and estuarine areas of the Nation include:

- *Nutrient enrichment/coastal eutrophication* — Many coastal areas are "overfed" by nutrients such as nitrogen and phosphorus from point and nonpoint sources, leading to excessive vegetation and algal blooms. Overgrowth of algae is associated with low dissolved oxygen, high turbidity, losses of submerged aquatic vegetation and bloom of nuisance species.

WETLANDS LOSS

In Louisiana alone, coastal wetlands are being lost at a rate of 65 km^2/year (EPA 1999).

- *Habitat change* — Development pressures have resulted in substantial physical changes along many areas of the coastal zone. Coastal wetlands continue to be lost to residential and commercial development, while the quantity and timing of freshwater flow, critical to river and estuarine function, continue to be altered. Cumulative negative impacts include degraded in-stream habitat conditions, loss or degradation of estuarine habitat, and changes in nearshore sediment transport due to erosion and sedimentation processes.

NUTRIENTS IN THE MID-ATLANTIC BIGHT

The EPA Mid-Atlantic Bight monitoring initiative has demonstrated that nutrients in coastal waters have been increasing at a statistically significant rate over the past 20 years. The translocation of nutrients from the estuaries, coupled with increased air deposition, is responsible. The result is a three-fold decrease in water quality, as measured by increases in plankton biomass and decreases in transparency, and increases in the numbers of harmful algal blooms (pers comm. W. Muir EPA Region 3).

- *Living aquatic resources* — Fish and other aquatic life are often the first to be affected by substances deposited in our Nation's waterways. Because they are often consumed by people, the quality of our living resources is a significant public health issue. Living aquatic resource issues include:
  - Increase of disease and decrease in fecundity, with the resulting decline in fish and shellfish harvest;
  - Contaminants in fish and shellfish, with resulting shellfish bed closures and public fears about seafood consumption;
  - Decline in fish stocks from overfishing and environmental causes;

- Loss of habitat for waterfowl and migratory birds and threatened and endangered species; and
- Loss of expected diversity for macrobenthic and finfish communities.

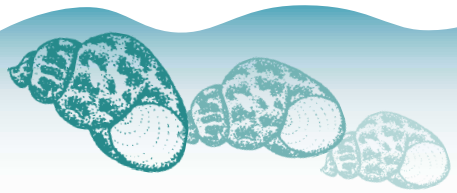
- *Invasive species* — Invasive species, such as the zebra mussel, threaten the abundance of native species, change system productivity, and cause significant damage to valued natural resources. Invasive species have been introduced through ballast water exchange in coastal water, aquaculture operations, importation of ornamental species, and intentional introduction to control pests or other purposes.
- *Pathogens* — The presence of pathogens in coastal environments can cause decreases in the population, size, or economic value of commercial species, or may directly impact the value of coastal resources through beach closures or other limitations of use.
- *Toxic contaminants* — Toxic contaminants introduced to coastal waters often accumulate in sediments, adversely affecting bottom-dwelling organisms, fish and shellfish that feed on them, or accumulate directly in living aquatic resources. Effects on estuarine biota include altered reproductive success, growth rates, and competitive abilities, and death. Toxic contaminants can be introduced to coastal waters from point sources such as permitted discharges or from nonpoint sources such as atmospheric deposition, agricultural runoff, and urban runoff.
- *Harmful algal blooms* — Harmful algal blooms (HAB) have deleterious effects on plants, animals, and/or humans. While HABs, such as red tides, have been occurring for centuries, they appear to be more frequent and extensive. HAB-associated human diseases include paralytic shellfish poisoning, neurotoxic shellfish poisoning, diarrhetic shellfish poisoning, and amnesic shellfish poisoning. *Pfiesteria piscicida* outbreaks along the mid-Atlantic and Carolina coasts in the 1980s and 1990s have been implicated in multiple large-scale fish kills and a variety of human health effects associated with exposure to HAB-contaminated water.

BEACH CLOSINGS

Since 1988, there have been more than 23,000 beach closings and advisories along U.S. coasts and the Great Lakes (NSTC 1997).

HUMAN HEALTH IMPACTS

In 1996, 2,193 fish consumption advisories were issued in 48 States. Mercury, PCBs, chlordane, dioxin, and DDT were responsible for almost all of these advisories (EPA 1998b).



CRITICAL COASTAL PROBLEMS IN THE U.S.

(from NSTC 1997)

- ***Deteriorating water quality*** *— One-third of our shellfish beds are closed; medical wastes and sewage close beaches and waters for use; toxic algal blooms close fisheries and shutdown tourism. Since 1988, it has been necessary to post approximately 23,000 beach closings and advisories along U.S. coasts, including the Great Lakes, to protect human health.*

- ***Invasive species and habitat loss*** *— Changes in freshwater input to the coast are producing unprecedented changes to habitats resulting in changes in species composition and diversity and fostering invasions by exotic species.*

- ***Physical modifications and habitat loss*** *— Physical modifications to the environment are altering the hydrology and increasing erosion, resulting in modified habitats and reduction in ecologically productive habitat, including those on which protected and endangered species depend.*

- ***Depletion of fisheries*** *— 43 percent of our fisheries are over-exploited; a $5 billion trade imbalance in fisheries products results in lost jobs.*

- ***Moratoria on oil and gas development*** *— Moratoria are imposed on offshore oil and gas development in some areas because existing scientific information could not effectively address environmental concerns for all the phases of oil and gas activities.*

- ***Coastal storms and widespread coastal erosion*** *— Storm losses have escalated to tens of billions of dollars due to increased development of coastal areas.*

NEED FOR INTEGRATED COASTAL RESEARCH AND MONITORING

An inventory of Federal monitoring programs conducted from 1991 through 1993 revealed that eight agencies were conducting at least 38 programs in the coastal ocean (NSTC 1995). The total direct effort of Federal research in the coastal ocean was $228 million in FY 1991, $218 million in FY 1992, and $227 million in FY 1993 (NSTC 1995). Federal agencies indicated that 45 percent of the funding was directed at questions related to environmental quality, 26 percent to living resources, 13 percent to nonliving resources, 10 percent to habitat conservation, and 6 percent for protection of life and property. Within the coastal zone, 43 percent of the Federal investment was directed at the ocean margins, 33 percent at estuaries, 15 percent at the Great Lakes, and 5 percent to shorelines. The four agencies expending the most dollars related to coastal research and monitoring were the Department of the Interior, Department of Commerce, Environmental Protection Agency, and National Science Foundation, which cumulatively accounted for about 95 percent of the total funding.

FEDERAL FUNDING FOR U.S. COASTAL SCIENCE

Four agencies account for almost 95 percent of all Federal research dollars directed for coastal ocean issues:

- *Department of the Interior* — *$92 - $102 million*
- *Department of Commerce* — *$66 - $69 million*
- *National Science Foundation* — *$26 - $29 million*
- *Environmental Protection Agency* — *$20 - $26 million*

Range of annual expenditures 1991 - 1993 (NSTC 1995)

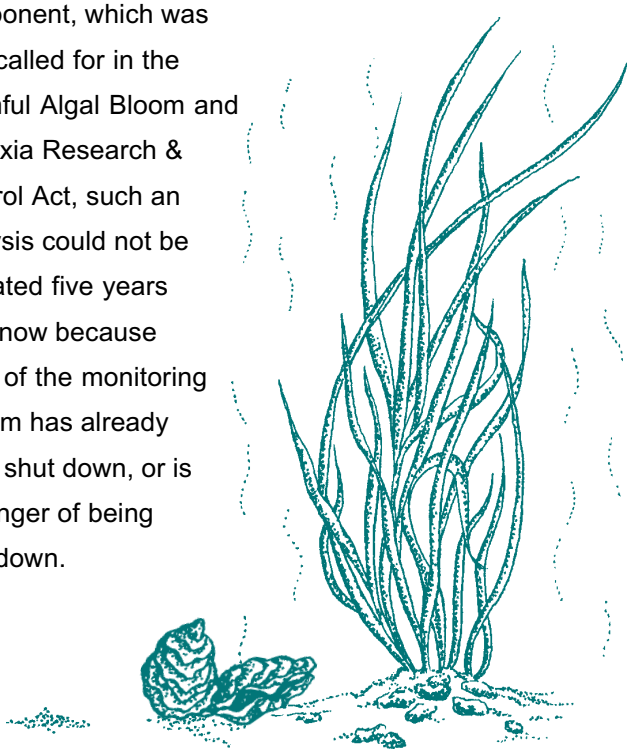
Despite the importance of the coastal region to the Nation's economy and well-being, and the high potential for human use or natural events to adversely impact coastal resources and ecosystems, information about the status and trends of critical environmental variables in coastal regions is often lacking. Other than programs for coastal weather, water levels, commercial fisheries, and point source discharges, there are currently no nationally provide the information necessary for effective management of coastal systems. Attempts to design one program that fits all cases have generally failed because all temporal and spatial scales are pertinent and important but impossible to design for use in one blueprint. EPA's and NOAA's current "national" programs, EMAP-Coastal and National Status and Trends (NS&T), respectively, address pieces of the *Coastal Research and Monitoring Strategy* but do not provide information at all pertinent scales. EMAP-Coastal measures most of the appropriate variables but not at a national scale and NS&T measures relatively few variables at a national scale (with some issues regarding the placement of sampling sites). EPA's new monitoring initiative, Coastal 2000, expands EMAP-Coastal's monitoring throughout all coastal States and effectively meets the requirements of the first tier proposed in the National Coastal Strategy.

This serious shortcoming in the Nation's past environmental programs has been recognized and

consistent, comprehensive monitoring programs to highlighted by government, academia, the environmental community, and industry. A group representing all four of these stakeholder groups recently developed the *Report of the Nation's Ecosystems* (The Heinz Center 1999). The report identified many specific deficiencies related to addressing national environmental problems. For example:

- National monitoring or consistent reporting processes for beach closures currently do not exist, even though thousands of closures occur each year;
- National monitoring of conditions leading to coastal eutrophication does not exist, even though half of our estuaries have oxygen depletion problems;
- Monitoring of the frequency or extent of harmful algal blooms, fish disease, or pathogens is not being addressed on a national level, even though every State is affected;
- No systematic effort exists to quantify the areal extent and fragmentation of salt marshes, sea grasses, coral reefs, and other important habitats, even though there are, for economically and ecologically important species, legislated mandates to protect and restore these habitats; and
- No systematic programs exist to monitor the loss of species, changes in species mix, or rates of invasions by exotic species, even though we know that these are growing serious threats to our ecosystems and economy.

Because we lack nationally consistent monitoring and observing guidelines, the difficulty in conducting analyses on national and regional scales is also hampering efforts to assess potential impacts on coastal systems. For the *National Assessment of Potential Impacts of Climate Variability and Change* (NOAA 2000 *In prep.*), the coastal and marine analysis has been based primarily on site-specific case studies, because nationally consistent trend (and forecast) data are not available for key parameters, such as temperature, salinity, current patterns, habitat extent, and biological community structure. Similar problems confront agencies responsible for developing the *National Assessments of Harmful Algal Blooms and Hypoxia* (Interagency Task Force on Harmful Algal Blooms and Hypoxia 2000 *In prep.*). These national assessments must rely on sparse, site-specific data and expert judgment to document the status of the problem; it is not possible to document trends. While sufficient data were available for the Gulf of Mexico/Mississippi River component, which was also called for in the Harmful Algal Bloom and Hypoxia Research & Control Act, such an analysis could not be repeated five years from now because most of the monitoring system has already been shut down, or is in danger of being shut down.



In addition to national assessments, Federal land management agencies such as the National Park Service (NPS) and Bureau of Land Management (BLM) have specific information needs to wisely manage the coastal areas. The NPS recently conducted a Geology of Coastal Ecosystems workshop which identified four major concerns: (1) the need to better understand the impact of people on coasts and coastal processes, (2) the need for more and easier access to scientific information; (3) better centralized information; and (4) rapid response to short-term needs. The difficulties BLM encountered in assembling inventory information for the newly created California Coastal National Monument exemplifies these concerns. The need for improved integration of coastal and ocean observation systems has also been identified by Congress. In response, the National Ocean Partnership Program has prepared a report outlining needs and response strategies for both basin-scale and coastal monitoring and observing systems. This report found that the "scarcity of observations on coastal ecosystems of sufficient duration, spatial extent, and resolution are major impediments to the development of a predictive understanding of environmental variability in coastal waters" (NOPP 1999).

> *"Effective prediction, assessment, policy, and management are built on accurate, timely, and appropriate observations and monitoring programs."*
>
> *from* **Setting a New Course for Coastal Ocean Science**, *National Science and Technology Council 1995*

The Administration's guidance for FY 2001 interagency research and development priorities highlights efforts within the Committee on Environmental and Natural Resources' initiative on Integrated Science for Ecosystem Challenges (NSTC 1997). This effort to "develop the knowledge base, information infrastructure, and modeling framework to help resource managers predict/assess environmental and economic impacts of stress on vulnerable ecosystems" depends fundamentally on monitoring and observation systems. The integrated science *Strategy* identifies several serious impediments to delivering the integrated science needed to sustain the Nation's ecosystems, and emphasizes the need to bring together social and ecosystems data to produce information and tools needed to effectively manage ecosystems.

These needs are not new. The call for an improved coastal observation system, as part of an integrated, interagency coastal ocean science strategy was described in the National Science and Technology Council report, *Setting a New Course for Coastal Ocean Science* (1995). This study recommended that, "Effective prediction, assessment, policy, and management are built on accurate, timely, and appropriate observations and monitoring programs. The output from some observation systems would feed directly into decision-making processes, others would support real-time forecasting and analysis capabilities, and still others must be combined with other data sets to form critical assessments of environmental risk. A hierarchy of observation systems would supply appropriate information in real time as seasonal and annual summaries, and as multi-year summaries." The spatial requirements of the observation systems include both regional and national scales.

A NATIONAL STRATEGY

This section of the *Strategy* presents the conceptual framework based on two models. The first is presented in the National Science and Technology Council's *Integrating the Nation's Environmental Monitoring and Research Networks and Programs* (NSTC 1997), which sets forth a common integrated strategy for future Federal investments in all fields of environmental research and monitoring. The second is the EPA EMAP coastal monitoring strategy, which has proven extremely successful as a framework for coastal pollution research and monitoring.

The framework will guide the direction of coastal monitoring and research across Federal agencies to address current and future environmental issues of the coast. The recommended coordination and collaboration of Federal agencies will permit future coastal research and monitoring activities to benefit from the specific knowledge and experience of each agency — the resulting decision-making capability will be greater than the sum of the parts.

Objectives of Research and Monitoring within an Integrated Assessment Framework

The complex and changing nature of coastal waters, bays, estuaries, and wetlands often requires the integration of physical, chemical, biological, and ecological data to assess coastal environmental conditions; and often requires the integration of research with monitoring to improve or extend our assessment capabilities. For the past decade, academic, Federal, State, and private sector scientists have been working toward new approaches to doing this (Messer et al. 1991; NSTC 1997). These integrated assessment efforts appear to have roughly the same common goal:

Provide the national, regional, and local capabilities to measure, understand, analyze, and forecast ecological change (natural and anthropogenic) that can affect coastal economies, public safety, and the integrity and sustainability of the Nation's coastal ecosystems.

Integrated assessments provide an effective format for bridging science and policy and, therefore, they are the appropriate context for designing a research and monitoring strategy. The objectives of integrated assessments are to:

- Document status and assess trends in environmental conditions at the necessary scales for scientific investigation and policy development;
- Evaluate the causes and consequences of changes in environmental status and trends;
- Assess environmental, economic, and sociological impacts of alternative policies for dealing with these changes; and
- Predict change and create an early warning detection.

Research is necessary to improve both the assessment techniques and the monitoring done to support these assessments. The research necessary to support these activities includes:

- *Analysis of environmental, economic, and sociological impacts of coastal policy* — A large number of National, State and Tribal policies direct the expenditure of billions of dollars of public and private money to protect the coastal zone. It is important to understand if these investments are well spent — if the coastal zone has been protected or restored.

- *Analysis of coastal physical and ecological processes* — An understanding of the physical and ecological processes of the coastal zone underlies all of the other objectives. Investments in research to improve this understanding are paid back directly or indirectly by our increasing our ability to truly understand current status or predict future trends, and to determine when a change is important or not.
- *Improvement or enhancement of monitoring and assessment tools* — Our ability to accomplish the objectives described above rests on our ability to use Federal investments wisely. Advancements in field monitoring and observation, remote sensing, and data management and display technology have created opportunities to acquire, manage, and disseminate coastal environmental data more efficiently and economically than was thought possible 10 years ago. The challenge is to wisely select or improve upon the toolbox of traditional, new, or emerging technologies that will effectively provide information needed for policy or management decisions.

The effective integration of monitoring and research will enable comprehensive assessments of the Nation's coastal resources and supporting management of the problem. This approach is essential for differentiating between actual and perceived environmental issues in the coastal zone, so that (1) we address all major coastal environmental issues appropriately and in a timely manner, and that (2) we avoid unnecessary environmental regulation or environmental damage. It follows that an integrated monitoring and research strategy focused on supporting the comprehensive management of our coastal resources requires an integration of key assessment and management elements with monitoring and research objectives (Figure 1).

Monitoring is crucial to documenting status and assessing trends, evaluating the cause-effect relationships between stressors and impacts, and assessing the effectiveness of management actions. Research is an important part of environmental monitoring and is particularly important for improving our ability to interpret monitoring data, and improving our assessment capability. Additionally, research is key to predicting impacts as a result of emerging trends and to forecasting and assessing the impacts and benefits of management actions.

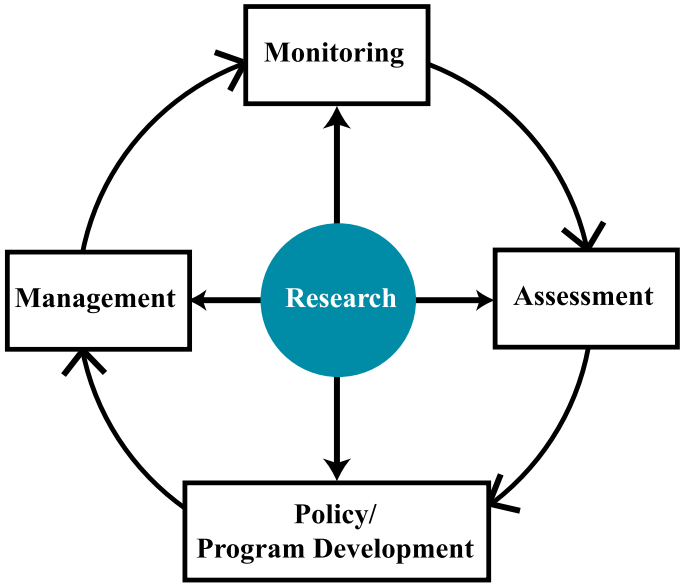


Figure 1. Monitoring-Research-Assessment-Management Cycle that Gauges Coastal Ecological Condition and the Effectiveness of Management Policies and Programs.

These objectives have been agreed to by the Workgroup as capturing the intent of the *Coastal Research and Monitoring Strategy* — to observe coastal status and differentiate between real and perceived coastal water issues, and to provide informed and expert judgement necessary for coastal policy and management. The objectives are, to a large extent, derived from national environmental monitoring and research objectives presented in

Integrating the Nation's Environmental Monitoring and Research Networks and Programs, the national framework established by the National Science and Technology Council (NSTC 1997). The NSTC objectives, as modified to address specific issues of coastal waters, overlap with charters of the Departments and Agencies represented in the Workgroup.

To be effective, an integrated assessment strategy for monitoring and research activities must be designed to accomplish all of these objectives. Only by addressing all components can the effectiveness of management actions be tracked.

Monitoring

A national coastal monitoring strategy must simultaneously meet the needs of the Nation, the coastal States, and Tribes. This *Strategy* is the most effective way to satisfy needs at these scales, and it is also essential to receive the necessary cooperation from the coastal States and Tribes. Only through this cooperation can the longevity of any national coastal monitoring effort be assured. The mechanisms to achieve this interaction are beyond the scope of this *Strategy*. However, key attributes of any subsequent program should include co-funding by Federal and State programs, nested designs to allow state-specific issues to be addressed in a national context, a uniform reporting protocol to facilitate data and information exchange, and further attention on specific State issues, collective reporting, and cross-system comparisons.

The coastal ecosystems addressed by this *Strategy* include estuaries, coastal waters, beaches, wetlands and the Great Lakes. Because the scale and

The Coastal Research and Monitoring Strategy addresses the physical, chemical, biological, and ecological conditions of coastal waters, bays, estuaries, beaches, wetlands, and the Great Lakes.

dimensions of these systems vary considerably, the "optimal" monitoring design is one that allows adaptation to each ecosystem while maintaining a similar core design that would allow comparison and tiered estimates of condition. As previously stated, attempts to design one program that fits all cases generally fail because all temporal and spatial scales are pertinent and important. Therefore, the design proposed here incorporates a flexible, nested approach that uses a base design (common to all) with details designed by the appropriate stakeholders at each level.

The strategy is based on the three-tiered approach developed by EPA (Messer et al. 1991) and a similar version was recommended by NSTC (1997) (Figure 2). The three-tiered monitoring strategy addresses several of the major attributes of an integrated assessment (Figure 3): (1) characterization of the problem, (2) diagnosis of causes, (3) management actions, (4) assessment of effectiveness of actions, (5) re-evaluation of causes, and (6) continued assurance of effectiveness of actions. These attributes, in combination with formulation of management actions, create the cycle of monitoring and attendant research necessary to identify, solve, correct, and manage environmental problems. The

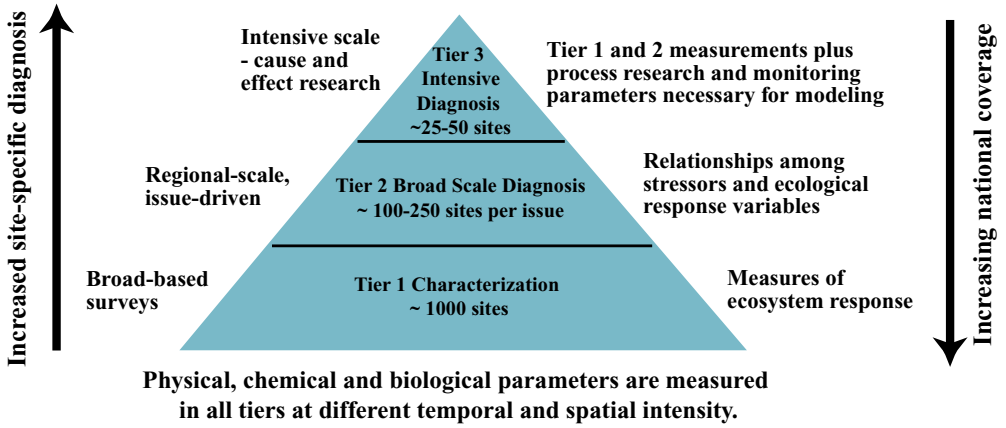


Figure 2. Conceptual Framework of a National Coastal Monitoring Strategy.

proposed three-tiered national coastal monitoring design features:

- *Characterization of Problem* (Tier 1) - Broad-scale ecological response properties as a base determined by survey, automated collection, and/or remote sensing;
- *Diagnosis of Causes* (Tier 2) - Issue- or resource-specific surveys and observations concentrating on cause-effect interactions; and,
- *Diagnosis of Interaction and Forecasting* (Tier 3) - Intensive monitoring and research index sites with higher spatial and temporal resolution to determine specific mechanisms of interaction needed to build cause-effect models.

Data and information generated at each tier help interpretation of results from the other tiers. For example, Tier 1 (Characterization) data provide geographic context for data collected at Tiers 2 and 3 (*e.g.*, how widespread is the problem and how much of the Nation's resources are affected by its occurrence). Tiers 2 (Diagnosis of Causes) and 3 (Diagnosis of Interactions) aid in understanding how serious a particular relationship or issue is. Tier 3 also aids in interpreting results at Tiers 1 and 2, and links process research with long-term ecological and environmental measurements to strengthen cause-effect linkages and predictive models that relate stresses and environmental responses.

CHARACTERIZATION OF THE PROBLEM (TIER 1)

Measurements in Tier 1 are designed to characterize problems by tracking the natural dynamics of coastal ecosystems in order to identify large-scale existing and emerging issues. Therefore, these measurements focus on the first step of integrated assessments (Figure 2) – documenting status and trends in order to characterize the problem(s). Tier 1 measurements generally would be taken at fairly coarse spatial and temporal scales based on probabilistic approaches, except for those that can be generated by remote platforms (*e.g.*, satellites) where coverages may be complete. This approach is State-oriented and through consistency of design and measurements produces a national coverage. Consistent with the most recent work in this area

(National Academy of Sciences 2000), indicators to be measured in Tier 1 include (1) Measures of community and ecosystem structure and function (productivity, abundances and distributions of plants and animals, diversity, and important attributes of nutrient and chemical cycling), and (2) environmental stressors (primary stressors of coastal ecosystems) and habitat variables (measures required to interpret natural variability in rapidly changing coastal environments).

Many measurements in Tier 1 can be derived through automated sensors (*e.g.*, satellites, aircraft reconnaissance, and buoys). However, several measurements must still be conducted through field sampling and laboratory analysis. These measures, collected using an integrated probabilistic design including all coastal States, would provide a comprehensive, integrated assessment of the "health" of each state and, through integration, the Nation's coastal resources. Approximately 50 sites are likely to be included at this level for each coastal State for each coastal environment (*e.g.*, wetlands, estuaries, beaches, offshore waters) and the Great Lakes.

DIAGNOSIS OF LARGE-SCALE CAUSES (TIER 2)

In order to assess the causes of problems identified in Tier 1, Tier 2 monitoring would be conducted only in areas identified as impacted by Tier 1 monitoring or through other available databases *(e.g.*, 303d list). This "national" sampling tier would be stratified by environmental issue, with a monitoring program associated with each stratum.

Examples of strata are:

- Eutrophication;
- Contamination by Metals and Organics;
- Contamination by Microbial Organisms;
- Invasive Species;
- Habitat Degradation;
- Fisheries Declines;
- Harmful Algal Blooms; and
- Hypoxia.

The primary purpose for the collection of monitoring data at Tier 2 levels would be to quantify the relationships among ecosystem response variables (*e.g.*, productivity, benthic abundance, bird

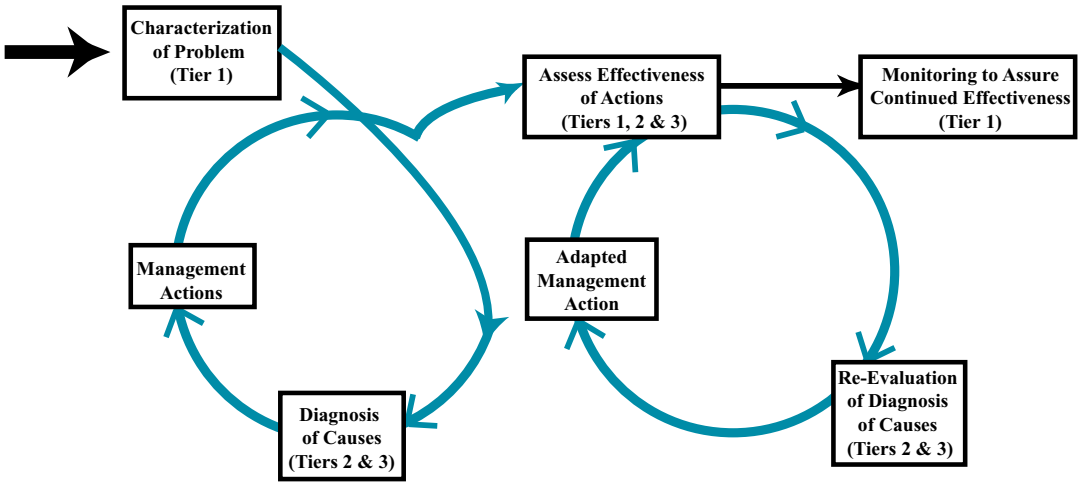


Figure 3. Integrated Assessment Process for Addressing Coastal Issues.

abundance) and environmental stressors (*e.g.*, nutrients, low dissolved oxygen, habitat loss) in order to diagnose the cause(s) of the observed environmental problem. It is through this quantification that better stewardship and better correctional operations can be determined. The number of sampling sites for each issue stratum would be largely determined by number of locations and regions displaying the particular issue, although an expectation of about 100-250 sites per issue stratum seems to be a reasonable expectation.

Tier 2 is not sufficient alone for understanding relationships well enough to develop predictive capabilities. The integration of Tiers 2 and 3 should provide that predictive power.

DIAGNOSIS OF INTERACTIONS AND FORECASTING (TIER 3)

Monitoring at Tiers 1 and 2 provide information that can be used to develop policies and actions to correct the environmental problems found throughout the Nation. However, many problems are the result of complex interactions of stressors, habitats, natural environments and anthropogenic activities. In order to determine these interactions and forecast the likely environmental response of these interactions, this *Strategy* proposes the development of Tier 3 sites. At these sites, measurements are spatially and temporally intensive and are completed at few locations over relatively short time periods (weeks to years). Much of the research necessary to develop indicators or indices with forecasting power will be accomplished at these sites, in conjunction with the intensive monitoring. Approximately 25-50 of these sites would exist.

The data and information generated at each tier assists in interpreting information from the remaining tiers. Tier 1 information places Tier 2 and 3 information into perspective: How broad a problem is the issue and how much of the Nation's resources are affected by its occurrence, its correction, and its understanding. Tiers 2 and 3 provide an understanding of the seriousness of a particular relationship or issue. At Tier 1, all problems are, in essence, treated equally, but work at Tiers 2 and 3 may show that losses of some species distributions are more important than others. Tier 3 aids in interpreting results at Tiers 1 and 2 and links process research with long-term measurements of ecological and environmental measures to strengthen cause-effect linkages and predictive models relating stresses and ecosystem response.

As more locations are studied for invasive species, and as the protocols for monitoring become more standardized, a more systematic knowledge will be gained of anecdotally known regional variations in invasion rates and species. Intensive study at specific locations where invasions had taken place, as well as at ecologically and climatically similar locations with invasion observed to a different extent or by different species, will help establish what factors put a particular area at risk from what species or types of species.

These three monitoring tiers correspond to the characterization of the problem, diagnosis of causes, and defining interactions of existing environmental problems within the integrated assessment model (Figure 3). Regardless of the requirements for specific spatial and/or temporal scales, these monitoring tiers provide the information for the assessment of the effectiveness of actions and continued assurance of that effectiveness.

Research

The interaction of research in the development, execution, and revision of monitoring coastal ecosystems is a closely paired activity as shown in Figure 3. Integrated assessments (Figure 2) depend on adapting the monitoring approach to take advantage of accumulated information, both through previous monitoring and from research to enhance measurement indicators, understand cause-effect relationships, and develop sampling approaches to reduce uncertainty.

Research activities must occur at all three tiers, representing differing specific research programs. Indicator research and development of survey methods and tools enhance our ability to characterize ecosystem condition (Tier 1). Initial monitoring activities to characterize (Tier 1) must be based on available, tested, and understandable indicators. This does not imply they are the best indicators of ecosystem condition (just the best available), and continuing research should produce better, more certain indicators. Cause-and-effect research enhances our understanding of what monitoring data represents. This research, whether at the larger scale (Tier 2) or intensive scale (Tier 3), provides the necessary interpretive information to bridge the gap between status and trend information and management actions.

Prediction of environmental problems is the long-term goal of the monitoring and research interaction. Currently, our monitoring approaches and research programs must be reactive — with monitoring results driving the research agenda and the research results modifying the monitoring approach. As cause-and-effect monitoring and research progresses, the results will provide the basis for predictive modeling, forecasting emerging environmental problems and separating changes due to natural variability from those resulting from anthropogenic stress. Once forecasting abilities can be verified, the interactive roles of monitoring and research (particularly at Tiers 2 and 3) would change, adapting to these new abilities to focus efforts in an unbiased manner rather than approaching the coastal environment as one large population.

After characterizing the coastal environment and predicting the probability of change from human activity and diagnosing the likely causes of these changes, environmental managers and stakeholders must make decisions on future policies, programs, and actions. Decisions include continuation of current activity (no action), control of future inputs, remediation of environmental contamination, or restoration of the coastal ecosystem to a desired state. Some of the uncertainties associated with these decisions are based on a lack of understanding of coastal system response, as indicated in the previous section. Research is needed to support the management decision element of the integrated assessment model, including:

- Development of standardized protocols for environmental remediation and restoration, which assure consistent outcomes;
- Evaluation of costs and effectiveness of management actions; and
- Development of decision analysis methods to help managers establish relevant goals and to facilitate consistent cost-effective decisions.

Therefore, research plays a vital role in interpreting outputs from, and methods used in, monitoring programs, and represents a key to the integrated assessment model. Research supports all phases of the assessment process. The steps in that process, and the relationships between monitoring and research, are outlined in Figure 4. Some characteristic research activities that support the integrated assessment process are presented below.

RESEARCH TO SUPPORT CHARACTERIZATION OF THE PROBLEM (TIER 1)

In addition to improving our ability to document status and trends, research at this level can also establish a means to provide early warnings.

Ecological characterization is a description of particular attributes at points in space and time, and comparison of those attributes with expectations or criteria. It is clearly impossible to do this for all environmental parameters and their changes, so indicators of these parameters are often sought. Indicators are properties that summarize elements of environmental change and provide the greatest information return for the least investment. The key question in indicator research is defining which parameters serve as appropriate surrogates for system condition and response. This is a difficult challenge because ecosystem processes are poorly understood, the distribution and intensity of stressors and their threats to ecological resources are uncertain, and it is not known which stressors place ecosystems at the most serious risk, or the extent to which critical ecological processes are being impaired. To help characterize systems, research is needed to address four basic questions:

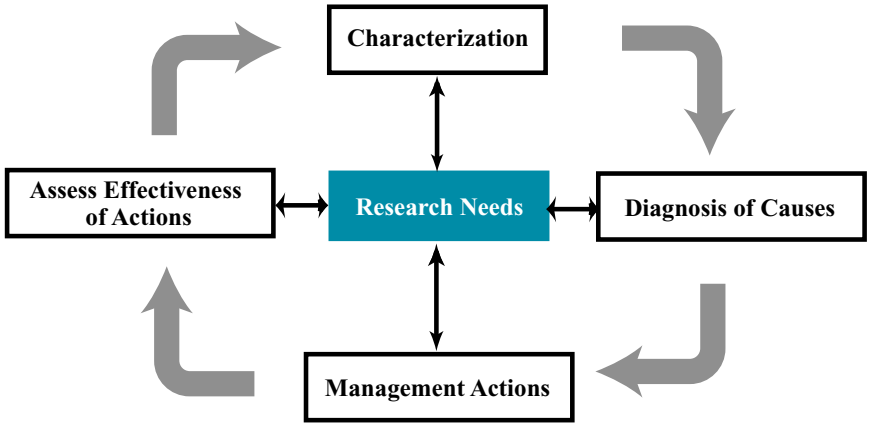


Figure 4. Research needs should be integrated with monitoring through an assessment framework.

- *What should be measured?* Answering this question requires an understanding of the important components of structure and function of the system (*i.e.,* a conceptual model), an evaluation of the appropriate levels of biological organization relevant to the monitoring purpose, and the classes of stressors that are potentially important for that resource and scale.

- *How should the indicator be measured?* The answer to this question requires that a standard protocol be defined.
- *How responsive is the indicator?* It is important to determine the degree to which a particular indicator actually responds to various stressor gradients at multiple scales, or if a stressor indicator responds to modification of input.
- *How variable is the indicator?* Ecological condition reflects the combined effects of natural variability and anthropogenic stress. Research is needed to determine methods by which natural or introduced fluctuations can be distinguished to allow detection of actual status and trends in ecological conditions.

RESEARCH TO SUPPORT DIAGNOSIS OF LARGE-SCALE CAUSES (TIER 2)

This step determines the causes and consequences of detected changes. Cause and consequence are usually determined by integrating relevant process-oriented research with tools to diagnose and predict system dynamics.

Once conditions and trends for an ecological system have been described, it is important to identify which parts of the system are changing, why they are changing, and whether particular environmental policies will be effective in dealing with those changes. To answer these questions, it is necessary to understand and be able to predict how a system will respond to individual or multiple stresses (*i.e*, develop a "load-response" relationship that describes how properties of concern relate to changes in natural and human inputs). To couple monitoring results with causes of system change, and to predict system responses, research must address three basic questions:

- *How are measures extrapolated across scales of organization?* Historically, much of the stressor-effects data used in ecological assessment have been obtained from laboratory tests, focused on responses at lower levels of biological organization. An implicit assumption in applying such results at the ecosystem level is that processes and mechanisms occurring at lower levels of organization are sufficient to describe the behavior of systems at higher levels of organization. This may have limited utility to identify properties that emerge only at higher levels. Greater understanding is needed about how impacts, measured at lower levels of ecological organization, reflect impacts at higher levels. Further research is also needed to evaluate how impacts measured in one estuary extrapolate to other estuaries.
- *How do human activities propagate through the ecosystem?* For many human activities, pathways of transmission and adaptation in ecosystems are poorly understood, hindering development of accurate assessment of ecological effects due to human activities. Additional research is needed to understand how human-induced changes in the landscape alter hydrologic and biogeochemical cycles in the coastal areas, and how adaptations or buffers in the system mitigate those changes.
- *What changes in system structure and function are due to changes in inputs.* Addressing this question requires a sound basis to link an ecological response and a change in input. In large complex systems, these links are usually developed based on observation of co-occurrence of input and response, and analysis of the strength and consistency of that co-occurrence. Due to lack of appropriate data at large scales, our current understanding is insufficient to assure correct identification of the cause of change in many systems or to predict the result of human activities on an ecosystem.

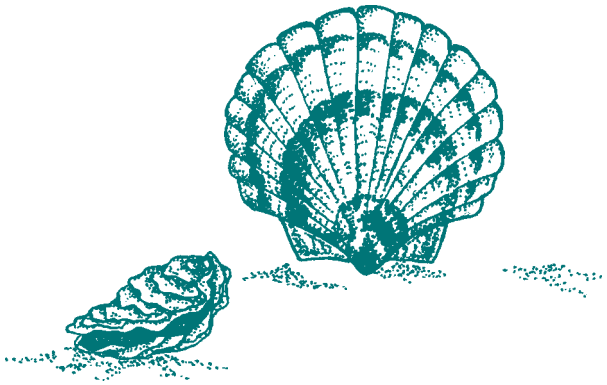
RESEARCH TO SUPPORT DIAGNOSIS OF INTERACTIONS AND FORECASTING (TIER 3)

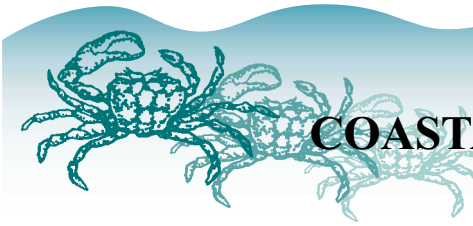
This step determines the causes, consequences, and interactions of detected changes at small or local spatial scales, particularly with regard to natural environmental changes. Cause and consequence, at this scale, are usually determined by integrating relevant process-oriented research at specific locations with tools to diagnose and predict system dynamics. The research questions at Tier 3 are identical to those at Tier 2 with the exception that at Tier 3 the scale is local, the importance of interactions may be greater, and the role of natural variability may be greater. Because of this similarity the specific research question for Tier 3 will not be repeated here.

RESEARCH TO SUPPORT DEVELOPMENT OF POLICY AND ENVIRONMENTAL MANAGEMENT PROGRAMS

While this research does not specifically correspond to one of the monitoring tiers, it is essential to the integrated assessment process. This level of research helps to determine if coastal environmental policies are having the desired effect, or if the same goals could be achieved in another manner. While monitoring can determine if management actions are achieving their desired goal, research is needed to reduce the uncertainties in ecological cause-effect relationships — the basis of predictions. Also, because management actions often involve behavior modification, it is important that economic and social considerations, inherent in the decision-making process, are assessed. Specific questions that must be addressed include:

- *How are multiple management options evaluated to select the best option?* This requires development of methods to model coastal ecosystem responses to changes so that future scenarios under different management alternatives can be simulated
- *How are ecological services and capital reserves valued in the decision process?* This requires the ability to integrate and predict economic consequences of ecological change in coastal areas. Methods to assess and predict non-monetary benefits and impacts to society, such as aesthetic or cultural requirements, are also needed.
- *How is human response to management actions measured?* Achieving desired results from many management decisions rests on the willingness and efficacy of humans to change behavior. Indicators are needed to measure this change in behavior.





COASTAL RESEARCH AND MONITORING — RECOMMENDED ACTIONS

While the objectives and the conceptual framework for the *Coastal Research and Monitoring Strategy* have been finalized, important aspects of the *Strategy* can only be defined as the *Strategy* evolves into a workable program. The *Coastal Research and Monitoring Strategy* identifies the programmatic actions recognized by the Workgroup as next steps; further development of action plans for each of the following recommendations and implementation of those recommendations is beyond the charter of the Workgroup.

To evaluate the proposed *Strategy* and develop specific recommendations, several case studies that apply the principles outlined above were analyzed (see Appendix B). The specific issues that were addressed include the major contemporary issues confronting coastal managers: eutrophication, physical habitat alteration, invasive species, toxic contaminants, and harmful algal blooms. From that analysis, from review of the rich literature on monitoring and research plans (see Appendix A), and from experience in operating the existing research and monitoring programs, the following six programmatic recommendations are offered:

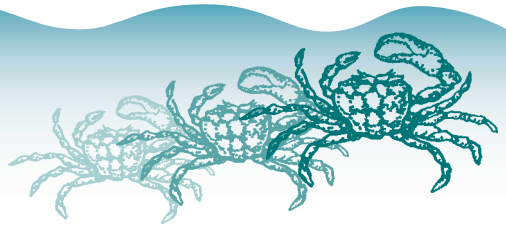
1. Enhance and adapt existing programs to support an integrated and effective national program.
2. Enhance and integrate interagency research efforts to fill data gaps, to increase the understanding of physical and ecological processes in the coastal zone, and to improve monitoring and assessment tools.
3. Conduct periodic national and regional coastal assessments.
4. Improve data management in support of the periodic assessments.
5. Establish mechanisms to assess and adjust monitoring and research with changing national coastal priorities.
6. Establish a mechanism for further action to define and develop an implementation plan for Recommendations 1 - 5 and to oversee efficient execution of a national program.

Enhance and Adapt Monitoring Programs

Many elements of this *Strategy* are in place, but they exist in multiple agencies and have not been brought together in a cohesive effort. The following are specific recommendations for transforming current efforts into a cohesive, interagency program.

CHARACTERIZING THE PROBLEM (TIER 1) - Although innovative partnerships between Federal and State governments, and between the Federal government and academia, are emerging, programs carried out at Tier 1 will require a commitment to develop new partnerships, particularly between the Federal, State, and Tribal environmental and resource agencies.

Tier 1 activities should be designed and, to a large extent, controlled by Federal entities to ensure a common design, approach, and indicator strategy among the coastal States. It is this striving for consistency in approach that will permit Tier 1 activities to determine whether the coastal environment is improving, remaining stable, or deteriorating. To properly address this question, a consistent monitoring approach must be implemented by State agencies, funded, in large part, by EPA and NOAA.



INFORMATION COLLECTED UNDER A NATIONAL PROGRAM WILL SUPPORT EXISTING FEDERAL REGULATIONS

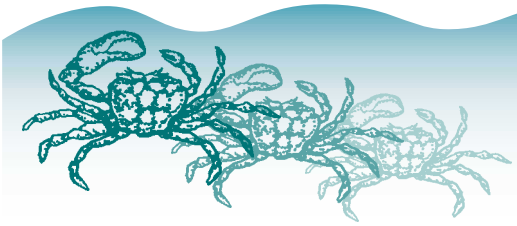
The data collected from all coastal States could provide a comprehensive picture of the "coastal health" of each State which would complement the partial requirement of Section 305(b) of the Clean Water Act. Data generated as a result of Tier 1 activities could be used to support States' 303(d) listing processes (i.e., locations found to be in a degraded condition could be added to a State's 303(d) list, while locations that indicate improved conditions and meet water quality standards could be removed from the listing). Similarly, data collected from States and Tribes in support of the Sections 303(d) and 305(b) could be used to track causal relationships of impacts to the coastal zone from coastal watershed activities and impaired waterways.

The following efforts would immediately help to solidify the proposed Tier 1 Program:

- *Develop a National Coastal Survey based on State-level consistent, coastal monitoring programs* through the integration of existing coastal programs, and expanding their use of ecological and biological indicators. Develop a joint operating agreement between EPA and NOAA to implement the present monitoring efforts as a single program implemented by the coastal States. Existing programs, such as EPA's Coastal 2000, NOAA's NS&T, and USFWS's National Status and Trends study, have somewhat complementary missions and approaches, and this joint operating agreement will outline the roles and responsibilities, common protocols and standards, and data exchange, management, and reporting methods. The sampling locations in a combined Tier 1 program must be probabilistic in nature (including some probabilistic trend sites fixed in time). The indicators for the joint Tier 1 sites should enhance existing programs' biological indicators, particularly the enumeration of pelagic and benthic species composition and new measures of ecosystem function (*e.g.*, productivity, chemical cycling). Collaborate with the USGS to develop operational capabilities for biomarkers and bioindicators.
- *Enhance remote sensing efforts* to provide high resolution laser and acoustic substrate/habitat maps, operational ocean color, turbidity, and sea surface temperature (SST) products, as well as coastal land and habitat coverage change.
- *Enhance the density of coastal buoy and shore-based meteorological and water-level observing system network* by adding temperature, salinity, nutrients, hazardous algal blooms and other chemical and biological sensors.

DIAGNOSING THE CAUSE(S) OF PROBLEMS (TIER 2) -

Tier 2 efforts will require a more fully developed and an integrated partnership among Federal, State, Tribal, and academic programs. A key emphasis for these regional programs is to add value to current Federal, State, Tribal and academic monitoring and to expand the utility of Tier 1. This can be accomplished by providing consistent protocols and standards for the augmentation of Tier 1 sampling sites to directly examine pertinent issues and problems while permitting data exchange, system



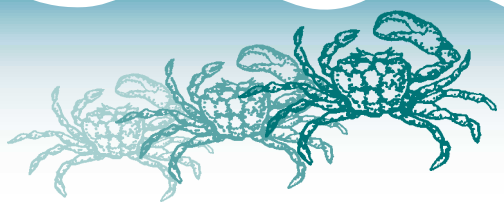
comparisons, and regional and national synthesis. Specific and immediate recommendations would include the following:

- *Expand existing programs to estimate riverine nutrient and contaminant loads* in Tier 2 regional programs by operating additional stations for sampling water quality and measuring water quality in coastal areas, as well as in the Mississippi River basin and the Great Lakes.
- *Further develop computer models relating land-based activities to the contaminant loads* through the use of Tier 2 monitoring coupled with land use information collected through remote sensing.
- *Expand the capability of regional programs to map and estimate nutrient and contaminant loads in sediments* and to look at the history of contaminant and nutrient distributions through examination of estuarine and offshore sediment deposits. Provide additional support to further develop models that determine the potential for mobilization, transport and redistribution of sediment-borne pollutants in the water column.
- *Expand air deposition monitoring networks* where coastal ecological problems have been identified to which air deposition of pollutants or nutrients is expected to contribute.
- *Develop a series of issue-based regional estuarine, Great Lakes, and coastal monitoring efforts supported by the National Coastal Survey*. These regional efforts should be established through Tier 1 analyses, 303d listings, and other sources to represent specific issue-based problems (*e.g.*, eutrophication, sediment contamination, habitat loss). Particular emphasis should be placed on National Estuary Programs, National Estuarine Research Reserves, and National Marine Sanctuary sites where these environmental problems exist.
- *Solicit on a national level proposals for regional issue-based monitoring/research efforts* and subject them to peer-review for relevance, capabilities, and adherence to nationally developed sampling designs, protocols, standards, and core parameter suites. Specific designs would be determined by representatives from appropriate Federal, State, Tribal, and/or academic institutions in the region.

DIAGNOSING INTERACTIONS AND FORECASTING RESPONSES (TIER 3) - Tier 3 activities are currently occurring at only a few locations. The NSF Long Term Ecological Research (LTER) and the Land-Margin Ecological Research (LMER) programs have many of the characteristics of Tier 3, but have only four locations that are currently funded. CISNet, a joint EPA/NOAA/NASA program, has funded three-year intensive ecological monitoring pilot programs at 10 sites. As CISNet pilots conclude, an interagency effort should be made to expand available programs *to develop a long-term continuing program for 25-50 U.S. coastal sites through a joint NSF/EPA/NOAA/NASA research program.*

Enhance and Integrate Interagency Research Efforts

As described previously, an effective approach to bringing scientific information to coastal decision making is through integrated assessments. Targeted research is often needed to reduce the level of uncertainty of those assessments and increase our ability to observe and predict phenomena. The uncertainties associated with our predictions, and the impacts of those uncertainties on our ability to manage the environment, are reduced through research. The following actions should be taken to



improve the efficacy and efficiency of various Federal coastal research and to reduce uncertainties in coastal assessments:

- Identify priority regional and national issues that need additional research to improve future integrated assessments. The research needs may be diverse, including understanding specific ecosystem functions, refining monitoring methods, or developing better predictive models.
- Develop interagency opportunities for soliciting, reviewing, and supporting research proposals targeted to priority needs. Interagency calls for proposals should call for both general and region-specific research. Appropriate methods would include both competitive external grant processes, and internal Federal competition and interagency agreements. In all cases, interdisciplinary approaches should be emphasized.

Such interagency efforts could be facilitated by an interagency oversight committee or other similar existing organization.

Conduct Periodic National and Regional Coastal Assessments

The best way to ensure that results from monitoring and research programs are being analyzed routinely for both relevance and completeness is to conduct regular, comprehensive assessments and report the results. Such assessments and reporting will require significant integration, analysis, and quality control of the data. However, they will provide the needed information about the status of the coastal environment, and will identify gaps and other shortcomings in research and monitoring programs. The assessments should be conducted using an integrated approach, and at a minimum provide the information necessary to report (1) status and trends within the environment, (2) critical issues of concern, and (3) issues in need of management or policy attention. Four types of assessments are envisioned:

- *National Summary Assessments* **-** National summary assessments of coastal ecological condition conducted every five years, summarizing the results and findings of the other reports, including an analysis of long-term progress and high-level recommendations to guide future policy;
- *National Habitat Assessments* **-** National habitat assessments focused around specific habitats such as beaches and wetlands, submerged aquatic vegetation, estuaries, offshore waters, and coral reefs, would be derived from activities conducted at Tiers 1 and 2 and would likely be developed on five-year cycles;
- *National Issue-Specific Assessments* - National issue-specific assessment would be developed as needed around issues that have emerged from national and regional efforts, as well as those mandated in Administration or Congressional directives (*e.g.*, the national assessments called for in the Harmful Algal Bloom and Hypoxia Research and Control Act); and
- *Regional Assessments* **-** Regional assessments would be based primarily on Tier 1 and Tier 2 efforts, where monitoring efforts have been designed and carried out to evaluate the causes and consequences of sets of specific regional issues. These assessments would likely occur on annual or biennial cycles.

The above assessments and the reports that result should be developed by regional and national experts, subject to peer- and stakeholder-review, and made

available to both technical and more general audiences. An effort of this scale requires dedicated and focused human and fiscal resources and the dedicated oversight of the committee charged with implementing a national program.

Improve Data Management in Support of Periodic Assessments

The recommendations for improving data management are two-fold. To effectively execute a national program, it is necessary to facilitate easy access to coastal environmental data; to use the data effectively for the purposes of assessing national coastal health it is vital that guidelines and standards for data management (*i.e.*, meta-data standards) be established.

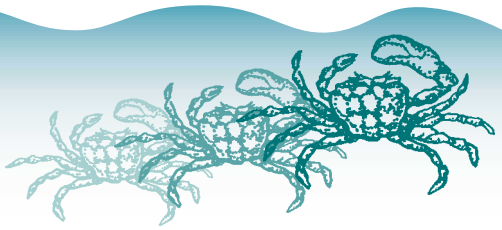
IMPROVING ACCESS TO COASTAL ENVIRONMENTAL DATA

Effective assessment and predictive capabilities in support of coastal policy and management are built on timely and appropriate observational and monitoring data, and an effective mechanism for sharing the data. Currently, coastal research and monitoring data are being acquired by multiple Federal agencies for multiple programs and applications. Additionally, the States, Tribes, municipalities, water authorities and other governmental agencies, as well as academia and private institutions, are acquiring a wealth of coastal water data for their own reasons. Through coordinated data sharing, organizations at all levels could assist the others in accomplishing their missions. A national data clearinghouse providing access to data from Federal and non-Federal programs nationwide would reduce redundant efforts, fill perceived data gaps, and provide an overview of the Nation's coastal environmental health not currently available.

The ability to share data among existing programs, among various levels of government agencies, academia and non-governmental organizations is key to the *Strategy*. There are enormous opportunities for data sharing among Federal agencies, State, Tribal, and local governments, as well as with academia and private institutions. Many State, Tribal and local programs that are currently being conducted to monitor coastal impacts could be integrated in the *Strategy*. Many of these programs have been established to comply with existing Clean Water Act provisions. Making these data serve beyond compliance makes economic and scientific sense.

A coordinated, Internet-based, national database or data clearinghouse that provides a directory of existing coastal monitoring data sources, including information about the listed programs with links to access the data would serve to enhance the ability to assess national coastal health, identify national or regional environmental issues, and assist in diagnosing the potential causes of these issues. Similarly many private research organizations and universities have extensive research data relative to ecosystem dynamics, biological processes, etc. that could aid in the prediction of impacts and assist in identifying priority issues. The Nation could also profit by making these data available through an organized program of data sharing.

The need for readily accessible national data related to environmental issues of the coast has been clearly identified in the *Clean Water Action Plan.* A similar call for the integration of all of the Nation's



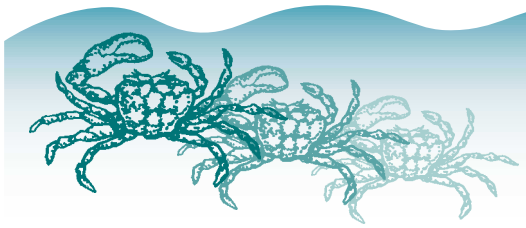
NON-FEDERAL COASTAL RESEARCH AND MONITORING PROGRAMS COULD CONTRIBUTE SIGNIFICANTLY TO EXISTING NATIONAL COASTAL ENVIRONMENTAL DATA

- *The Massachusetts Water Resources Authority manages a coastal water quality monitoring program related to ocean outfall from the metropolitan Boston area. This multi-year, multi-million dollar program addresses multiple issues related to nutrient enrichment in coastal waters, transport and fate of toxic contaminants from point and nonpoint sources, and recovery of ecosystems.*
- *The annual expenditures in coastal water research and monitoring of the water management districts of the State of Florida exceeds $5 million.*
- *The water management districts of Los Angeles and Orange counties have managed multi-million dollar multi-disciplinary coastal monitoring and research programs for the past 20 years.*

environmental data was made in the *One-Stop Reporting Program*, the 1995 Presidential initiative to reinvent environmental data reporting and management programs. Within EPA, this initiative has, in turn, been implemented in an 1997 EPA directive *Reinventing Environmental Information (REI).* These latter two initiatives and programs are of interest in that they have fostered the concept of sharing environmental data in a national environmental data repository populated with State, Tribal, and other governmental data. The *REI* program offers cash incentives to States to participate in data sharing. The technical foundation for a national coastal environmental data clearinghouse model exists in on-going programs, such as the EPA/USGS National Water Quality Inventory, the National Atmospheric Deposition Program and NOAA's National Oceanic Data Center. Similar to these initiatives or as a part of these programs, limited funding or technical assistance could be made available to assist State, Tribal and local programs in developing and adopting standard protocols, or contributing to national databases as an incentive to participate.

The Workgroup recommends that this key element of the *Strategy* be further investigated. The issues that should be addressed regarding the scope, content, and structure of the clearinghouse include:

- *Creation of a program to collect, integrate, and share coastal monitoring and research data from all appropriate Federal agencies, and from State, Tribal, and other governmental agencies* — this would include the development of a national coastal environmental data clearinghouse. The lead agency, charged with preparing the National Summary Report, should develop and maintain the Internet-based data



*The **One Stop Reporting Program** began in 1995 as a Presidential Initiative to reinvent environmental reporting and data management systems to achieve three goals:*

- *Integrate environmental information to improve State and Federal regulatory program management and promote multimedia approaches to solving environmental problems;*
- *Improve public access to information about environmental decisions and performance and assist communities in understanding and making environmental choices; and*
- *Reduce the burden of environmental reporting on industry, States, and communities by streamlining and rationalizing requirements and capitalizing on new technologies.*

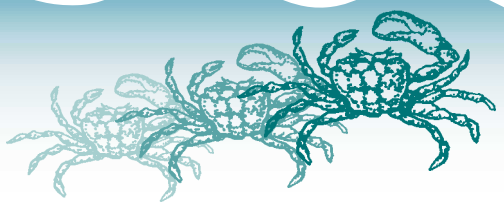
clearinghouse. Universal access to coastal environmental data should be facilitated through the Internet. Mechanisms that will allow streamlined Internet data access will reduce burdens on States and increase the likelihood that programs at all levels will participate.

- *Data input protocols for participating Federal agencies, States, Tribes, and other organizations* — The input of data from multiple Federal and non-Federal sources into a national data repository will be facilitated by the use of a single set of data input protocols. A single set of data management protocols should be encouraged and existing protocols for coastal water quality data should be reviewed for universal use and ease of implementation. Incentives for using standard protocols should also be considered.

- *National framework for geographic referencing of coastal water quality data* — The possible expansion of the EPA/USGS National Hydrographic Database to include coastal water is one of several alternatives for standard geographic referencing.

- *Data output and reports (types of tables, figures, GIS output, etc.)* — A national data clearinghouse for coastal water quality data, if it is accessible and user friendly, and contains the appropriate reporting features for targeted user groups, will be an invaluable resource. Researchers, water quality professionals, coastal managers, and the general public, to name a few of the potential user groups, each have separate interests and data needs that can be met with data assessment and report features. However, to successfully provide a reporting feature, data comparability among programs will need to be thoroughly addressed.

- *Management and promotion of the national coastal data clearinghouse* — Data sharing of coastal water quality data through a national data clearinghouse will only occur through implementation of a well-conceived plan addressing user needs, and a plan for continuously modifying or updating data sources to include new monitoring and research data, changing environmental data needs, and the rapid advances in technology. Addressing these issues in the future will require the identification of a lead organization to



coordinate these efforts and will require the dedication of technical and financial resources sufficient to perform the tasks.

META-DATA STANDARDS

A consistent finding among several studies of the impacts of monitoring programs is that the utility of monitoring data is compromised by the lack of "meta-data," (*i.e.*, data about the data; sample collection protocols, processing protocols, laboratory analytical methods, etc.). This lack of information generally becomes more severe as one moves from physical data, which are derived from relatively few methods and are generally unambiguous, to chemical data, which are influenced by sample collection and laboratory methods, to biological data, which are influenced more by collection protocols and interpretation. The Intergovernmental Task Force on Water Quality Monitoring (ITFM), the predecessor of the National Water Quality Monitoring Council (NWQMC), established extensive meta-data guidelines for chemistry data and a data dictionary for use by all Federal agencies. Similar entities set guidelines and develop standards for geographical (*e.g.*, the Federal Geographic Data Committee, (FGDC)) and biological data (*e.g.*, the National Biological Information Inventory). These efforts are important and adherence to them should be encouraged (ITFM 1995, Appendix M). Another significant advance to improve meta-data handling is EPA's updated STORET water-quality data system which includes fields for meta-data and is structured to enforce adherence to data standards adopted by EPA and other Federal agencies.

Generic problems of data management can seem overwhelmingly complex. However, if the above recommendation for a series of reports on the coastal environment is adopted, the problem becomes much more tractable because specific goals will be established during the peer review and development of these reports. Specific recommendations for data management include:

- A directory of meta-data resources should be included in the data clearinghouse. This is much easier to achieve than in the past, but this task is critical to a successful monitoring and reporting program. Although individual collecting agencies will also maintain their own databases, the coordinating agencies can aid in establishing meta-data standards that must be maintained for inclusion of data in the reports.
- Performance-based standards for data management and delivery should be adopted. Meta-data requirements should be based on

The National Atmospheric Deposition Program provides an example of an effective monitoring network where data are delivered because a specific design objective (i.e., the loads of air pollutants in wet deposition) was adopted. Many Federal agencies including USGS, NOAA, EPA, NPS, BLM, USDA, TVA, private companies, State, and local governmental agencies, working in a collaborative partnership, operate this network. Sample collection protocols and quality assurance plans have been established, and the data are considered authoritative by the environmental community.

standards. This will provide the necessary flexibility for integrating data, from a wide variety of sources, in a scientifically defensible manner.

- A large number of Federal, State, academic, and private agencies, laboratories, and other organizations will be involved in the collection of the monitoring data. Therefore, it is vital that data sets of the same kind from various sources be comparable and interchangeable so that they can be combined to develop national, regional, and other large-scale environmental quality and natural resource assessments. Where appropriate the National Water Quality Monitoring Council (NWQMC) Methods and Data Comparability Board should be used to evaluate the comparability of data obtained by different participants in furtherance of the Council's responsibilities under Key Action Number 60 of the Clean Water Action plan. For data types beyond the responsibility of NWQMC, the reporting agency must assume responsibility for assuring data comparability. The results evaluations should be used to judge the level of error associated with combining data of the same type from various sources.

Establish Mechanisms to Assess and Adjust Monitoring and Research

A basic premise of this *Strategy* is that wise stewardship of our nation's coastal and marine resources depends upon a robust, yet adaptive, monitoring, research, and reporting system. This system must provide information that serves those who use, manage, and study the marine environment; must be integrated across both geographic and time scales; and must be adaptive to respond to changing environmental conditions or societal priorities.

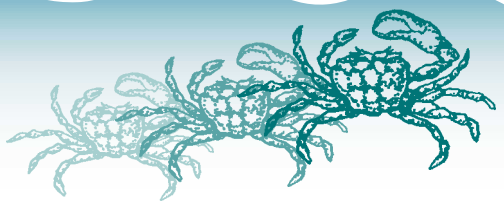
Such a system must provide timely and comprehensive information to managers to guide current management decisions, as well as to track the effectiveness of previous management decisions. Such a system, however, requires sufficient capacity at every level of monitoring and research, whether at the Federal, State, Tribal, or local level. In addition, these activities must be coordinated across political jurisdictions and institutional lines.

To better coordinate monitoring and research activities, a formal coordination and advisory structure should be established, charged with coordinating a national program. This advisory structure should consist of two components;

- A user-advisory committee, composed of representatives from Federal, State, and local governments; academia; not-for-profit organizations; and the private sector to ensure that the products and services of the system are relevant and stay on track, and that data are collected, reported, and stored in a consistent manner; and
- A technical advisory committee composed of representatives from Federal, State, and local governments; academia; not-for-profit organizations; and private sector science organizations to ensure that development and implementation of the system uses the best available scientific methods and technologies.

The coordinating structure, including the user advisory group and the technical advisory group, should work as necessary on a national and regional basis to establish programs and mechanisms to accomplish the following:

- Build the monitoring and research capacity of Federal, State, and local agencies that are



responsible for managing marine resources, and academic institutions that study the marine environment;

- Involve stakeholders in the coastal research and monitoring planning cycle; and
- Identify and/or establish the flow of scientific information into appropriate decision support systems, such as databases, GIS systems, and Internet on-line resources.

The committee should be able to identify resources for responding to time-critical environmental issues or policy questions.

Establish a Mechanism for Further Action

The Workgroup was charged with defining a broad strategy that identifies an approach for achieving Action Items 59 and 60 from the Clean Water Action Plan. This *Strategy* is the culmination of that effort. However, to effectively implement Recommendations 1-5, additional work will be necessary to organize and develop an implementation plan. The mechanism and organization needed to ensure effective implementation and continued success will require agency-to-agency coordination and cooperation, and the coordination of coastal monitoring and research activities between Federal and non-Federal entities (State, Tribe, local, and private organizations). An inter-governmental program, as recommended by this *Strategy*, requires the coordination of Federal research and monitoring efforts to address environmental problems in coastal waters. This implies an interagency infrastructure that establishes and acts on national coastal water priorities. Currently, there is little experience with coordination of Federal investments in research and monitoring in coastal waters and few mechanisms have yet been established to implement a program. Such an effort will require the full support and cooperation of the responsible Federal agencies and the issues and concerns of each agency about a national program will need to be addressed. Therefore, the Workgroup recommends the creation of an interagency oversight committee that will prepare an interagency charter (EPA, NOAA, USDA, DOI) and develop the implementation plan. This committee could be established under the auspices of the Committee on Environment and Natural Resources (CENR), the National Water Quality Monitoring Council, or some other existing structure that can transcend short-term changes in management and program policy as well as different levels of government. The committee should be composed of representatives of agencies with research and monitoring responsibilities. Long-term viability of such a committee is essential.

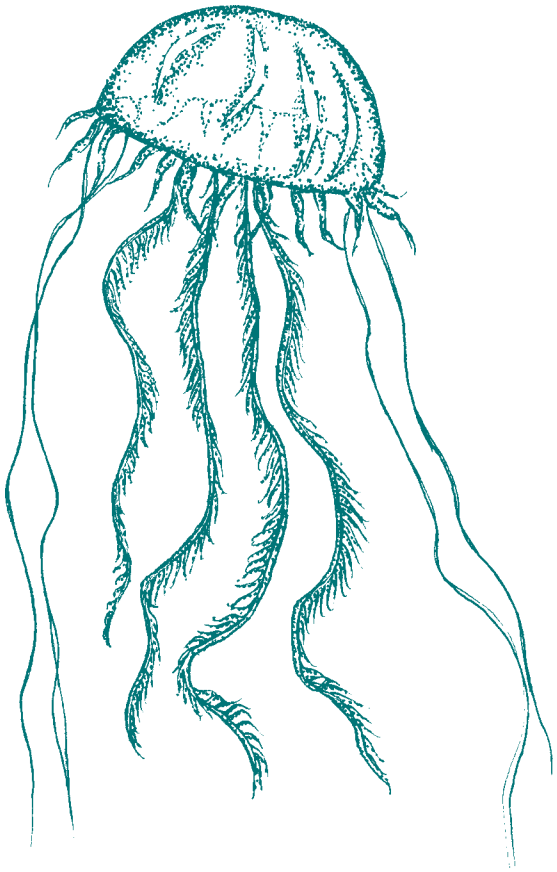
The first objective of the committee will be to develop a charter for the organization that will manage future efforts. The charter should:

- Define the technical scope of a national program and the organizational structure necessary to implement a national program;
- Identify the agencies participating in the national program and establish the level of involvement required to guide the environmental monitoring and research agenda and budgets of the participating agencies;
- Define the working relationship between a national program and participating agencies

- Define the working relationship between a national program and non-participating agencies (other Federal agencies, States, and Tribes); and
- Define the working relationship with other Federal workgroups, such as CENR.

Following the development of the charter, the oversight committee will develop an implementation plan for Recommendations 1 - 5. Committee responsibilities include:

- Setting consistent standards to effectively assess the "health" of the coastal zone;
- Ensuring effective streamlining of Federal coastal monitoring efforts to eliminate redundancy and identify and coordinate coastal zone monitoring needs;
- Ensuring effective communication and data sharing among various Federal, State, and Tribal agencies charged with managing coastal resources;
- Ensuring that monitoring and research activities support and assess the effectiveness of management actions in the coastal zone; and
- Periodically assessing the monitoring and research needs with changing coastal environmental priorities and emerging issues.



The Workgroup has prepared recommendations that the oversight committee should consider when developing the implementation plan. These recommendations are provided in the following section.

CONSIDERATIONS REGARDING IMPLEMENTATION

Although detailed planning for implementation is beyond the scope of this Workgroup, many important elements of an implementation plan emerged during the development of the *Strategy*. Some considerations that must be addressed during the implementation planning process are presented below.

Monitoring Appropriate Properties

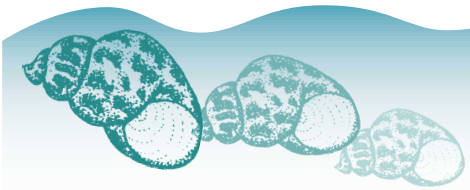
The number of properties that can be measured as part of a monitoring program is nearly limitless. However, considerations of economy and practicality mandate that only relatively few can actually be included in a monitoring program. The properties included in a national program should be those that can serve as integrative indicators of ecosystem quality and/or trends in such quality. They should be measures that can be directly related to answering the specific objectives established for the program. These include indicators of the condition of major coastal ecosystem components, such as plankton and benthic communities, as well as indicators of the levels of stressors, such as toxic substances, enriching nutrients, and invasive nonindigenous species. Such measurements can be obtained in several ways, including remote sensing with sensors in satellites or aircraft, continuous measurements with *in-situ* sensors attached to buoys or other platforms, and discrete sampling by field teams using boats and other means.

Selecting Reliable Indicator Properties

To determine the specific measurements to be included in a national program, a number of criteria should be applied to ensure that the selected properties provide scientifically valid data that are relevant to the programmatic goals, and that are practical and cost-effective for use as indicators of coastal environmental quality. The following specific research questions should be considered in the selection of indicators:

- Can the proposed indicator be quantified in a simple manner?
- Does the indicator respond to a broad range of conditions?
- Is the indicator sensitive to problematic conditions or concerns?
- Can the indicator resolve meaningful differences in such environmental conditions?
- Can the measurement provide an integrated view of effects over time and space?
- Are the results from the measurement reproducible?
- Is there reference information by which to judge the results obtained?
- Can the results be compared across differences in time and space?

It is also important that the significance of the selected indicator properties be understandable and relevant to environmental managers and others, including the general public, who will use the results provided by the monitoring to guide policy decision making.



Assuring Data Comparability

A large number of Federal, State, academic, and private organizations, laboratories, and other organizations will be involved in the collection of monitoring data for any future program. Thus, there will be a number of sources for most categories of data. It is vital that data sets of the same kind from various sources be comparable and interchangeable so that they can be combined to develop national, regional, and other large-scale environmental quality and natural resource assessments. To help assure data comparability, recommendations should be developed for methods and procedures to be used for obtaining specific types of environmental observations, and for gathering and analyzing environmental samples for specific types of environmental quality measurements. However, procedures should be established to evaluate the comparability of data of the same type obtained by different participants and at different times.

These procedures should include the implementation of comparison exercises. These exercises should include a comparison of data from participants which made field observations or laboratory measurements on a common set of properties in identical samples or situations under identical conditions. The results from such performance-based evaluations of data comparability should be used to judge the level of error associated with combining data of the same type from various sources.

Assuring Information Development and Delivery

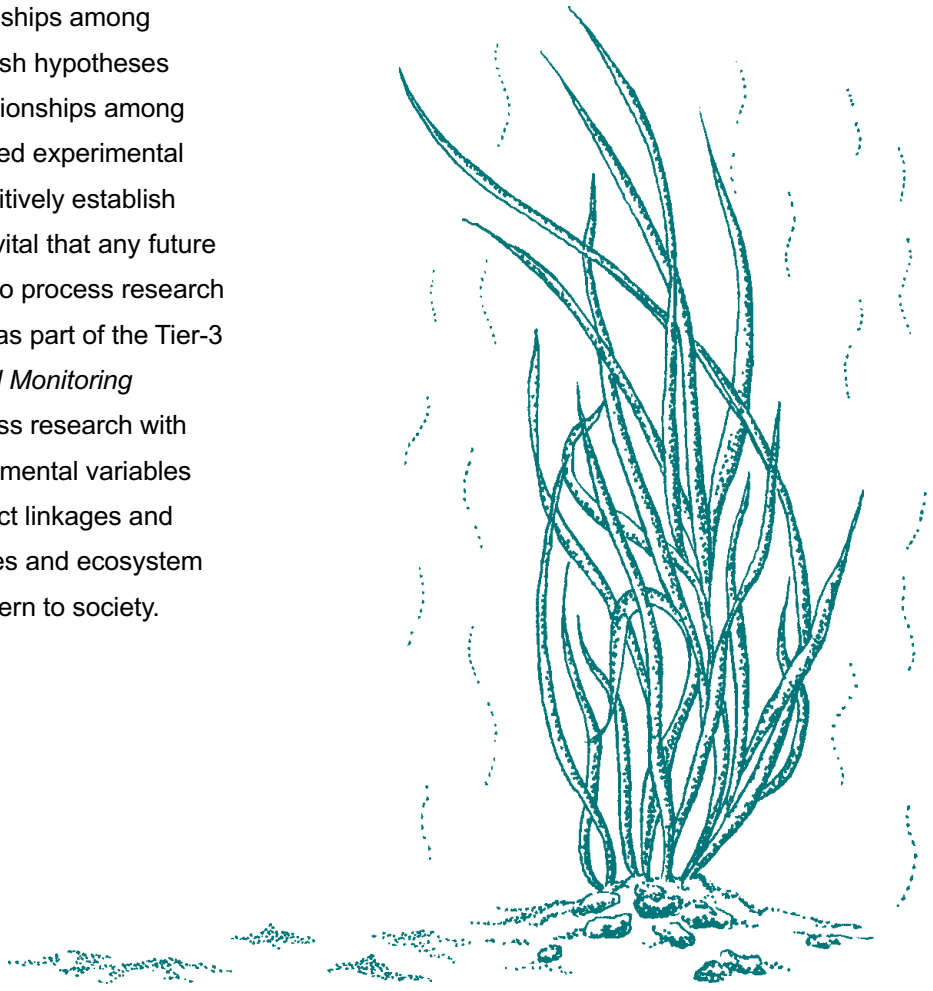
The data and information collected through the execution of a National program should provide the basis for environmental and resource management decision making. Thus, it is important that the monitoring program be designed to obtain information and data to meet the monitoring objectives. Additionally, it is vital that this information be presented in meaningful formats and that it be readily accessible to decision makers. A meaningful format could be a display of patterns of indicator data, relative to time and space, and relative to potential anthropogenic and other causes. However, this approach also has limitations. The results from individual indicator properties do not usually provide an overall or complete characterization of ecological health, cumulative stressor threat, or other integrated properties that are often the primary management concern.

An alternate approach would be to combine the data from the measurement of several ecological or stressor properties at a site to produce a single value that could serve as an index to the magnitude of an integrated characteristic of primary concern. A national coastal monitoring program should develop and utilize a number of such indices. For example, data on the abundance of individual species or other taxonomic categories of benthic organisms should be combined to develop an index value that reflects the health of the bottom biological communities. Additionally, to provide

the integrated information needed by environmental managers, the data obtained should be utilized in the development and verification of environmental models that can provide status and forecasts of important environmental properties and indices. The modeling results should provide environmental managers with predictions of the environmental consequences of various potential alternative management actions.

Linking Monitoring and Research

Monitoring provides information on the condition and changes in the levels of environmental properties. By comparing the patterns of the spatial and temporal distributions of different properties, monitoring results can be used to evaluate the relationships among various properties and, thus, establish hypotheses regarding the cause-and-effect relationships among these properties. However, controlled experimental research is usually required to definitively establish causative relationships. Thus, it is vital that any future national program be closely linked to process research studies. This will be accomplished as part of the Tier-3 studies. The *Coastal Research and Monitoring Strategy* recommends linking process research with long-term measurements of environmental variables at these sites to develop cause-effect linkages and predictive models that relate stresses and ecosystem responses regarding issues of concern to society.



REFERENCES

Intergovernmental Task Force on Monitoring Water Quality (ITFM). 1995. The Strategy for Improving Water-Quality Monitoring in the United States: Final Report of the Intergovernmental Task Force on Monitoring Water Quality, Open-File Report 95-742. U.S. Geological Survey. Reston, VA.

Interagency Task Force on Harmful Algal Blooms and Hypoxia 2000. *In preparation*. National Assessment on Harmful Algal Blooms. Draft available url: http://www.hbhrca.noaa.gov.

Interagency Task Force on Harmful Algal Blooms and Hypoxia 2000. *In preparation*. Integrated National Assessment on Hypoxia. Draft available url: http://www.hbhrca.noaa.gov.

The Heinz Center. 1999. Designing a Report on the State of the Nation's Ecosystems. The H. John Heinz Center, Washington D.C. 119pp.

Messer, J.J., R.A. Linthurst, and W.S. Overton. 1991. An EPA program for monitoring ecological status and trends. *Environ. Monitor. Assess.* 17: 67-78.

National Conference of State Legislatures. 1993. Report to Congress. The Mix of Land and Sea: Estuary Protection Under the National Estuary Program. ISBN 1-55516-376-9.

National Oceanic Partnership Program (NOPP). 1999. Towards a US Plan for an Integrated Sustained Ocean Observing System. Report to the National Ocean Research Leadership Council, Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Pollution Program Office, Washington DC. 68pp.

National Science and Technology Council (NSTC). 1995. Setting a New Course for U.S. Coastal Ocean Science. Final report of the Committee on Environment and Natural Resources, subcommittee on U.S. Coastal Ocean Science. Washington DC. 110pp.

National Science and Technology Council (NSTC). 1997. Integrating the Nation's Environmental Monitoring and Research Networks and Programs: a Proposed Framework. Final report of the Committee on Environment and Natural Resources, Environmental Monitoring Team. Washington D.C. 96pp.

US Environmental Protection Agency (EPA). 1999. The Ecological Condition of Estuaries in the Gulf of Mexico. The US EPA Office of Research and Development, National Health and Environmental Effects Research Laboratory, Gulf Ecology Division. EPA 620-R-98-004.

U.S. Environmental Protection Agency (EPA). 1998a. National Water Quality Inventory: 1996.

U.S. Environmental Protection Agency (EPA). 1998b. Clean Water Action Plan: Restoring and Protecting America's Waters. EPA-840-R-98-001. 87pp.

APPENDIX A: Summary of Recent Reports

Reference: EPA. 1997. Deposition of Air Pollutants to the Great Waters. Second Report to Congress. Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA-453/R-97-011. June 1997. 218pp + apps.

Great Lakes

Research is needed to:

- Identify sources of atmospheric contributions;
- Identify HAPs (hazardous air pollutants) that may pose the most significant risk to human health and aquatic resources;
- Quantify the contribution of atmospheric deposition of pollutants and the subsequent exposure;
- Determine Relative loadings of pollutants to assess the extent of contamination attributed to the atmosphere; and
- Define the extent of problems related to toxic pollution in tributaries and in the air.

High priority efforts for the Great Lakes basin include:

- Research and monitoring techniques to reduce uncertainties in loading calculations;
- Dispersion and deposition models currently being developed to link emission in inventory information to atmospheric loadings of Great Lakes pollutants at the water's surface;
- Apply results of and modeling tools derived from the Lake Michigan Mass Balance data to the development of a general mass balance model for other hazardous air pollutants;
- Increase efforts to identify local and long-range sources of Great Lakes pollutants through various sources apportionment modeling and emissions inventories; and
- Continue efforts to develop and implement strategies and recommendations to reduce generation and release of pollutants affecting the Great Lakes.

Chesapeake Bay Program

Priority studies identified during the June 1994 workshop are:

- Conduct intensive, coordinated, and integrated monitoring studies at special locations within the watershed that characterize wet deposition, dry deposition, and local catchment areas;
- Improve existing atmospheric models (*e.g.*, reduce grid size, account for the effect of mountains);
- Improve models of chemical retention in watersheds;
- Improve emission inventories and projections;
- Conduct measurements to extend vertical and spatial meteorological and chemical concentration coverage in models; and
- Establish an extensive array of less intensive measurement stations to improve spatial resolution for selected variables.

National Estuary Program (NEP)/Coastal Waters

Recommendations for future atmospheric deposition research in coastal waters include:

- Utilize existing databases and ongoing work or established research programs and coordinate research initiatives with these programs;
- Protect and enhance existing monitoring programs;
- Establish long-term water and air quality monitoring programs that incorporate sampling for atmospheric deposition of contaminants for a subset of NEP estuaries representing various geographical regions and environmental conditions;
- Use sampling data from monitoring programs to track trends and spatial variability to develop more accurate loading estimates;

- Coordinate efforts between NEP estuaries and other Great Waters program studies to identify local, regional, and national sources of airborne pollutants;
- Pursue detailed atmospheric chemistry and deposition models for estimating atmospheric depositions to NEP estuaries;
- Develop a multiparty effort to identify and demonstrate appropriate pollution prevention techniques;
- Apply existing atmospheric circulation models to fill data gaps between measured and estimated atmospheric deposition and to aid in tracing the pollutants in the estuaries back to their probable sources; and
- Support process-related research to establish cause and effect relationships between atmospheric deposition of contaminants and alterations of water quality, fisheries, recreational, and other economic and ecological resources of receiving estuarine and coastal waters.

Reference: Anderson, D.A. (Ed.). 1995. ECOHAB. The Ecology and Oceanography of Harmful Algal Blooms. A National Research Agenda. Woods Hole Oceanographic Institution, Woods Hole, MA. 66pp.

ECOHAB (The Ecology and Oceanography of Harmful Algal Blooms)

Three main research priorities represent the program elements of ECOHAB:

The Organisms:

- Develop methods to rapidly and accurately identify, enumerate, and physically separate HAB species from mixed phytoplankton assemblages.
- Identify the life history stages of major HAB species, determine what factors control transitions between those stages, and establish the role of the stages in bloom dynamics.
- Characterize the physiological responses and tolerances of HAB species to differing environmental conditions.
- Develop methods to permit in situ measurements of species-specific rates of growth, photosynthesis, and nutrient uptake, and assess the physiological conditions of cells at different times and locations.
- Characterize the nutritional requirements, uptake and nutrient assimilatory characteristics of HAB species.
- Determine the functional role of toxins and/or exudates produced by HAB species.
- Define the genetic basis of toxin production, elucidate toxin biosynthetic pathways, and determine how toxin accumulation in cells is regulated.
- Investigate the mechanisms and importance of motility and other behaviors of HAB species.

Environmental Regulation of Blooms:

- Determine the extent to which HAB events reflect increases in growth rates versus physiological transport, immigration, and accumulation.
- Investigate physical and ecological processes that control the partitioning of nutrients within a system and the relationship between nutrients inputs and population dynamics of HAB species.
- Investigate whether there are specific physical, chemical, and biological regimes or processes that are associated with HAB events.
- Determine whether some ecosystems are more susceptible to HABs than others. If so, determine what makes them unique and whether they share characteristics that can be used to anticipate HAB events in other systems.
- Characterize HAB population dynamics, including rate processes, required in predictive models of bloom incidence.

Food-Webs and Community Interactions:

- Determine the extent to which bloom formulation results from a breakdown of grazing or from harmful species out competing other phytoplankton for limiting resources.
- Determine whether biological controls are the cause of bloom termination.
- Investigate how HAB effects on the food web are controlled by toxin dynamics, food web routing of toxins, and the differential susceptibility of species at higher trophic levels; determine whether chronic, sublethal, impacts of HABs are more significant than acute (lethal) impacts.
- Determine if HAB impacts are controlled by the degree of temporal and spatial overlap between blooms and critical life cycle stages of target species.
- Determine whether high biomass (non-toxic) HABs adversely impact the food web directly through reduced food quality, or indirectly through environmental effects.

Reference: Boesch, D.F., D.M. Anderson, R.A. Horner, S.E. Shumway, P.A. Tester, and T.E. Whitledge. 1996. Harmful Algal Blooms in Coastal Waters: Options for Prevention, Control, and Mitigation. NOAA Coastal Ocean Program Decision Analysis Series No. 10. National Oceanic and Atmospheric Administration Coastal Ocean Office, Silver Spring, MD. 46pp + app.

Federal and State agencies with responsibilities for resource management, environmental protection, and public health should support research directly focused on the prevention, control, and mitigation options for HABs, including:

- Effectiveness and side-effects of chemical, physical, and biological controls;
- Better measurements of toxins and HAB species for application in monitoring;
- Ballast water treatments; and
- Effects of chronic exposure on human health.

Research should seek to contribute a basic understanding of the causes and behavior of HABs to address control, prevention, and mitigation, specifically:

- The role of anthropogenic nutrient sources in stimulating and sustaining blooms and the potential effectiveness of nutrient control strategies in reducing blooms;
- The effects on blooms of trophic alterations, such as changing grazing pressure, that result from human over-harvesting or habitat changes;
- The importance of “seeding” in the genesis of blooms and mechanisms for inoculation;
- Critical stages of bloom formation and propagation that may be suitable targets for control strategies;
- The role and potential impacts of parasites and predators in suppressing blooms;
- Molecular or other indicators of harmful algal species which may improve the sensitivity and reliability of monitoring;
- Remote sensing of blooms that provides advanced warning and supports tactical mitigation; and
- Modeling of physical and biological processes which may be applied in forecasting the occurrence and movement of harmful algal blooms.

Reference: Pacific Northwest Regional Marine Research Program (RMRP). 1993. A Directory of Regional Programs to Enhance Research on Water Quality and Ecosystem Health in the Nation’s Marine Waters. Produced for NOAA by the Pacific Northwest Regional Marine Research Program and Washington Sea Grant Program. June 1993.

The Regional Marine Research Program (RMRP) has established regional research programs in support of efforts to safeguard water quality and ecosystem health in the Nation’s marine and coastal waters. The following research priorities and strategies have been developed for each of the nine regions whose boundaries coincide with natural ecosystem divisions.

Alaska Region:

- Models to identify gaps in our understanding of ecosystem change;
- Physical transport of nutrients, larvae, or other waterborne constituents on biological resources; and
- Linkages with pelagic and benthic food chains including the effects of various commercial fisheries in restructuring the ecosystem.

California Region:

- Variability of coastal and estuarine ecosystems;
- Effects of stress on ecosystem functions with emphasis on cumulative impacts of spatial and temporal changes;
- Protection and restoration of coastal and estuarine habits; and
- Information synthesis and dissemination of research in the priority areas.

Greater New York Bight Region:

- Interaction of human population with coastal and marine ecosystems;
- Integrated coastal management, including, perhaps, watershed-based planning and management;
- Waste disposal; nutrient enrichment/eutrophication; and
- Fisheries management from life cycle, habitat conservation or restoration perspective.

Gulf of Maine Region:

- Patterns and transport mechanisms of contaminants, including nutrients, and their effects on living marine resources; and
- Physical, chemical, and biological controls on noxious/excessive phytoplankton phenomena.

Gulf of Mexico Region:

- Habitat use
- Nutrient enrichment
- Freshwater input
- Ecosystem modifiers
- Population dynamics
- Trophic dynamics
- Physical modifiers
- Toxic materials
- Coastal erosion
- Saltwater intrusion
- Catastrophic events
- Global events
- Nuisance species

Insular Pacific Region:

- Assessment and monitoring of water quality, species, and habitat;
- Contaminant sources, transport, fate and effects;
- Impacts of coastal development and resource use; and
- Analysis, communication and application of research results.

Mid-Atlantic Region:

- Demographic and coastal land use changes that effect the environmental quality of coastal waters;
- Role of anthropogenic changes in natural environmental variability;
- Synthesis and interpretation of historical and contemporary data ;
- Historical effects of demography and land use activities on regional water quality and ecosystem health;
- Existing regional conditions and projected changes as a result of management of land use activities in the region; and
- Conceptual and analytical models of the region.

Pacific Northwest Region:

- Understanding the natural system in order to detect and understand ecosystem change;
- Alteration of marine and estuarine habitats due to anthropogenic activities and natural phenomena;
- Fate, effects, and transport of contaminants; and
- Synthesis, interpretation and communication of information about the Pacific Northwest region.

South Atlantic Region:

The four habitats of greatest concern and highest priority are:

- Marine wetlands (mangroves/salt marshes)
- Reefs
- Sandy beaches
- Coastal lagoons

Reference: Turgeon, D.D., K.G. Sellner, D. Scavia, and D. Anderson. 1998. Status of U.S. Harmful Algal Blooms: Progress Towards a National Program. U.S. Department of Commerce National Oceanic and Atmospheric Administration. October 1998. 22pp

The National HAB Plan includes the following objectives for harmful algal bloom research, monitoring, and assessment activities in U.S. coastal waters during FY98 and FY99:

- Isolate and characterize toxins;
- Detection methods for HABs;
- Toxin effects on ecosystems/humans;
- Forecasting capabilities;
- Management and mitigation;
- Rapid response to HABs;
- Communication, outreach, education; and
- Databases.

The goal of the National Plan is to develop a predictive modeling capability for HABs in all U.S. coastal waters. Research has begun on two toxic species and regions, *Alexandrium* in the Gulf of Maine and *Gymnodinium* in the Gulf of Mexico. The remainder of the coastline and other HAB species need investigation; the following additional research is needed:

- Brown tide populations in Long Island and off Texas;
- *Pfiesteria* in Mid- and South Atlantic states;
- Macroalgal blooms in Florida's and Hawaii's coral reefs;
- Ciguatera dinoflagellates in sub-tropical and tropical U.S. possessions;
- *Pseudo-nitzschia* in the northwestern Gulf of Mexico and along the west coast; and
- *Chaetoceros* and *Heterosigma* in the Northwest.

Major support is needed to obtain a better understanding of toxin impacts, both acute and chronic, on coastal resources and humans, including:

- identification of toxins and toxic cells in water and tissues;
- development of rapid, reliable, and inexpensive assays for their field detection;
- identification of biomarkers for monitoring HAB toxins in wildlife and humans; and
- establishment of exposure thresholds for toxicity.

The Federal government has initiated a rapid assessment capability to assist States and regions impacted by unexpected HAB outbreaks.

Reference: U.S. Department of the Interior, Centers for Disease Control and Prevention, U.S. Food and Drug Administration, U.S. Department of Agriculture, U.S. Environmental Protection Agency, National Oceanic and Atmospheric Administration, and National Institute for Environmental Health Sciences. National Harmful Algal Bloom Research and Monitoring Strategy: An Initial Focus on *Pfiesteria*, Fish Lesions, Fish Kills, and Public Health. November 10, 1997. 26pp.

Eight research and monitoring objectives have been developed to address the recently observed incidents of *Pfiesteria*-related species and fish lesions and kills in the Mid- and South Atlantic coastal area. Six of the objectives focus on new *Pfiesteria*-related research (R) and/or monitoring (M) efforts.

Objective 1: Isolate, characterize toxins

- Develop/characterize each potentially toxic strain of *Pfiesteria* and the *Pfiesteria*-complex (R)
- Determine toxicity of each strain and begin the isolation and identification of toxins produced (R)
- Determine life cycles an toxicities of life stages for each isolated strain (R)

Objective 2: Detection methods

- Refine methods for detect toxins (R)
- Develop methods for field detection of *Pfiesteria*-like cells (R/M)
- Field test and apply cellular probes that have been under development (R/M)
- Develop biomarkers of lethal and sublethal neurotoxicity for fish and/or humans (R/M)

Objective 3: Toxins in marine food webs, fisheries, and humans

- Biotoxin impacts on marine organisms: direct and indirect effects; thresholds; hazard identification methods (M/R)
- Biotoxin impacts on humans: direct and indirect effects; thresholds (M/R)
- Biotoxins: pathways and transformation (M)
- Human symptomologies and epidemiology (M)

Objective 4: Forecasting capabilities (including ecology)

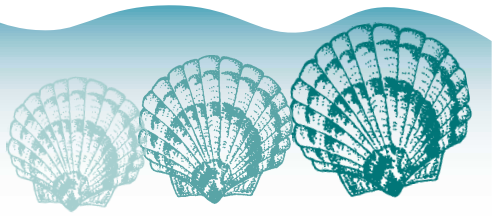
- Determine factors causing toxic blooms: link physics, hydrology, ecology and physiology of species (R/M)
- Develop model for identifying specific systems optimal for growth (R/M)
- Delmarva Nation Water Quality Assessment Program (NAWQA; R/M)
- Role of veterinary pharmaceuticals in bloom formation (R)
- Plankton observer networks (M)
- Develop ability to distinguish among causes of fish health problems (R/M)

Objective 5: Develop management and mitigation options

- Non-point source control: improve animal feeding operations, TMDL, and air deposition models (M/R)
- Research on prevention, control and mitigation strategies, including hydrological/biological conditions (M/R)
- Development of water quality criteria for nutrients (R/M)
- Develop health care responses for human toxic exposure and risk assessment studies on bloom impacts/benefits of control (R)
- Evaluation of economic impacts to support cost-benefit analyses of mitigation strategies (R)

Objective 6: Rapid response to HABs

- Providing interagency Rapid Response Team capability for all future events in U.S. coastal waters (M)
- Federal assistance to State monitoring programs (M)



Reference: Chesapeake Bay Program Scientific and Technical Advisory Committee. 1994. Atmospheric Loadings to Coastal Areas: Resolving Existing Uncertainties. A Report of the Atmospheric Loadings Workshop, Baltimore, MD. June 29-30, 1994. 31pp.

The Atmospheric Loadings Workshop, sponsored by the Scientific and Technical Advisory Committee and the Air Quality Coordination Group of the Chesapeake Bay Program, was charged with constructing a prioritized listing of practical studies that would reduce current uncertainty in estimates of atmospheric deposition and its contribution to declining aquatic ecosystem health.
The priorities, listed in order of importance, are:

1. ***Establish integrated monitoring studies***
   Conduct intensive, coordinated, integrated monitoring at special locations within the watershed, with wet deposition, dry deposition, and local catchment area characterizations. The single most limiting factor in assessing the adequacy of current models is the lack of quality data on actual deposition within the target watershed. Until an integrated monitoring station is operational, there will be no comprehensive data set for evaluating model performance.

2. ***Improve existing atmospheric models***
   Work to improve existing atmospheric nitrogen deposition models. In brief, there are many limitations of current models, especially their limited grid size and their incomplete description of orographic and chemical factors.

3. ***Improve biogeochemical watershed models***
   Workshop participants recognize the important role of watershed chemical retention and emphasized the need for close linkages with the appropriate scientific community.

4. ***Improve emissions inventories and projections***
   Emissions estimates are currently highly imperfect in both the adequacy of reporting requirements and the spatial resolution used to report the emission values. Assessments of atmospheric deposition are necessarily at the mercy of these estimates.

5. ***Enhance current data collection efforts***
   Conduct process-oriented measurements to extend vertically and spatially coverage of meteorology and chemical concentrations, and to quantify representativeness. The latest assessment models need more advanced input data than do the simpler models used in early assessments. As information demands rise and as these models evolve, input data requirements will increase even further. Workshop participants concluded that measurement programs to provide the data required by the models should be initiated.

6. ***Create an extensive array of less intensive measurements***
   These measurement sites would compliment the integrated monitoring stations of ***Priority 1***.
   In essence, a nested network is envisioned, with a small number of ***Priority 1*** intensive stations supporting a denser array of simple stations designed to provide improved spatial resolution for some selected variables.

Reference: U.S. Department of the Interior. The National Coastal and Marine Geology Program. 1997. An Updated Five Year Plan for Geologic Research on Environmental, Hazard, and Resource Issues Affecting the Nation's Coastal and Maine Realms. U.S. Geological Survey. March 1997. 27pp.

A five-year plan for research and mapping activities has been developed by the Coastal and Marine Geology Program (formerly Office of Marine Geology) of the United States Geological Survey (USGS). The investigations included in the plan are designed to describe marine and coastal systems, understand the fundamental geologic processes that create, modify and maintain them, and develop predictive models. The investigations address four themes and their corresponding objectives. Three of the themes focus on research and are summarized below. The fourth theme, information technology, focuses on coordination of mapping, synthesizing information and developing a national source of information on the geology of the Nation's marine realms.

Theme 1 – Environmental quality and preservation

- Pollution and Waste Disposal – identify and map the extent of sediment deposits and associated contaminants on the seafloor; understand the processes by which pollutants and waste material interact with and accumulate in sedimentary deposits; improve our knowledge of transport of sedimentary particles and associated pollutants; increase our understanding of the processes by which pollutants migrate through subsurface deposits and are reintroduced to the seabed and water column.
- Fragile environments – increase our understanding of the delicate balance of geological processes necessary to maintain the Nation's fragile coastal and marine environments and to improve our capability to predict ecosystem response to both natural processes and human activities.
- Marine reserves and biological habitats – gather, interpret, and distribute geologic information about areas that are identified as of national importance, either as biologic resource or for their intrinsic value.

Theme 2 – Natural hazards and public safety

- Coastal and nearshore erosion – understand the geological environment within which erosion, transport, and deposition of sediment occur, and ultimately to predict erosion caused by natural processes and human activities.
- Offshore earthquakes, tsunamis, and landslides – understand the geologic, environmental, and recent history of great earthquakes, landslides, and tsunamis in the marine realm; evaluate the future potential and probable impacts of such events on a regional basis; make research results available in an effective form for application in USGS evaluations (e.g., seismic risk zonations)

Theme 3 – Natural resources

- Water resources (coastal aquifers) – understand the distribution and geological characteristics of fluid transport in coastal aquifers and marine environments in conjunction with USGS-Water Resources Division (WRD).
- Marine Mineral resources – improve understanding of the geological, geophysical, and geochemical characteristics of nearshore and offshore mineral deposits, the geological systems in which the deposits form, and the processes and chemical fluxes that lead to mineral concentrations.
- Energy resources – improve understanding of the complex and dynamic geological processes that have formed continental margins to better understand the genesis, accumulation, and preservation of associated energy deposits.

Reference: Valigura, R.A., W.T. Luke, R.S. Artz, and B.B.Hicks. 1996. Atmospheric Nutrient Input to Coastal Areas: Reducing the Uncertainties. NOAA Coastal Ocean program Decision Analysis Series No. 9. NOAA Coastal Ocean Office. 24pp. + apps.

The NOAA Air Resources Laboratory (ARL)/Atmospheric Nutrient Input to Coastal Areas (ANICA) program was developed to address the need for an objective methodology to assess the importance of atmospheric input to coastal regions, using Chesapeake Bay as the pilot. The program was designed as a targeted research program to answer two specific questions: (1) To what extent is the perceived problem due to deposition from the atmosphere? and (2) How can this understanding be extrapolated to other circumstances?

Dissemination of information on atmospheric issues was identified as a need that could be addressed under the ANICA program. Consequently, ANICA scientists were involved in three informational projects.

Literature Synthesis

The literature synthesis concluded with the following research recommendations for steps to reduce uncertainties associated with prediction of atmospheric loadings.

- Conduct monitoring and research experiments focused on improving measurements and modeling techniques to further understand and quantify the emission cycles of the key chemical species.
- Develop and perform nitrogen speciation experiments including on organic nitrogen and ammonia compounds; subsequently, conduct intensive studies of the dry deposition rate of nitrogen compounds from air crossing the watershed zone of the Chesapeake Bay region.
- Investigate the effect of localized contaminant deposition in both urban and near-urban environments; specifically, develop estimates of surface water loadings attributable to urban runoff and investigate the temporal and spatial distribution of NO_y deposition.
- Establish integrated monitoring sites of atmospheric emission and deposition.
- Establish over-water precipitation chemistry sites and compare the results with those from land-based precipitation chemistry sites.
- Identify how urban areas serve as a source of atmospheric contaminants to surface waters; conduct research on sampling methods for small particle deposition and source attribution for organic contaminants.
- Investigate the bioavailability of material deposited from the atmosphere; conduct exposure studies to learn how chemical speciation influences exposure.

Reference: Chesapeake Bay Program Air Quality Coordination Group. 1995. Airsheds and Watersheds – The Role of Atmospheric Nitrogen Deposition. A Report of the Shared Resources Workshop, Warrenton, VA. October 11-12, 1995. 32pp.

The focus of the Shared Resources Workshop (also called the "Airlie Workshop") was on atmospheric nitrogen compounds, but many of the conclusions apply equally well to other pollutants occurring in the air, such as toxic chemicals, trace metals, and persistent organic compounds. The following five recommendations summarize the conclusions drawn by the participants at the workshop.

- Efforts to resolve scientific uncertainties associated with the quantification of atmospheric deposition and the resulting loading should be continued. The 1994 Mt. Washington workshop should serve as a useful reference for planning future work. Future research should focus on quantifying atmospheric nitrogen fluxes to the coastal ocean and characterizing the biochemical cycle of organic nitrogen through Chesapeake Bay watershed.
- Although there is uncertainty in many areas, enough is known to determine a general direction for action. Managers and regulators should move forward and not wait for all of the uncertainties to be resolved.
- A set of basic information for use in explaining the cause for concern about atmospheric deposition and water body effects to the public, politicians, regulators, etc., should be generated. It is considered likely that a single set of basic material could be used as the core of issue-related material addressing current understanding about emissions, atmospheric depositions loadings by watershed and water body, areas of greatest uncertainty, etc. This would promote cooperation and coordination across the organizations involved, so as to avoid sending mixed messages.
- A cross-media approach to quantifying atmospheric deposition and resulting loadings needs to be developed. Greater cooperation across issues, estuaries, and bays, scientific disciplines, and government units is essential. Barriers to greater cooperation should be identified and eliminated.
- In order to assure that such coordination continues, a future meeting of the present kind (but with representation from an enlarged group of organizations) should be held, in about a year.

The following actions lay out the path to reach the above recommendations.

Short-Term Actions (within 1 year)
The 10 short-term actions are designed to enhance scientific and public awareness of the causes, dynamics, and effects of atmospheric nitrogen compounds.

Mid-Range Actions (1-5 years)
The basic tenets of the six mid-range actions will be to achieve public understanding and acceptance of the issues surrounding all atmospheric pollutants (toxic chemicals, nitrogen, ozone, etc.) and to eliminate barriers to cross-media cooperation/collaboration.

Long-Term Goals (5+ years)
The direction and scope of long-term goals will be directly affected by the success of previous stages. In general, the various communities should explore the benefits of pressing for a cross-media, results oriented environmental protection act.

Reference: Chesapeake Bay Program Air Subcommittee. 1997. Airsheds and Watersheds II: A Shared Resources Workshop. Raleigh, NC, March 5-7,1997. 34pp.

This was the second in a series of workshops addressing the regional impact of atmospheric nitrogen deposition on East and Gulf Coast estuarine eutrophication. The workshop had three goals: (1) determine the essential connections between issues, programs, agencies, organizations and jurisdictions which would have advanced our ability to address the atmospheric nitrogen issues; (2) identify and/or create new platforms for discussion of solutions; and (3) identify management issues around which additional research and policy work is needed to advance our understanding of the ecosystem impacts of nitrogen as it moves between airsheds and watersheds.

A list of research priorities was developed at the 1994 Mt. Washington meeting and subsequently endorsed at the Airlie (Shared Resources) Workshop. These priorities were carried forward to this workshop ("Raleigh Workshop").

- Long-term, high-quality monitoring and modeling programs are needed to quantify the deposition of nitrogenous compounds and airborne toxic chemicals to the water bodies and their watersheds. In particular, there is a need to improve dry deposition estimates to the water bodies and to their surrounding catchment areas.
- Other forms of nitrogen must be considered in addition to the current focus on reactive nitrogen compounds (primarily oxides of nitrogen), such as ammonia/ammonium (reduced nitrogen compounds) and organic nitrogen compounds. These species can contribute ~25% of the flux of nitrogen compounds from the atmosphere.
- Accurate and defensible methods are needed to describe the cycling of deposited pollutants through watersheds, on a regional basis.
- There is a need to understand and consider the effects of important fine-scale phenomena, such as processes affecting groundwater transport of deposited pollutants in certain watersheds (which are masked by the 20 km grids of the best available models).

Participants at the Raleigh Workshop endorsed each of the above priorities, and added two more.

- Develop a method to account for within-year and inter-annual variability in weather and meteorological events, including inundations associated with hurricanes, severely cold winter, or very hot summers.
- Determine the form and severity of atmospheric nitrogen's biological consequences in coastal and estuarine waters, compared to other nitrogen inputs (e.g., wastewater treatment plants, storm water runoff); what improvements to living resources would be observed if reductions in atmospheric nitrogen deposition were achieved; and how much of this improvement would vary be location.

Reference: Steidinger, K.A. and H.L. Melton Penta (Ed.). 1999. Harmful Microalgae and Associated Public Health Risks in the Gulf of Mexico. Gulf of Mexico Program, U.S. Environmental Protection Agency. Florida Marine Research Institute, Florida Department of Environmental Protection. 63pp + app.

Harmful Algal Bloom (HAB) species, or groups of species, that cause the greatest impact to Gulf of Mexico (GOM) states (Texas, Louisiana, Mississippi, Alabama, and Florida), their resources, residents and visitors, and coastal economies include:

- *Gymnodinium breve* - a red tide organism; causes human respiratory irritation and animal mortality
- *Gambierdiscus toxicus, Prorocentrum, Ostreopsis,* and other benthic dinoflagellate species that may or may not be associated with the tropical fish poisoning known as Ciguatera.

- Dinoflagellates that are associated with tumor promotion in experimental animals and may be associated with tumors in marine fishes and turtles.
- *Pfiesteria*-like organisms that may potentially pose a threat to natural resources and human health (a special section).

Five types of seafood poisonings including the species causing the poisoning, and the human symptoms/ illness are described.

Marine event information (e.g., a red tide or hurricane), including good and bad press releases; mortality event reporting sheets; facts and frequently asked questions about Florida's Red Tides; and technical facts about *Gymnodinium palchellum,* is presented.

Presentation and Slides
General information on harmful algal blooms is presented including the effects on marine animals and humans, and how they can be controlled and managed.

Species Identification
General summary and technical information on 15 species of dinoflagellates and diatoms

Field Sampling and Laboratory Procedures
Instructions for proper collection of water samples and how to prepare them for analysis; shellfish monitoring; fish sampling; sediment sampling; and volunteer information and observation data sheets

1) counting phytoplankton, 2) mouse bioassay for Neurotoxic Shellfish Poison, 3) summary information for monitoring brevetoxins in shellfish by receptor binding assay, 4) summary information for monitoring brevetoxins in shellfish by Ouabain-Veratridine Dependent Cytotoxicity Assay, 5) Detection of *Gymnodinium breve* and Brevetoxins by ELISA, 6) Brevetoxin Analysis Using High Performance Liquid Chromatography (HPLC)

Pfiesteria and Pfiesteria-like species
Summary and technical information on *Pfiesteria piscicida* and two *Pfiesteria*-like species and procedures for collecting and shipping sediment and water samples

HAB Meeting Summaries
Summaries of 1) ECOHAB meeting, Aug. 1994, 2) Florida Red Tide Research Planning and Coordination Meeting, Nov 1996, 3) Proceedings of the Workshop for Application of Remote Sensing to Red Tide Forecasts in the Gulf of Mexico, July 1997, 4) EPA Harmful Algal Bloom Workshop, Oct. 1997

Appendix
Public Health Contacts; Species Identification Contacts; Toxin Assay Contacts; Selected Internet Addresses; U.S. Food and Drug Administration- Center for Food Safety and Applied Nutrition, 1995; Contingency Plans and Related Information from the GOM states; Acronyms and Abbreviations; and Glossary

Reference: Epstein, Paul R. (Principal Investigator), 1998. Marine Ecosystems: Emerging Diseases as Indicators of Change, Health of the Oceans from Labrador to Venezuela. Year of the Ocean Special Report. Health Ecological and Economic Dimensions of Global Change Program, Funded by NOAA and NASA. 70pp + app.

Emergence and resurgence of diseases affecting marine life - e.g., marine mammals, fish, sea birds and coral reefs - and effects on humans as they interact with a changing marine environment.

No coastal bay, harbor, or inlet, from Labrador to Venezuela, is immune to the impact of algal blooms and marine-based disease events. Six data sets are integrated in the Health, Ecological and Economic Dimensions of Global Change Program (HEED) framework, funded by NOAA and NASA.

The Ecosystem Stresses

Mechanisms for the increasing frequency and severity of HABs and factors contributing to mass mortality events include

Temperature Anomalies and Immunity - Evidence that changing water temperature affects immune systems

- Underlying Ocean Warming? - Ocean warming changing flora and fauna distribution

Consequences

- Harmful Algal Blooms (HABs) - consisting of red tides, brown tides, non-toxic diatoms, cyanobacteria; and the effects from blooms including tumors and human health concerns
- Public Health Concerns - concerns about seafood consumption, swimming-related illnesses, chronic impacts- “Estuarine distress syndrome”

Diseases of Marine Wildlife Populations

- Marine Mammals - adverse events involving marine mammals can serve as another sentinel indicator of ecosystem health; they are top predators that bioaccumulate over time; El Nino events and major marine mammal mortality events
- Shore Birds - migratory birds are often forced to flock to smaller areas where unhealthy conditions develop and disease is easily spread
- Sea Turtles - coming under increasing pressures from loss of nesting habitat, by-catch and direct take mortalities, and now the proliferation of disease, specifically fibropapillomas
- Fish - significant physical environmental anomalies can render entire fish populations vulnerable to infection. HAB biotoxins can also render fish populations more susceptible to diseases.
- Invertebrates - Environmental fluctuations emerge as chief contributors to invertebrate mortalities, and protists are often involved. A strong association exists between diseases of invertebrates and El Nino conditions.

Diseases of Habitat

- Seagrasses - HEED data indicates seagrass die-offs appearing in association with sea surface temperature (SST) anomalies and extreme precipitation. Seagrasses can be affected by persistent brown tides that block light and deplete oxygen from the water column.
- Coral Reefs - Coral Reefs provide many environmental and economic benefits such as, habitat for many marine species, buffers against waves and tropical storms, and a resource for tourism. Climate change and increasing SSTs are compounding with local stresses to affect coral reefs worldwide (e.g., coral reef bleaching).

Spatial Perspectives - Major Marine Ecological Disturbance (MMEDs) by Large Marine Ecosystems (LME)

The LME perspective illustrates the variation in types of impacts from one economic region to another including the Caribbean Sea Ecosystem, the Gulf of Mexico Ecosystem, the Southeast U.S. Continental Shelf Ecosystem, the Northeast U.S. Continental Shelf Ecosystem, and the Scotian and Newfoundland Shelf Ecosystems.

Temporal Perspective - Case study of the 1987 El Niño Southern Oscillation (ENSO) event

In 1987, there was an El Niño event, followed by a strong La Niña event in 1988. Biological impacts from anomalous movements of the Gulf Stream were observed including red tides, oysters and mussels, bottlenose dolphins and humpback whales, seagrasses and coral reefs, and human ingestion of harmful and fatal levels of fish and shellfish biotoxins.

Costs - The Economic Impacts of Harmful Algal Blooms

Serious economic harm can result from the occurrence of a harmful algal bloom, through shellfish bed closures, impacts on tourism, losses to the seafood industries, and subsequent damage to ecosystem structural stability.

Monitoring, Mapping and Modeling

- Public Health Early Warning Systems
- Environmental Policy Implications

Reference: Steidinger, K.A., J.H. Landsberg, C.R. Tomas, and J.W. Burns. 1999. Harmful Algal Blooms in Florida, submitted to Florida's Harmful Algal Bloom Task Force by the Harmful Algal Bloom Task Force Technical Advisory Group. 38pp.

Harmful Algal Blooms (HABs) are defined by harmful effects - visible (dead fish) or hidden (loss of habitat), and affect public health (people become ill)

- 40 species of toxic marine microalgae
- 20 freshwater and freshwater-estuarine species
- Causes of HABs include excess nutrients due to nutrient runoff from farms, human waste from malfunctioning septic systems, modification of estuarine circulation.

Red Tides (Gymnodinium breve) -

Effects depend on cell concentration

- Over the last century, maximum duration of 20 months and 70% occur in late summer-fall
- Most red tides in Florida occur between Tampa Bay and Charlotte Harbor

Resource Impacts

G. breve blooms can cause animal mortalities and affect human health

- Marine mammal mortalities include dolphins, sea turtles and manatees

Public Health Impacts

G.breve produces hemolysins and neurotoxins that can affect humans

- Poisonings can occur from edible bivalves that accumulated brevetoxins.
- Shellfish areas closed to harvesting when *G. breve* levels are above background concentrations.

Economic Impacts

Businesses, tourism, community recreational activities adversely affected by red tides

Pfiesteria-like Species (PLS) in Florida's Estuarine Waters

- PLS are small, heterotrophic dinoflagellates that morphologically resemble *Pfiesteria piscicida.*
- Anthropogenic factors may lead to PLS blooms (ex. nutrient enrichment and bacterial loading or nonpoint discharges from urban runoff, agriculture and wastewater treatment plants).
- 75% of toxic *Pfiesteria* outbreaks were in nutrient-enriched waters.

Resource Impacts

- Ulcerative mycosis (UM) in estuarine fish, predominantly menhaden and mullet, characterized by deep, penetrating ulcers, chronic inflammation and presence of a fungus, usually *Aphanomyces* spp.
- Environmental stressors, including *P. piscicida*, may initiate lesions but *P. piscicida* is not necessarily the cause of "*Pfiesteria*-type" deep lesions.

Public Health Impacts

- *Pfiesteria piscicida* produces a neurotoxic, water-soluble compound that causes human health-related problems, including memory loss and respiratory stress.
- Accurate identification of these dinoflagellates is paramount for developing risk-assessment strategies and examining the environmental triggers and circumstances that allow these species to bloom.
- Possible scenarios for natural resources and public health concerns caused by PLS

Economic Impacts - not available for Florida

Ciguatera

Toxin-producing cyanobacterium associated with reef biota

- Toxin is accumulated through the food chain and large piscivorous fish acquire enough toxin to cause symptoms in humans that eat them.
- Causative organism of Ciguatera is *Gambierdiscus toxicus*, a toxic dinoflagellate.
- Outbreaks are associated with disturbances to reefs from hurricanes, coral bleaching, dredging, commercial harvesting of fish or corals by destructive methods.

Resource Impacts

If there are cyclical changes in the distribution or potency of biotoxic organisms and their subsequent effect on aquatic organisms, then there may be a connection between the food preferences of the species affected, the level or type of toxin found, and associated disease outbreaks in aquatic populations.

Public Health Impacts

Ciguatoxin is a lipid-soluble molecule that accumulates in the flesh of fish that consume it.

- Reef fish that acquire the toxin remain toxic permanently. Because these fish do not migrate, they remain exposed to the toxin sources.

Economic Impacts

In the Caribbean, economic impacts are estimated to be over $10 million.

In the U.S. and Canada, costs for time off from work and hospitalization are estimated at $20 million.

Toxic Blue-Green Algae (Cyanobacteria) in Fresh/Estuarine Waters

Cyanobacteria blooms in Florida represent a major threat to water quality, ecosystem stability, surface drinking water supplies, and public health.

- Type of toxins (secondary metabolites) produced are neurotoxins, hepatotoxins, and dermatotoxins, and their production can be affected by environmental variables.
- Molecular probes help to differentiate toxic and nontoxic strains.

Resource Impacts

Blue-green algae can reduce ambient light levels below those required for submerged aquatic vegetation (SAV) to survive.

- Blue-green algae can form surface scum with low dissolved oxygen levels (<0.5 ppm) to cause lethal conditions in fish and invertebrates.

Public Health Impacts

Exposure to cyanobacteria can cause severe respiratory distress, kidney and liver disease, allergenic asthma, neurointoxication, skin rashes or necrosis, and death.

Economic Impacts - have not been quantified

Harmful Microalgae as Tumor Promoters

Potential long-term effects of biotoxins on aquatic animals or on public health may be expressed in terms of susceptibility to disease, immunosuppression, reduced growth, effects on reproduction, or the development of tumors.

Resource Impacts

Development of tumors in aquatic organisms such as shellfish and fish consider several factors: oncogenic viruses, genetic predisposition, chemical contaminants, ultraviolet radiation from sunlight, or other environmental factors.

Public Health Impacts

Potential chronic effects on cyanobacterial toxins on human health is currently unknown.

- Possible link between human cancer and cyanobacteria in water supplies.

Economic Impacts

Chronic presence of natural toxins in food chain would likely affect endangered species and commercial and recreational fisheries.

Macroalgae

Can adversely affect natural resources, fisheries, tourism, and local economies

Not as frequent as microalgal blooms, but they are dramatic because of sheer biomass

- Florida waters support a wide range of green, brown, and red algae that can bloom.

Resource Impacts

Marine macroalgal blooms can smother the sea bottom, whether coral reef or sand, which often kills the bottom community.

Can cause hypoxia and anoxia with the same result

- Can also occur in freshwater habitats

Public Health Impacts - no known impacts

Economic Impacts - affect local industries associated with recreational use of waters, such as diving, fishing, and tropical fish collection

Reference: Frankic, Anamarija, Ph.D. 1999. Coastal/Estuarine Management Issues and Information Needs Report. Submitted by the Coastal States Organization, Project Contract Number: 40-AANC-8-01324. 37pp.

The Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) receives information on coastal and estuarine management issues to use as a guide for strategic planning and project selection. The Coastal States Organization (CSO) identifies coastal and estuarine management priorities and information needs in the National Estuarine Research Reserve System (NERRS) and Coastal Zone Management Programs (CZMP).

Coastal Management Issues

Literature Review Results

Three key national coastal management issues are: 1) nutrient overload, 2) pathogens and toxic contamination, and 3) habitat modification and loss.

Survey Results

Nutrient enrichment and habitat degradation/loss and restoration are identified as high priority issues in all regions except the Pacific Region where pathogens and toxic contamination are the highest priorities.

Coastal States Management Technology/Information Needs

Survey responses and literature reviews identify three information and technology needs that apply to all management issues: 1) need for comprehensive base-line data, 2) need for timely, accurate and cost-effective monitoring, and modeling technology, and 3) need for improved ways to access and evaluate information gathered through monitoring programs.

Organizations Similar or Comparable to CICEET Mission and Goals

There is no single agency addressing both coastal management issues, caused by anthropogenic contamination, and developing relevant technology/information on the local and state scale. CICEET is required to focus on projects and activities that link directly to management issues.

CICEET seeks to achieve its Mission by:

- effectively using the National Estuarine Research Reserve System (NERRS) as living laboratories;
- fostering interdisciplinary work among biological and physical scientists, engineers, resource managers, and policymakers;
- being problem-driven and solution-oriented;
- ensuring the distribution of innovative environmental technology and techniques to user groups;
- and enhancing the current capabilities of estuarine science and management programs.

Project Findings

Literature Review on National and Regional Coastal Management Priority Issues and Information/ Technology Needs

National Coastal Management Issues

Nine major coastal environmental issues identified, as a basis for determining scientific priorities to meet national coastal needs.

- Association for National Estuary Program (ANEP) proposed the development of a “Technology Transfer Document” that will provide guidance on water quality and living resources issues in terms of translating and using technologies to develop and attain management objectives.
- CSO survey results identified and prioritized twelve management issues and needs of coastal state management agencies.

Regional Coastal Management Issues

The Regional Marine Research Programs (RMRP) of the U.S. coastal areas were designed to identify regional research needs, set priorities among them, carry out needed research and better coordinate existing research.

- Issues frequently identified in RMRPs were: ecosystem degradation, alteration and loss; nutrient enrichment, eutrophication and HAB; habitat restoration; anthropogenic contamination and toxic materials; erosion; invasive species; and freshwater input.

Information and Technology Needs

- Eight products and services were identified by coastal program managers to address coastal management issues.
- Three sections were identified to address technology, information, and research needs through literature reviews: nutrient enrichment, habitat degradation/loss and restoration, pathogen and toxic contamination.

Survey of Coastal States Priority Management Issues and Technology/Information Needs

Methodology

Primary goal was to identify priority coastal and estuarine management issues in coastal states and territories that can be addressed by environmental monitoring, modeling, restoration/mitigation, technology/technique and information transfer consistent with the CICEET Mission.

- Responses to the survey were received from 53 individual coastal and estuarine programs representing 35 coastal states and territories.

Survey Results

All regions identified three general areas of management concern: nutrient enrichment (eutrophication, HAB); habitat degradation/loss and restoration; and pathogens and toxic contamination.

- Another high priority issue identified in the Pacific and Island regions was erosion and sedimentation.
- Other issues frequently identified by the survey included invasive species, dredging, negative impacts of recreational uses, and hydrologic modifications.
- Three general areas of information and technology needs that apply to coastal and estuarine management concerns are: comprehensive baseline data; timely, accurate, and cost-effective monitoring, and modeling technology; and improved ways to access and evaluate information gathered through monitoring programs.

Regional Survey Results

Survey results from the seven regions included: Great Lakes, Northeast, Mid-Atlantic, Southeast, Gulf, Pacific and Islands.

Findings on organizations with similar mission and goals to CICEET

The most relevant organization identified in this report is the EPA's Office of Research and Development (EPA/ORD). Its research programs have been established to improve ecosystem risk assessment and risk management as highest priority research areas for investment over the next 10 years. There is no mission to link activities with coastal management priorities or needs.

- Other agencies or programs that have relevant goals to CICEET are: NOAA/CSC (Coastal Services Center), NOAA/C-CAP (Coastal Change Analysis Program), EPA/OST (Office of Science & Technology), USGS/BEST (Bio-monitoring of environmental status & trends), USDOE/NABIR (Natural & Accelerated Bioremediation Research Program), U.S. Fish and Wildlife Service/Environmental Contaminant Program, NOAA/Sea Grant, and Battelle (Science and Technology Institute).

Conclusions

One of the significant challenges facing coastal managers today is how to move toward an integrated, ecosystem-based management that incorporates feedback from the natural environment.

To support restoration of coastal habitats, managers and researchers expressed a need for science and technology transfer initiatives to establish "pilot studies" that relate to habitat change and process-oriented research *in situ.*

APPENDIX B: Issue - Specific Case Studies

To explore how the concepts described in the main body of the document apply to coastal issues, case studies have been developed to highlight the similarities, as well as differences, in the research and monitoring approaches. The following case studies are examples of some of the most common environmental issues impacting coastal and estuarine systems.

Coastal Eutrophication

Excess growth of algae, stimulated by addition of nutrients to water bodies, is referred to as eutrophication, a process that is responsible for degradation of water quality. An overgrowth of algae is associated with low dissolved oxygen, high turbidity, losses of submerged aquatic vegetation (SAVs), and toxic and nuisance bloom events. Delivery of nutrients to water bodies from the surrounding watershed, and in some cases airsheds is a natural process but, in recent decades, has been greatly accelerated by various human activities. The concomitant degradation of water quality has also been accelerated.

Eutrophication differs from many other environmental problems because the cause, excessive nutrients, is much better understood than the causes of most other problems. Despite the cause-and-effect linkage, some aspects of eutrophication are not well defined and the exact response of a water body to nutrient additions cannot be predicted. For example, the level of nutrients that cause problems in one estuary may not cause problems in another, and the symptoms may last from weeks to months in one estuary and for only days in others. Despite the cause-and-effect linkage, some aspects of eutrophication are not well defined and the exact response of a water body to nutrient additions cannot be predicted. Additional variables may affect this relationship. These variables may include land use patterns and physical modifications to the systems, changes in freshwater flows, changes in suspended sediment levels or water color, flushing rates, density stratifications, increased suspended sediment and sedimentation.

Furthermore, not all of these sources of nutrients and their contributions relative to one another are well known. This information is important, in addition to information on the variables affecting the response of the estuary, for developing management strategies. For example, how much of the nutrients come from air pollution depositing either directly onto the estuary or to its watershed compared to point sources or urban and rural runoff? There are also outstanding research questions related to sources of nutrients such as how the marine atmosphere affects the deposition to coastal waters.

Studies conducted during the last 25 years have provided some understanding of the nutrient-symptom linkage, and nutrient management strategies designed to reduce these problems have worked in several estuaries. Results of a recent NOAA report on the characteristics, timing (duration and time of year), and severity of eutrophication, on a national basis, revealed that, for 17 of 139 systems (12 percent) included in the study, there was insufficient information from which to develop conclusions about eutrophic conditions. For an additional 33 estuaries (24 percent), the conclusions made about eutrophication were based on uncertain information. The report also describes development of an index designed to predict and rank the susceptibility of estuaries to development of eutrophic symptoms. This ranking, in addition to the eutrophic condition results, provides a basis for setting priorities for monitoring and management action, and for resource allocation among the Nation's estuaries.

Data, Information, and Assessment

The eutrophication case study provides some important lessons for coastal research and monitoring. Assuming that an evaluation of estuarine eutrophication was limited by available data, NOAA found that gathering expert experience-based knowledge of conditions and trends in an estuary, rather than attempting to analyze a comprehensive database of water quality and response parameters, was a more effective approach to assessing the scale and severity of eutrophication. Other assessments of environmental problems could be conducted in a similar fashion. The results, although partly subjective, are comparable and consistent and provide a starting point for design of monitoring programs.

Given these results, the following tiered monitoring strategy would be effective.

Tier 1A — Baseline Monitoring of Symptoms and Response Variables

For all estuaries, response variables, such as dissolved oxygen and chlorophyll *a*, should be monitored on an annual basis so that trends can be determined. Priority should be given to acquiring data for the 17 estuaries with insufficient information and for the additional 33 estuaries for which existing data were uncertain. Based upon our knowledge of when problems are likely to occur, monitoring could be targeted to specific time frames. Sampling once per year during critical periods might suffice for some systems.

Tier 1B — Intensive Monitoring of Response Variables

For estuaries that are considered sensitive — those susceptible to developing problems based on physical and hydrologic characteristics, but not yet showing evidence of eutrophication — more intensive monitoring of response variables may be necessary. More intense monitoring should be a priority for estuaries that will potentially receive significant nutrient loads, based on predicted population increases or land uses that are direct sources of nutrients (*e.g.,* animal feed lots).

Tier 2 — Monitoring Stressor/Response

For estuaries exhibiting eutrophication stress or moderate to well-developed symptoms, fall-line riverine monitoring should be initiated to estimate annual loads and also direct inputs of nutrients. Where atmospheric deposition may contribute nutrients, deposition monitoring should also be initiated. This will permit calculation of initial nutrient budgets to determine the major source of the stressor. Appropriate management actions may also be indicated.

Tier 3 — Site-Specific Studies

To develop specific management plans, additional data collection and analysis (*e.g.,* developing estuarine circulation models and higher-resolution of temporal load estimates) is necessary to determine the most cost-effective management strategy. Recent successful efforts to limit nutrient inputs with positive water-quality responses, such as those in Tampa and Sarasota Bays, could be used as examples of targeted monitoring and research.

Physical Change of Ecosystems

Physical modification of coastal ecosystems range in scale from obvious habitat losses in coastal forests, wetlands, and estuaries, to subtle changes in physical parameters, such as stream diversity and complexity. The principal drivers of these modifications are human population growth, with resulting urban, suburban, and rural development and direct economic exploitation of natural resources through anthropogenic activities, such as damming streams for hydroelectric power generation and irrigation, logging forests for timber, converting land for agriculture, and building roads. Among the cumulative effects of these modifications are degraded in-stream habitat conditions, loss or degradation of estuarine habitat, and changes in nearshore sediment transport along the coast.

It is generally accepted that the quality of the riparian area adjacent to streams is the most important characteristic for providing the kind of habitat needed for healthy biologic communities. In many coastal watersheds, anthropogenic alterations, related to construction/excavation, agricultural/forestry practices, and other activities, can result in significant loads of fine- and coarse-grained sediments that cover spawning areas, suffocate eggs and larvae, and reduce production of macroinvertebrates, which are the food source for coastal fish populations. Within and adjacent to estuaries and tidally influenced coastal streams, physical modifications, such as dredging projects, frequently alter estuarine hydrologic patterns and, in turn, affect timing and quantity of freshwater flow. Timing and quantity of fresh water are critical for riverine and estuarine structure and function because they affect circulation, salinity patterns, nutrient availability, transport and fate of contaminants, and the distribution of living resource populations.

Another detrimental effect of physical modification is loss of habitat by fragmentation. On occasion, as wetland areas are fragmented, ecosystem production can initially increase with the increase in surface water area. However, this trend is soon reversed as habitat structure and function of the remaining wetland is affected, and populations of inshore-dependent species will decline.

Watershed analysis through research and monitoring is necessary to determine the health and problem areas of watersheds and coastal areas. The selection of appropriate ecosystem parameters or indicators of system function is important to relate trends (i.*e.,* losses, fragmentation, and degradation) in the amount and condition of habitat to effects on resource populations. Resulting data and information on habitat availability, species usage, rates of habitat change, biologic community trends, scaling issues (such as regional similarities and comparability of various habitat types, and functional values of natural and restored habitats) will improve our capability to predict effects of physical and hydrologic changes on coastal and estuarine habitats and systems.

Tier 1 — Baseline Monitoring of Symptoms and Response Variables

Impacted or coastal areas of concern should be monitored on an annual or cyclic basis so that characteristics and trends can be determined for response variables such as:

- Extent and density of aquatic habitat;
- Sediment load;
- Temperature;
- Salinity;
- Bathymetry, geomorphology, and grain size;
- Land cover and land use; and
- Community structure and productivity.

Tier 2 — Monitoring Stressor/Response

More intensive monitoring could be indicated to measure water flow timing and amount in areas where this is considered problematical and where baseline information is insufficient.

Tier 3 — Site-Specific Studies

Potential areas for research that would complement monitoring activities might be directed at studies to:

- Develop improved methods to assess cumulative ecological effects of multiple physical stressors on coastal ecosystems.
- Further refine GIS and other analysis methods for determining changes in terrestrial and/or aquatic habitat cover, coupled with numerical models for assessing and predicting trends and patterns of habitat change or loss.
- Identify and quantify the effects of natural variability that act in combination with human-induced physical stresses on coastal systems.
- Better define local-to-regional scaling and compatibility issues as they relate to comparing environmental conditions among areas.

Invasive Species

Certain species can thrive in areas outside the habitat where they have evolved and naturally live. Such nonindigenous or invasive species are being disseminated throughout the world, both intentionally and inadvertently by human activities. Introductions of nonindigenous species can be very disruptive to the ecosystems that they invade. Invasion of nonindigenous species is a leading cause of species extinctions and loss of biodiversity in coastal ecosystems. Such introductions can (1) threaten the abundance of native species, with which they compete or on which they feed as predators, parasites, or pathogens; (2) change the productivity and other functions of receiving ecosystems; and (3) cause significant damage to valued natural resources.

Aquatic invasive species are often spread in coastal ecosystems through introductions with ballast water, which has been taken in at locations far from the site of subsequent release. The speed of modern ships allows ballast-water organisms from one area to survive interocean voyages and, therefore, facilitates the transfer of viable invasive organisms to a new compatible environment. Nonindigenous invasive species, especially parasites and pathogens, are also spread inadvertently in coastal waters through aquaculture operations and importing of ornamental and pet species. In some cases, invasive species are also introduced and spread intentionally to control pests or for other purposes.

A number of recent studies, often based on serendipitous discovery of invasive species, have documented the appearance and spread of such species in U.S. coastal waters, including the Great Lakes. Efforts to identify and track reports of invasive species, however, have only recently started to be coordinated at a national level. Often this coordination is limited to a specific species (*e.g.*, Zebra Mussel), region (*e.g.*, 100th Meridian Initiative), or mode of introduction (*e.g.*, ballast water). A comprehensive monitoring program is clearly needed to (1) detect invasive species, (2) identify their

location and mode of initial release, (3) evaluate the spread of such species, (4) evaluate their impacts on biodiversity, and (5) evaluate the success of control and mitigation measures.

Data, Information, and Assessment

Although a coordinated national program for monitoring the occurrence and spread of invasive species can provide much valuable information and support for dealing with such species, additional information regarding these species is often available as a by-product of unrelated efforts. Thus, the initial discovery of a new invasive species in coastal waters may be made serendipitously, as part of a project being conducted for a different purpose.

A national focal point for coordinating the collecting and organizing invasive species information and data from *all* available literature, experts, specialized clearinghouses, and other sources should be established. This focal point would use these data and information to develop assessments on the threats associated with individual species, as well as on patterns in biological characteristics, locations of origin, modes of introduction, and other factors that affect the introduction of problematic invasive species.

The following monitoring strategy would be effective in addressing these needs.

Tier 1A — Baseline Monitoring of Biodiversity

Representative samples of the major biological communities (*e.g.,* nekton, plankton, benthos) should be collected from locations in the major coastal regions every few years. The composition and abundance of species in these samples, as well as indicators of the species health, would be determined. Evidence of parasitic and pathogenic infections in those biological communities and, if possible, the causative agents for these infections should also be identified.

Tier 2 — Intensive Monitoring of Response Variables

In locations where new invasive species are identified, more detailed monitoring to assess the magnitude and extent of occurrence, and the rate at which the species is spreading, would be carried out to support the development of strategies for control and mitigation. Continuation of such monitoring would track environmental fluctuations in the invasive species and in the biodiversity of the associated biological communities to evaluate the success of control and mitigation measures.

Tier 3 — Site-Specific Studies

As more locations are studied for invasive species, and as the protocols for monitoring become more standardized, a more systematic knowledge will be gained of anecdotally known regional variations in invasion rates and species. Intensive study at specific locations where invasions had taken place, as well as at ecologically and climatically similar locations with invasion observed to a different extent or by different species, will help establish what factors put a particular area at risk from what species or types of species.

Toxic Contaminants

Toxic contamination relates to the release of toxic chemicals or their breakdown products into coastal waters. The following case study is an example of toxic contamination of estuarine waters but similar problems occur within other coastal waters.

Additions of toxic chemicals may affect estuarine biota by altering their reproductive success, growth rates, competitive abilities, or simply by causing death. The typical response of the estuarine ecosystem to toxic contaminants is incorporation of the contaminants into sediments and/or living tissues. These accumulations can result in immediate responses (*e.g.,* growth changes, community changes, mortality) or similar kinds of longer-term changes, depending upon the persistence of the chemical.

Humans introduce heavy metals, such as lead and zinc, and organic chemicals, such as PCBs and pesticides, into coastal areas through industrial and sewage outfalls, stormwater runoff, disposal from boats, runoff from agricultural and suburban areas, river discharge, and in rain and dust. Additional information is still needed on the pathways by which toxic contaminants enter the waterbodies, including how much of the loadings come from each of the various pathways. For example, for toxic contaminants deposited from the air, there are few monitors in coastal areas to determine how much is deposited. Other outstanding questions in this area include what different forms of contaminants are emitted from various types of facilities, how far the contaminants travel before they are deposited, and the characteristics of mixtures of contaminants from cities. These materials may affect water quality or settle to the bottom and contaminate the sediments in which important food web organisms live.

Toxic contamination in coastal areas differs from many other environmental problems because, like eutrophication, its cause is well understood, but its effects on estuarine biota are not well known. Clearly, fish and other estuarine organisms can bioaccumulate contaminants in their tissues, but the effect of the bioaccumulation is not well understood. In the immediate area of high concentrations, toxic contaminants can kill all marine life; however, rarely are toxic contaminants found at such lethal concentrations in nature.

Studies conducted over the past two to three decades have provided clear evidence that additions of contaminants to estuarine water and sediments can have negative biological and ecological effects, although the direct dose-response relationships or the effects of contaminant mixtures are not well understood. In addition, when contaminants are bioaccumulated in significant concentrations, the potential for human health effects through ingestion of the contaminated products (*e.g.,* fish or shellfish) can be serious.

Results of recent monitoring studies have shown that about 75 percent of the Nation's estuarine sediments are contaminated by heavy metals and organic chemicals, but generally in low concentrations. Only about 5 percent of these sediments are contaminated at concentrations that are expected to result in severe biological and ecological consequences (*e.g.,* mortality of biota). However, the effects of either short- or long-term exposure to contaminant concentrations generally found in estuarine sediments are not well known.

Data, Information, and Assessment

This case study in toxic contamination is an important lesson in demonstrating that massive amounts of data can exist and still result in a deficiency of information to assess ecological condition. While large

amounts of toxic contamination data exist (for example, the EPA Sediment Inventory), little of this information has been collected in a consistent manner that would permit its integration over space or time. Even if such consistency were available, the lack of clear dose-response relationships, particularly for mixtures, is apparent and limits the availability these data for decision making. Finally, specific research is required to determine the roles of natural environmental variability on contaminant releases and their effects on biota. The lack of consistency can be addressed by a Tier 1 coordinated survey, the conversion of data to information is addressed by Tier 2 issue-based monitoring and studies, and the role of natural variability could be addressed by Tier 3 specific studies.

Given this information, the following monitoring strategy would be effective.

Tier 1 — Baseline Monitoring of Symptoms and Response Variables

For all estuarine waters, response variables comprised of the benthic triad (benthic community, sediment toxicity, and sediment chemistry) and tissue residues in target species should be monitored on an annual or cyclic basis so that concurrent status and trends can be determined. Collection of the triad data and tissue residue concentrations will provide sufficient information to gauge the condition of the estuarine population and to discern whether deficiencies in condition are likely due to contamination.

Tier 2 — Monitoring Stressor/Response

Based on the results of Tier 1 monitoring, sensitive estuaries, impaired estuaries believed to be sensitive, and estuarine segments that are contaminated by toxic chemicals would require more intense spatial and temporal monitoring of response and stressor variables. Response variables would include benthic community composition, bioaccumulation, and reproductive capacity. Stressor variables would include sediment chemistry parameters, and physical and chemical attributes. Additionally, monitoring of pathways by which contaminants may get into the coastal waters and sediments, such as air deposition, would be important. Intensive Tier 2 monitoring would be completed along gradients of toxic contamination to determine the dynamics of the relationship between the response variables and the environmental stressors. Recommendations could then be made to either eliminate and/or repair the environmental damage caused by the toxic components. As these “repairs” are made, estuarine segments could be removed from the 303(d) list.

Tier 3 — Site-Specific Studies

To fully understand the interactions of toxic contaminants with the environment, and the relationships of toxic-induced response variables to natural changes in the environment (*e.g.,* salinity, temperature, sediment composition) or to the potentials for mixing multiple contaminants and their interactions, a small number of site-specific study areas would be established. At these sites, the details of process mechanics, and small-scale temporal and spatial inter-relationships would be examined. Information from the site-specific study areas would be useful for the Tier 2 monitoring because the efficacy of proposed solutions at that level may be significantly influenced by the data from site-specific study areas.

Human Health Effects Associated with Harmful Algal Blooms

Algae are unicellular microscopic plant cells that are the foundation of life. An algal bloom develops in the marine or freshwater environment when there is an excess of growth of these organisms due to

changes in that environment. A harmful algal bloom (HAB) is defined as a bloom that has deleterious effects on plants, animals and/or humans. HABs, such as red tides, have been occurring for centuries. Since the 1970s, they appear to be more frequent and extensive, both in the United States and worldwide. In the United States, the coasts have become the prime target of HABs. Some of the most affected areas are Florida, Maryland, Virginia, North Carolina, Louisiana, Texas, and Alaska.

HAB-associated human diseases are categorized into two groups, based on their primary transvectors.

- Shellfish harbor the toxins that produce paralytic shellfish poisoning (PSP), neurotoxic shellfish poisoning (NSP), diarrhetic shellfish poisoning (DSP), and amnesic shellfish poisoning (ASP).

- Fish carry the toxins responsible for ciguatera poisoning and tetrodotoxin (fugu or pufferfish) poisoning.

The shellfish-associated diseases generally occur in association with algal blooms or “red tides,” which may be characterized by patches of discolored water and dead or dying fish. The fish-associated diseases are more localized to specific reef areas (ciguatera poisoning) and fish (fugu poisoning). In addition, skin and aerosol exposure have reportedly resulted in human health effects with brevetoxin red tides (also the cause of NSP), allegedly the *pfiesteria* organism and its *pfiesteria*-like organisms, and the cyanobacteria (also known as the blue green algae).

The primary target of HAB toxins is the neurologic system, although affected individuals usually present a wide range of symptoms, resulting in a confusing clinical picture. Gastrointestinal symptoms begin minutes to hours after eating contaminated seafood. In the case of PSP, fugu, and ciguatera, accompanying acute respiratory distress may be fatal within hours. Ciguatera and ASP may also produce debilitating chronic neurologic symptoms lasting months to years. Chronic disease (neurologic, immunologic, carcinogenic, etc.) associated with the HAB toxins is an area of active scientific research. For example, the blue green algae produce carcinogenic toxins that may be associated with an increased risk of liver cancer in humans consuming contaminated drinking water.

Other Natural Marine HABs

Pfiesteria piscicida and the so-called *Pfiesteria*-like organisms were originally discovered in a laboratory setting, and then implicated in subsequent fish kills in the late 1980s and early 1990s. Investigators discovered the organism in some of the water and/or fish samples received from field biologists during events such as lesioned fish and fish kills occurring in North Carolina estuaries. Over the past several years, HABs in the Mid Atlantic States have been associated with extensive fish kills, as well as multiple reports of a variety of human health effects associated with skin and aerosol exposure to HAB-contaminated water. Other *Pfiesteria*-like organisms have been implicated in fish events, in addition to *Pfiesteria piscicida*. For example, in February 1998, a new marine organism, a cryptoperidiniopsoid dinoflagellate resembling *Pfiesteria piscicida* morphologically and genetically, was identified in the estuarine waters of the St. Lucie River (St Lucie County, FL). This newly identified organism has been associated with fish lesions and has been identified in the MidAtlantic fish events, often associated with *Pfiesteria piscicida*. No definitive human health effects have been reported associated with exposure to the waters of this river, although there has been considerable community and public health concern. To date, despite continued experiments, no toxin(s) have been isolated in the laboratory from either *Pfiesteria piscicida* or the *Pfiesteria*-like organisms.

The blue green algae or cyanobacteria represent a diverse group of organisms that produce highly potent natural toxins. These organisms can form toxic blooms in freshwater, estuarine, and marine environments. There have been numerous case reports of severe morbidity and mortality in domestic animals from exposure to these toxins through drinking contaminated water. There have been relatively few case reports or even epidemiologic studies of the effects of these toxins on humans. In one major Brazilian epidemic, because of exposure to toxins over 100 persons on renal dialysis suffered from severe liver disease with 50 percent mortality. An intriguing study by Yu et al. (1995) found an increased association between primary liver cancer in humans and the use of surface drinking water sources in China. A major potential route of human exposure to these toxins is through the consumption of contaminated drinking water. Surface drinking water supplies are particularly vulnerable to the growth of these organisms; current drinking water treatment in the United States does not monitor or treat for the blue green algal toxins.

Data, Information, Assessment

The major goal associated with monitoring for HABs is the prevention of human health effects. In the case of the HAB-associated human diseases, three needed levels of prevention are lacking.

- *Primary prevention*: The exposure and the resulting human disease never occur due to the prevention of exposure and the disease. Although primary prevention is the ideal, it is not always achievable in the case of the HAB-associated diseases.

- *Secondary prevention:* Decrease the prevalence of the disease by decreasing the number of cases; this is traditionally performed by the early detection of cases to prevent additional cases, as well as rapid intervention with those already exposed to prevent illness.

- *Tertiary prevention:* Decrease the extent or severity of the disease in persons already ill.

Unfortunately, although some wealthier nations conduct surveillance for the toxin-producing organisms and/or toxin levels in specific shellfish beds, there is no accurate surveillance of human diseases caused by the HAB-associated organisms. Even in the wealthier nations, reporting and surveillance are inadequate. Both PSP and ciguatera are reportable diseases in the United States, but there is considerable under-reporting. This is partially due to ignorance on the part of ill persons and healthcare workers with respect to diagnosis and reporting, especially when contaminated seafood arrives in non-endemic areas. In developing nations, especially in poor coastal and island communities, these diseases have been tolerated endemically for years due to lack of surveillance, diagnosis, and treatment. Thus, the true extent and impact of these diseases in the human population are unknown.

The major issue for the study of the HAB-associated human diseases, especially their epidemiology and their impact on human health worldwide, is the lack of reliable data on number of incidences the number of incidences and the possibility of their increasing incidence. In some countries with significant resources (e.g., the United States), the shellfish-associated marine seafood toxin diseases receive primary prevention through dinoflagellate/toxin monitoring of the shellfish beds; this type of primary prevention is not available for other emerging HAB-associated diseases, especially in poorer countries where the lack of data on incidence means that scarce resources are not allocated for primary prevention. In the case of ciguatera, due to the more mobile fish transvector, primary prevention is currently not practiced even in countries with significant resources. Furthermore, contamination of drinking water sources with cyanobacteria appears to be an increasing problem.

The HAB-associated diseases and their causative organisms are integrally linked with local and global environmental changes. Evaluation of these factors, both epidemiologic and environmental, will be multivariate and extremely complicated. Biomarkers of exposure and disease in humans must be developed for the diagnosis and epidemiologic study of the HAB-associated diseases. Increased surveillance and reporting of these diseases in human populations to evaluate acute and chronic health effects will only occur with education of healthcare workers and occupationally exposed groups on the diagnosis, treatment, prevention, and reporting of the HAB-associated diseases in humans. Epidemiologic and economic evaluation of the incidence of disease in human populations and the environment secondary to HABs should be performed. Finally, the integration of human health effects data with other databases and scientific disciplines studying the environmental and toxicologic effects and causes of HABs is essential. This can only be accomplished through the interdisciplinary collaboration of the scientists and agencies working on this issue.

Given this information, the following monitoring strategy would be effective:

Tier 1 — Baseline Monitoring of Symptoms and Response Variables

Of note, many of the tools necessary even for Tier I monitoring are not yet available for human health evaluation with regards to the HABs. Therefore, considerable research is necessary to develop these tools. Furthermore, although reporting is officially required for several of the human health diseases associated with HAB exposure, these diseases are highly under-diagnosed and under-reported.

- Develop biomarkers to diagnosis exposure and disease in humans and conduct an epidemiologic study of the HAB-associated diseases;
- Educate healthcare workers and occupationally exposed groups on the diagnosis, treatment, prevention and reporting of the HAB-associated diseases in humans;
- Surveillance and increased reporting of these diseases in human populations to evaluate acute and chronic health effects;

Tier 2 — Monitoring Stressor/Response

- Surveillance and increased reporting of these diseases in human populations to evaluate acute and chronic health effects;

Tier 3 — Site-Specific Studies

- Epidemiologic studies of the possible acute and chronic health effects of these diseases in human populations;
- Economic evaluation of the burden of disease in human populations and the environment secondary to HABs;
- Integration of human health effects data with other databases and scientific disciplines studying the environmental and toxicologic effects and causes of HABs.