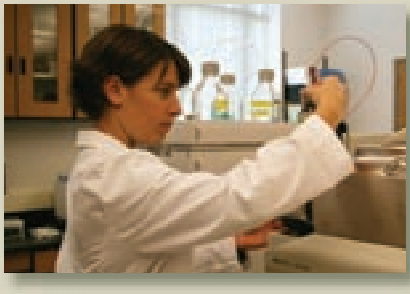
National Plan for Algal Toxins and Harmful Algal Blooms

HARRNESS

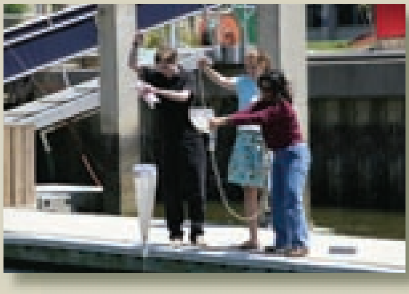
Harmful
Algal
Research &
Response
National
Environmental
Science
Strategy

2005–2015



RESEARCH

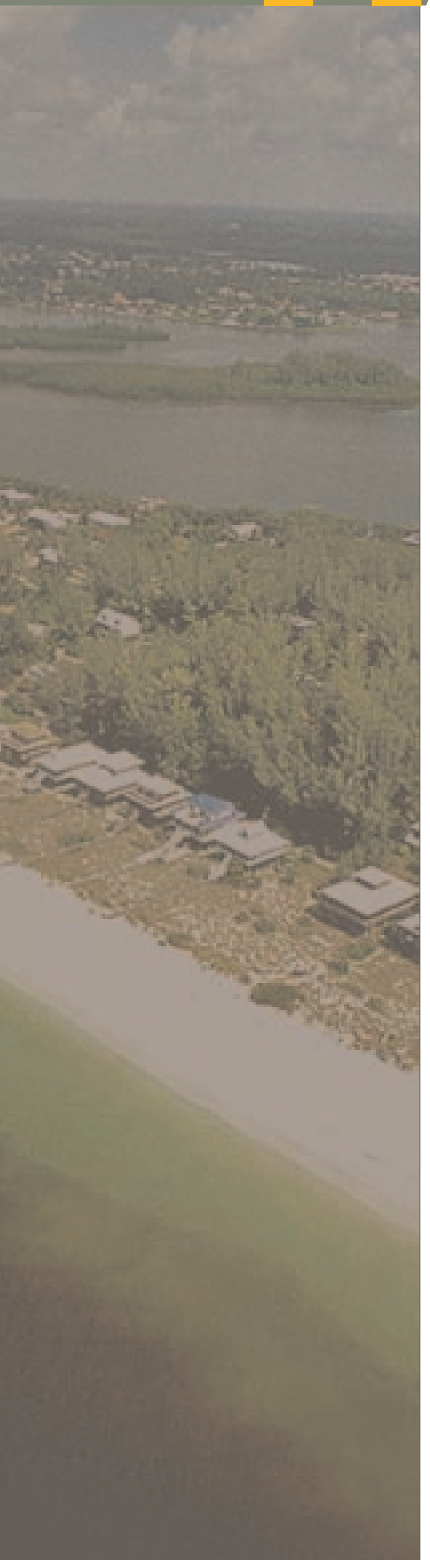
RESPONSE



National Plan for Algal Toxins and Harmful Algal Blooms

HARRNESS

Harmful Algal Research and Response:
A National Environmental Science Strategy
2005–2015



Acknowledgments

Several hundred scientists and managers, from a wide array of different fields, contributed to the extensive knowledge base on which this science strategy is based. Over the last two years, an intensive collaborative effort was undertaken including an open forum discussion of 200 participants at the US National HAB Meeting, a detailed web-based questionnaire yielding more than 1,000 targeted responses, a workshop of 50 US HAB experts, an Advisory Committee to guide, and a Steering Committee to assemble and review the most current information available for use in developing this document. Thanks are due to the entire US HAB research and monitoring community for identifying critical needs and formulating the vision needed to advance research and monitoring on algal toxins and harmful algal blooms, and to the federal and state agencies, academic, industry, and interested public who, as Advisory Committee members, provided critical document review. Special acknowledgment is due to the National Plan Scientific Steering Committee and Editorial Board members whose extensive time and efforts have sharpened thinking and clarified presentation.

The Report was produced by the Ecological Society of America with support from the National Centers for Coastal Ocean Science (NCCOS) part of the National Oceanic and Atmospheric Administration National Ocean Service. Major funding for report development was handled through the NCCOS Center for Sponsored Coastal Ocean Research, Coastal Ocean Program (NOAA Award #NA03NOS4260029). Additional NCCOS support to enhance community involvement was provided by the Center for Coastal Environmental Health and Biomolecular Research. Further support was also provided by NCCOS (to D.M.A.) for operation of the US National Office for Biotoxins and Harmful Algal Blooms.

Proper citation of this document is as follows:

HARRNESS, 2005. Harmful Algal Research and Response: A National Environmental Science Strategy 2005–2015. Ramsdell, J.S., D.M. Anderson and P.M. Glibert (Eds.), Ecological Society of America, Washington DC, 96 pp.

For additional copies or information, please contact:
Judy Kleindinst
National Office for Marine Biotoxins and Harmful Algal Blooms
Woods Hole Oceanographic Institution
Biology Department, MS# 32
Woods Hole, MA 02543
Phone: 508 289-2745
Fax: 508 457-2027
jkleindinst@whoi.edu

This report is also available via the internet at:
National Office for Marine Biotoxins and Harmful Algal Blooms at
Woods Hole Oceanographic Institution
http://www.whoi.edu/redtide/nationplan/2005nationalplan.html

Cover Photo Credits
Karenia brevis bloom off Florida coast, photo: courtesy of P. Schmidt, *Charlotte Sun*;
Mass spectrometry and algae sampling, photos: K. Nowocin;
Maine buoy, photo: http://gyre.umeoce.maine.edu/images/maine_buoy.jpg;
Dead whale, photo: G. Early.

Contents

The Marine Mammal Center often rescues more than 100 sea lions per year with domoic acid poisoning.

Source: Marine Mammal Center.

List of Acronyms

AOAC	Association of Official Analytical Chemists
APEC	Asia-Pacific Economic Cooperation
ART	Analytical Response Team of NOAA
ASP	Amnesic Shellfish Poisoning
AZP	Azaspiracid Poisoning
BTRI	Brown Tide Research Initiative
CDC	Centers for Disease Control and Prevention
CEOHAB	Chinese Ecology and Oceanography of Harmful Algal Bloom Program
CFP	Ciguatera Fish Poisoning
CLEANER	Collaborative Large-Scale Engineering Analysis Network for Environmental Research
COHH	Center for Oceans and Human Health
COP	NOAA Coastal Ocean Program
CSCOR	NCCOS Center for Sponsored Coastal Ocean Research
CUAHSI	Consortium of Universities for the Advancement of Hydrologic Science, Inc.
DMAC	Data Management and Communications
DOI	US Department of Interior
DSP	Diarrhetic Shellfish Poisoning
EC	European Commission
ECOHAB	Ecology and Oceanography of Harmful Algal Blooms
EPA	Environmental Protection Agency
ESA	Ecological Society of America
EST	Expressed Sequence Tag
EUROHAB	European Harmful Algal Bloom Program
FAO	Food and Agricultural Organization of the United Nations
GEF	Global Environment Facility
GEOHAB	Global Ecology and Oceanography of Harmful Algal Bloom Program
GLOBEC	Global Ocean Ecosystem Dynamics Program
GOOS	Global Ocean Observing System
HAB	Harmful Algal Bloom
HABHRCA	Harmful Algal Bloom and Hypoxia Research and Control Act of 1998
HABSOS	Harmful Algal Blooms Observing System
HACCP	Hazard Analysis and Critical Control Point Principles of Seafood Harvesting
HARRNESS	Harmful Algal Research and Response: A National Environmental Science Strategy 2005–2015
HSB	Health Studies Branch of CDC
IAEA	International Atomic Energy Agency
ICES	International Council for the Exploration of the Sea
IGBP	International Geosphere-Biosphere Programme
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research Program
IOC	Intergovernmental Oceanographic Commission
IOOS	Integrated Ocean Observing System
ISSC	Interstate Shellfish Sanitation Conference
IUPAC	International Union of Pure and Applied Chemistry
LOICZ	Land-Ocean Interactions in the Coastal Zone project
MBARI	Monterey Bay Aquarium Research Institute
MERHAB	Monitoring and Event Response for Harmful Algal Blooms
NASA	US National Aeronautics and Space Administration
NCCOS	National Centers for Coastal Ocean Science
NCEH	National Center for Environmental Health
NCER	National Center for Environmental Research, EPA

NEON National Ecological Observatory Network

NGO Non-governmental Organization

NHC National HAB Committee

NIEHS National Institute of Environmental Health Sciences

NMFS National Marine Fisheries Service, NOAA

NMR Nuclear Magnetic Resonance

NOAA National Oceanic and Atmospheric Administration

NOS NOAA Ocean Service

NRC National Research Council

NSF US National Science Foundation

NSP Neurotoxic Shellfish Poisoning

OGP Office of Global Programs

OHH Oceans and Human Health Program

ONR Office of Naval Research

ORHAB Olympic Region HAB Monitoring Program

ORION Ocean Research Interactive Observatory Networks

PCM Prevention, Control and Mitigation

PSP Paralytic Shellfish Poisoning

SCOR Scientific Committee on Oceanic Research

SOP Standard Operating Procedures

STAR Science to Achieve Results Program, EPA

START Solutions To Avoid Red Tide Organization

USDA US Department of Agriculture

WHO World Health Organization

WHOI Woods Hole Oceanographic Institution

***Karenia brevis* bloom off the Florida coast.**

Source: P. Schmidt, *Charlotte Sun*.

Executive Summary

The US Problem of Harmful Algae

Harmful algal blooms (HABs) are proliferations of microscopic algae that harm the environment by producing toxins that accumulate in shellfish or fish, or through the accumulation of biomass that in turn affects co-occurring organisms and alters food webs in negative ways. Like much of the world's coastlines, nearshore marine waters of the US have experienced increases in the number, frequency, and type of HABs in recent years. Freshwaters are also experiencing HAB events. Impacts include human illness and mortality following direct consumption or indirect exposure to toxic shellfish or toxins in the environment; economic hardship for coastal economies, many of which are highly dependent on tourism or harvest of local seafood; as well as dramatic fish, bird, and mammal mortalities. Equally important are the devastating impacts HABs may cause to ecosystems, leading to environmental damage that may reduce the ability of those systems to sustain species due to habitat degradation, increased susceptibility to disease, and long term alterations to community structure. In short, HABs lead to poisonous seafood, mortality of fish and other animals, economic impacts to coastal communities, losses to aquaculture enterprises, and long-term ecosystem changes.

Coordinating Approaches to HAB Problems

The US science community has been guided by the *National Plan for Marine Biotoxins and Harmful Algae* (Anderson et al. 1993) for the past 12 years. This Plan served as the foundation for the development of numerous national, regional, state, and local programs and for the considerable advancement in scientific knowledge on HABs and their impacts. HABs are complex in their mode of action and the ecosystems in which they proliferate are equally complex. Our decision-making and management systems, however, have not changed to reflect that complexity. Better approaches and tools are needed to not only gather the knowledge and data required to understand these organisms and systems, but also to manage these events from an ecological and public health perspective. Additionally, management of the threat of HABs currently involves a complicated array of scientists, managers, agencies, and legislatures operating at various governmental levels. Support for their activities is guided by diverse national and international programs. The HAB community recognizes that it is time to re-define the magnitude and diversity of the HAB problem, strengthen coordination among agencies, partners, and stakeholders, and unveil a new vision to significantly reduce problems from HABs in the US. Accordingly, the National Plan has been updated to reflect the current state of the HAB problem, needs and priorities, and the approaches available to address these problems. The new plan, *HARRNESS, Harmful Algal Research and Response: A National Environmental Science Strategy 2005–2015*, reflects the views of the research and management community and a framework for actions over the next decade.

No single agency has the resources or mandate to address the many dimensions of the HAB problem. As a result, there is presently a range of programs and agencies that address specific aspects of HABs, such as ecology, toxicology, HAB monitoring, and human health impacts. Much effort and substantial funds are directed on a case-by-case basis without coordination or foresight. Federal funding remains low relative to the scope, complexity, and importance of HABs. The new US plan, HARRNESS, is designed to facilitate coordination by highlighting and justifying the needs and priorities of the research and management communities and by suggesting strategies or approaches to address them.

Critical Needs for HAB Research and Response

The research and response needs of the US scientific and management communities are many. New tools are critically needed to detect, analyze, predict, and manage HAB outbreaks and the associated illnesses they cause. Underlying this broad goal is the need to maintain the development of new technologies and methodologies through responsible investment of public resources.

The major priorities and critical needs for additional capability and understanding fall into four thematic areas or foci: *Bloom ecology and dynamics; Toxins and their effects; Food webs and fisheries; and Public health and socioeconomic impacts.* General topics for investigation and focus within each of these themes are given below.

Bloom Ecology and Dynamics

Much progress has been made over the past years in many aspects of bloom ecology and dynamics. Yet many areas need further study, including the interactions of HABs with grazers, the sublethal effects of HABs on community dynamics, and the application of predictive models. Priority areas for the near future are:

- Organism detection and assessment of harmful status
- Harmful algal genetics and physiology
- Community ecology and ecosystem dynamics
- Prevention, control, and mitigation

Toxins and their Effects

Purified toxins are essential to implement assays and calibrate instruments used to monitor toxins in water or seafood. Both simple to use assays and sophisticated toxin analysis are the front line tools for monitoring, event response, and research. Refinement of methods and validation is needed. Priority areas for the near future are:

- Establishment of reference material infrastructure
- Purification of toxin reference materials
- Instrument analysis and biological assays
- Biosynthesis and metabolism of toxins
- Integrated toxin effects and mechanisms of susceptibility

Food Webs and Fisheries

While it is recognized that harmful algae and their toxins can have large impacts on ecosystems, there is much yet to be learned concerning the transfer and pervasiveness of toxins in food webs and how trophic structure is impacted by such events. Priority areas for the near future are:

- Impacts of HABs on food webs
- Impacts of HABs on aquaculture and wild harvest
- Capacity for forecasting HABs
- Top-down control and changes in trophic structure by HABs
- Detrimental effects of HABs on higher vertebrates

Public Health and Socioeconomic Impacts

Growing demand for seafood and the globalization of trade have expanded the geographic boundaries for human exposure and illness. The economic and public health impacts of HABs are profound, yet still largely uncharacterized. Priority areas for the near future are:

- Socioeconomic impacts of HABs
- Seafood safety impacts
- Public health impacts
- Recreational and drinking water impacts

A more detailed list of priority recommendations is given in the following table. Clearly, many of the recommendations crosscut disciplines and unify the four program foci.

HARRNESS Program Elements

HARRNESS is a framework—a proposed organization of HAB-related initiatives and programs that identifies and addresses current and evolving needs associated with HABs and their impacts. It allows for multiple levels of participation and involvement, identifies numerous disciplinary priorities and requirements, and lays out the multiple pathways and approaches needed to ensure a coordinated response by the research and management community.

HARRNESS will function through a number of distinct components or program elements. Some—such as specific research funding programs—are in place, but other elements require additional funds, new directions, and new coordination. HARRNESS program elements are summarized below.

The National HAB Committee

A core component of HARRNESS will be a rotating, interdisciplinary group of individuals representing priority research and management areas.The mission of the National HAB Committee (NHC) will be to facilitate implementation of HARRNESS among the many agencies, groups, disciplines, and initiatives having shared HAB goals and objectives. Activities of the NHC will include:

1. Facilitating implementation of HARRNESS and garnering support among all stakeholders;
2. Fostering communication between all components of the HAB community;
3. Interfacing with related national and international initiatives, such as GEOHAB, IOOS, GOOS, CUAHSI, CLEANER, NEON, and ORION;
4. Forming ad hoc technical advisory committees as needed to address issues or requests; and
5. Raising the visibility and understanding of HAB issues nationally.

Funding and Research Programs

The foci of HARRNESS will be the four previously identified primary areas of Bloom Ecology and Dynamics, Toxins and their Effects, Food Webs and Fisheries, and Public Health and Socioeconomic Impacts. Each of these foci shares a need for a suite of management and research activities directed at various scales of the HAB problem—including highly focused studies, regional

The Detailed Recommendations From HARRNESS Share Common Themes

Reference Materials and Data Management	• Establish facilities for toxin standards, cultures, and genomic resources • Establish facilities for archiving case and clinical samples • Establish information databases
Monitoring and Surveillance	• Conduct sustained time series measurements of the biotic, chemical, and physical environments impacted by HABs • Strengthen early warning systems • Identify metabolites that contribute to animal and human illnesses and metabolic pathways for detoxification • Develop methodologies for rapid field-based detection of HABs and toxins
Algae Physiology and Molecular Biology	• Develop whole-genome sequences for selected HABs to guide physiological and behavioral studies • Identify genes linked to toxin production • Determine inter- and intra-specific variations in physiological responses • Strengthen understanding of life histories, ecophysiology, behavior, and in situ growth and death rates
Ecological Interactions and Impacts	• Trace toxin impacts and amplification through the food web • Quantify kinetics of toxin uptake, accumulation, and retention • Elucidate effects of eutrophication, over-fishing, and climate alteration on HABs
Human and Animal Health	• Establish standard reporting procedures for HAB toxin incidents • Develop new, cost-effective epidemiological methods appropriate for HABs • Identify susceptible subpopulations • Incorporate algal toxins into water quality standards for drinking and recreational waters
Models and Forecasting	• Develop food web models for fate and effects of toxins • Develop and improve species-specific models that link physical-biological models • Model long term risk of exposure to HAB toxins for individuals and populations • Develop models of socioeconomic impacts and costs of mitigation at local and regional scales
Controls and Mitigation	• Develop effective, environmentally sound techniques to control/reduce HABs and their impacts • Develop early warning systems, response plans, and methods to reduce exposure • Improve coordination of responses across local and regional scales
Training, Education and Outreach	• Increase awareness of the effects of anthropogenic activities on HAB proliferation • Expand documentation of HAB toxins in drinking and recreational waters • Provide information on HAB toxins to medical practitioners and public health departments • Train more taxonomists in classical and molecular techniques • Develop strategies to assist aquaculturists/seafood farmers to limit crop loss

and inter-regional scale field investigations, and policy and resource management activities.

A combination of existing, restructured, and new programs will be required. New or modified agency partnerships will also be required, as the priorities of some agencies have changed through time with respect to HABs and their impacts. Example programs that might be continued in their present form or modified somewhat include ECOHAB, MERHAB, and the OHH programs of NOAA, NSF, and NIEHS. New program examples might include a HABs and food web impacts program and a chemistry and toxicology of HABs program. Presently, these topics receive inadequate funding from existing HAB programs, and thus may require focused attention, and perhaps specific targeted funding initiatives. Likewise, the practical aspects of HAB prevention, control, and mitigation are presently inadequately covered by ECOHAB. A separate program could readily be justified. New programs should not draw funds from, or compete with, important fundamental studies of ecology and oceanography. Furthermore, with the exception of the Great Lakes, which fall under NOAA's jurisdiction, freshwater HABs have not been addressed in ECOHAB, MERHAB, or the OHH HAB programs. These phenomena are, however, an important priority within the HABHRCA re-authorization and within HARRNESS, and therefore new, targeted funding initiatives are recommended.

Infrastructure

HARRNESS includes infrastructure elements that include activities and services required by all program elements.The HAB community is committed to providing the research, management, and education communities with the resources needed to accomplish their goals.These range from reference materials to data visualization products and shared facilities. Several community-wide activities or resource centers must be established:

1. Provision and quality assurance of reference materials (preserved specimens, live cultures, molecular probes, certified toxin standards, etc.);
2. Access to data management and data visualization tools;
3. A national education and outreach effort; and
4. Shared facilities (instrumentation, analytical capabilities, etc.).

The HAB research community has developed regional capacities to collect HAB and HAB-related information, but sustained support for these facilities is required. These infrastructure elements are summarized on the following page.

Next Steps

The support provided to HAB research through ECOHAB, MERHAB, COHH, OHH, Sea Grant, NSF, and other national programs has had a significant impact on our understanding of HAB phenomena and on the development of management tools and strategies. As outlined in this report, however, there are many unknowns and issues that must be addressed if we are to achieve the goal of scientifically based management of coastal and freshwater resources affected by HABs. The national HAB program clearly needs to be modified and expanded to meet these future needs through HARRNESS.

Experience over the past decade makes it clear that HARRNESS is best implemented as a collection of initiatives and programs that together address the many issues related to HABs and their impacts. No single agency or program can cover the diverse array of issues and needs of a national initiative on this topic. Some of the necessary programs exist and are functioning well, with good agency, HAB community, industry, and congressional support. Others are ongoing, but need to be evaluated and modified. Still others do not exist, but are needed to provide the comprehensive coverage that an effective national plan needs. For all of these programs, agency partnerships are highly desirable, yet only a few are in place. A strategy to develop these partnerships is therefore needed as well. Coordination of all of these implementation steps will be an important job of the National HAB Committee.

The coordinating structure, research foci, and infrastructure of HARRNESS will require considerable discussion among the community to fully implement the recommendations put forth. The detailed steps required for program implementation are beyond the bounds of the HARRNESS workshop or of this report. As a result, the NHC will be charged with preparation and distribution of an Implementation Plan for HARRNESS. The Implementation Plan will further prioritize the recommendations of HARRNESS and specify the steps and associated funding mechanisms to accomplish these goals.

The Benefits of HARRNESS

Implementation of HARRNESS will yield many benefits, both for research scientists and for the public health and management communities. Full implementation will not be simple and will require substantial investment. The socioeconomic costs of not addressing these needs, however, greatly exceed the initial investment. Although individual benefits relate to specific aspects of the currently impaired ecological health of our aquatic ecosystems and threatened public health, the greatest benefit is the cross-linking of science and management to achieve improved mitigation, control, prevention, and education.

Anticipated benefits from full implementation of HARRNESS include:

Improved ability to detect HAB species and analyze HAB toxins

Accurate and rapid tests for cells and toxins are the essential first step in monitoring; however, sophisticated analyses are the cornerstone to confirm HAB events and determine the health hazards posed by HABs. Access to certified reference materials and official validation of methods is of central importance to assure the accuracy and precision of detection methods.

Improved capability for monitoring and forecasting HABs in a cost effective and timely manner

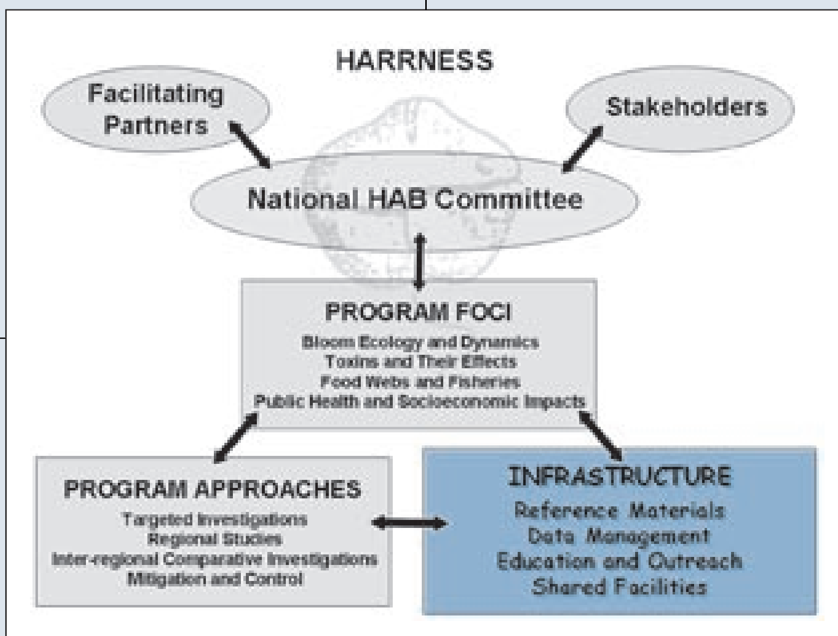
New technologies, coastal observing systems, and models will yield enormous advancements in monitoring temporal-spatial progression of HABs and forecasting their threats to ecosystems, human and animal health, and local economies.

Reference Materials

There is a national need for reference materials for researchers, managers, educators, pathologists, toxicologists, and public health scientists. The needs include preserved specimens, live cultures, molecular probes, certified toxin standards, and databases. Repositories or facilities where such resources are maintained must be accessible to all who need these materials, but may exist at multiple or different physical locations. These materials are at the core of advancing HAB science.

Data Management

To effectively carry out a coordinated national research program, access to data management and data visualization tools is needed. A common data management and communication structure will enable effective communication with other US initiatives focusing on terrestrial or hydrodynamic observing systems. Databases that provide online workrooms and multi-dimensional graphical viewing of data will be valuable for researchers and the broader community responsible for public health.



Education and Outreach

An integrated and coordinated education and outreach program is critically needed. It must have comprehensible information on harmful algae, be regionally focused, ethnically diverse in nature, and useful for both science and public health education. Such a program will allow accurate knowledge to be conveyed and professionals and practitioners to be trained, and will promote community involvement.

Shared Facilities

Many regional capacities are now in place, but sustained support for centers with specific expertise is needed. In some cases, instrumentation and/or arrays of detection equipment are too expensive to replicate; in other cases, expertise, standards, or reagents may be localized and should be mobilized when a new area may be in need. The ability to electronically link regional institutions, laboratories, and facilities will ensure rapid access by all to needed assays, protocols, instruments, or expertise.

Improved protection of human health

Improved toxin monitoring of seafood and surveillance of human exposure, better definition of sustained health effects and susceptible populations, and heightened awareness among the general public and medical communities will assure safe seafood and the health of coastal residents and visitors.

Improved protection of endangered species and improved ecological health

Research on trophic transfer through the food webs and understanding differences in susceptibility of wildlife species to the acute and sustained effects of algal toxins will improve diagnosis, health management, and the formation of endangered species recovery plans.

Improved prevention and mitigation strategies

Knowing the underlying causes and biology of HABs will lead to more options for intervention strategies, including more cost-effective monitoring, early warning prediction systems, and possible use of physical, chemical, or biological intervention to eliminate or reduce effects.

Improved economic cost estimates of HAB events

More accurate cost estimates of the impacts of HABs and associated management strategies will allow communities and business sectors to develop proactive measures to protect assets from the economic impact of HAB events.

Improved economics for aquaculture and shellfish safety

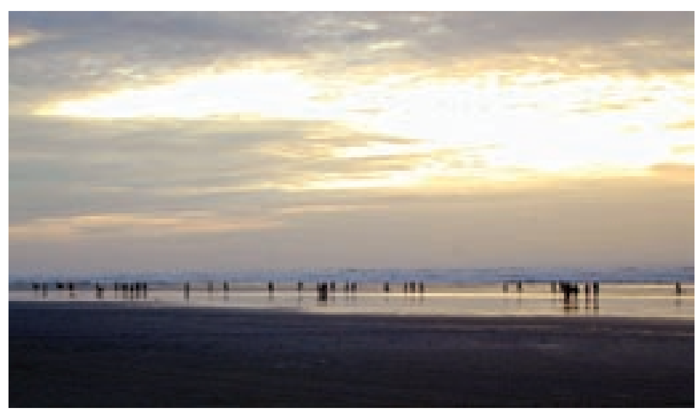
Improved information about, and dissemination and coordination of, harmful and toxic algal-shellfish interactions, supplemented with cost effective monitoring, will allow harvest of under-utilized resources and development of new high value markets.

An educated and informed public

Improved societal awareness will aid the medical community in diagnoses, will aid the seafood safety community in conveying the importance of closures, and will provide the public with better models and forecasts with which to make informed decisions.

These are but a few of the many benefits and capabilities that will derive from the planned cooperation and coordination of academic and government scientists and resource managers through HARRNESS. Realistically, the extraordinarily diverse nature of HAB phenomena and the hydrodynamic, genetic, and geographic variability associated with outbreaks in fresh and marine waters throughout the US pose significant constraints to the development of this type of coordinated program. Nevertheless, the HAB community in the US has matured scientifically and politically and is fully capable of undertaking these challenges. The US Commission on Ocean Policy is primed to move ocean science forward at an accelerated pace in this awakening century, and we have advanced scientific and information technologies and an unprecedented population shift to coastal areas that will define a new age of community participation and stewardship. The HAB community has joined together to develop HARRNESS and has initiated program implementation through the establishment of a National HAB Committee. It is time for the scientific community, the facilitating agencies, and stakeholders to support the development of a HARRNESS Implementation Plan and bring this vision to reality.

HABs will still occur, but large unsightly events that impact important economic sectors of tourism and recreation will be fewer in number, the adverse impacts of poisonous seafood, wildlife mortality events, aquaculture kills, and ecosystem disruption will be carefully managed, and the general public will experience a resurgence of stewardship of coastal ecosystems.



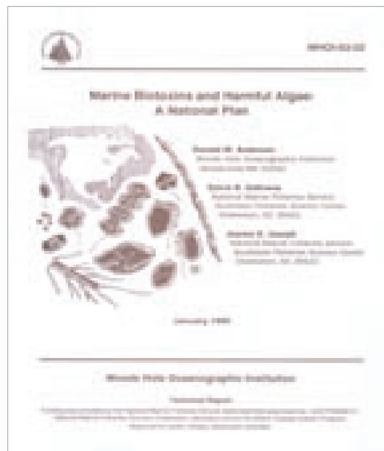
Americans have valued their coastal resources for generations. HARRNESS will protect coastal resources and economies from extreme natural events such as harmful algal blooms far into the future.

Source: The Raging Main.

CHAPTER 1

Recognizing the Magnitude and Diversity of the US HAB Problem

The marine and fresh waters of the US and those of many countries throughout the world are increasingly impacted by the growing environmental problem of harmful algal blooms (HABs). This problem is due to the growth of various macro- and microscopic algae that impact the environment in deleterious ways. These impacts include human illness and mortality from direct or indirect exposures to toxins; economic hardship for coastal economies dependent on seafood; dramatic fish, bird, and mammal mortalities; as well as more subtle, but equally devastating, ecosystem and environmental damage. Local jurisdictions have had a strong and successful record of managing risks associated with HABs, and implementing extensive and expanding monitoring programs. This has seriously strained fiscal and personnel resources of local governments.



The first US National Plan on Biotoxins and HABs was published in 1993.

HAB phenomena are broad and pervasive, affecting multiple regions, resources, and sectors of society. They occur in marine and freshwater systems and are problematic in both. As with other issues that have significant socioeconomic and environmental impacts, there is a need for a national HAB policy and program to coordinate and direct funding for research, monitoring, and event response activities. It is also necessary to inform the public and agency officials about the dangers as well as the tools and knowledge that can be used to manage affected waters. At present, however, marine and freshwater management responsibilities are dispersed among an array of agencies at the federal, state, and local levels. While new scientific understanding has taught us that the natural systems that include HABs are complex and interconnected, our decision-making and management systems do not reflect that complexity. Better approaches and tools are needed to gather the knowledge and data necessary to understand and manage the complex marine and freshwater environment.

In 1993, *Marine Biotoxins and Harmful Algae: A National Plan* was formulated by scientists, agency officials, and private sector representatives with expertise in marine biotoxins, harmful algae, seafood safety, and public health (Anderson et al. 1993). The goal of the 1993 National Plan was "Effective management of fisheries, public health and ecosystem problems related to marine biotoxins and harmful algae." The National Plan has served as the foundation for a US national program on marine biotoxins and HABs for the last ten years, guiding the planning efforts that have led to implementation of numerous national, regional, state, and local research and monitoring programs such as ECOHAB (the Ecology and Oceanography of Harmful Algal Blooms), MERHAB (Monitoring and Event Response for Harmful Alagal Blooms), and COHH (Centers for Oceans and Human Health). Now, ten years later, it is necessary to update and expand the National Plan so that future financial, human, and physical resources are directed to priority topics that reflect the changing nature of the HAB problem in the US, as well as the progress that has been achieved thus far.

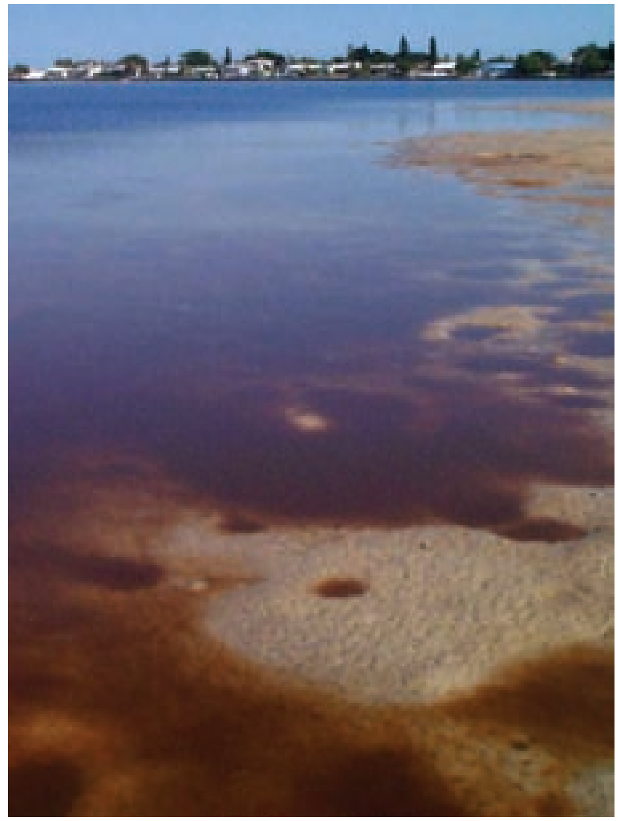
The newly formulated National Plan, *HARRNESS, Harmful Algal Research and Response: A National Environmental Science Strategy 2005–2015*, described

"What many of you may not realize is that harmful algal blooms and hypoxia are a significant threat to human health, commercial fishing, and recreational water use throughout the United States.... Harmful algal blooms actually encompass a wide variety of events. They occur in both marine and freshwater environments. These dense mats of algae produce toxins dangerous to aquatic life and to humans, some of which are so potent that eating just one contaminated mussel could make you ill, resulting in anything from mild nausea to paralysis, and even death in some cases, depending upon the species causing the bloom.... Harmful algal blooms and hypoxia are also causing problems closer to my home, the Great Lakes, where these events are more and more frequently fouling the water. In the past 30 years major advances were made to improve Great Lakes water quality, but recently scientists have observed an increase in both harmful algal blooms and hypoxia. The reasons for this are unclear, but may be related to invasive species changing the way nutrients are cycled in the lakes."

Representative Vernon J. Ehlers, Chair Subcommittee on Environment, Technology, and Standards Committee on Science Opening Statement for Hearing on Harmful Algal Blooms and Hypoxia: Strengthening the Science, March 13, 2003

"Pressures on ocean and coastal areas continued to intensify and new threats loomed, such as sea-level rise and increased storm frequency attributed to global climate change, as well as puzzling and sometimes deadly algal blooms."

US Commission on Ocean Policy Final Report, Chapter 2, p. 25.



Red tides in Florida have been a common occurrence for many years.

Source: Susan Cook, Florida Fish and Wildlife Conservation Commission.

herein, is based on the views of the research and management communities. These views were developed through numerous community interactions. This document describes the recent findings and trends that led to the need for a new plan of action, the process by which this plan was developed, the critical issues, and the recommended actions.

What are HABs?

Marine and fresh waters teem with life, much of it microscopic, and most of it harmless; in fact, it is this microscopic life on which all aquatic life ultimately depends for food. One major group of aquatic microorganisms includes photosynthetic algae and cyanobacteria, as well as non-photosynthetic protists. Some of these organisms cause problems when they accumulate in sufficient numbers due to their production of endogenous toxins, their sheer biomass, or even their physical structure. These are the HAB species. As with most algal or cyanobacterial blooms, HABs result from a combination of physical, chemical, and biological mechanisms and their interactions that are, for the most part, poorly understood.

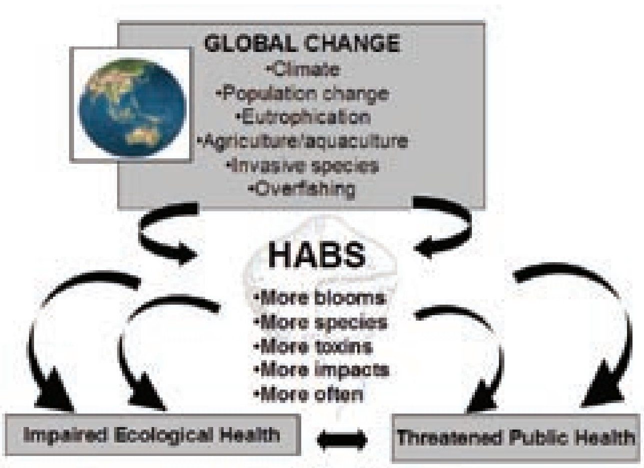
HABs have one unique feature in common—they cause harm, due either to their production of toxins or to the manner in which the cells' physical structure or accumulated biomass affect co-occurring organisms and alter food-web dynamics. These blooms were formerly called "red tides" because high algal density can sometimes make the water appear red, but blooms may also be green, yellow, or brown, depending on the type of organisms present and their pigmentation. Some blooms are not visible at all; dangerous conditions can occur when the water is clear with very low cell concentrations of a toxic HAB species. The term "HAB" also applies to some non-toxic macroalgae (seaweeds) that can grow out of control and cause major ecological impacts such as the displacement of indigenous species, habitat alteration, or oxygen depletion.

Recent Trends— National and Global Changes

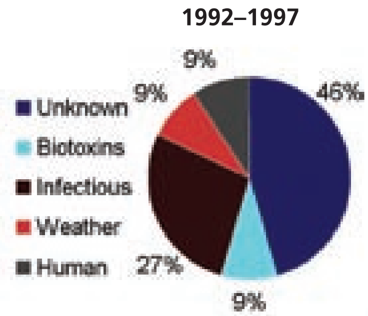
The nature of the US HAB problem has changed considerably over the last several decades in both marine and fresh waters. Whereas 30 years ago the problem was scattered and sporadic, today virtually every state is threatened by harmful or toxic algal species. Few would disagree that the number of harmful blooms, the economic losses from them, the types of resources affected, and the number of toxins and toxic species have all increased dramatically in recent years in the US and around the world (Anderson 1989; Smayda 1990; Hallegraeff 1993).

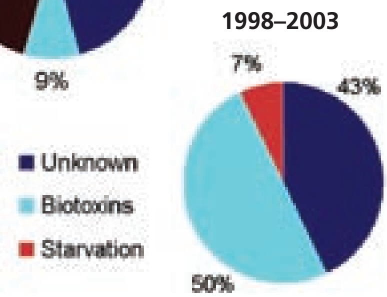
Although some of the factors contributing to national—and global—expansion are natural, such as biological species dispersal (Sellner et al. 2003), many others are considered to be a result of human activities. Increases in nutrient loading, changes in agriculture and aquaculture practices, overfishing, ballast water discharge, and global climate change may all be important in the global increase in HABs (Anderson 1989; Hallegraeff 1993; Anderson et al. 2002). Another factor that must be recognized in understanding the global 'expansion' of HABs is that improved tools and methods have led us to detect more species more often. In other words, years ago we were not aware of the size or complexity of the HAB problem, but as we became better at detecting toxins and recognizing HAB phenomena, we have more clearly defined the extensive boundaries of the problem. The fact that some of the increase is simply a result of better detection or more observers does not diminish the seriousness of the problem.

Several examples underscore these trends. In the Western Gulf of Maine, occurrences of *Alexandrium*



Both impaired ecological health and public health are consequences of the global expansion of HABs.





The improvements in detection of algal toxins since 1998 have led to the confirmation that half of unusual marine mammal mortality events are a result of HABs.

Source: T. Rowles.

and paralytic shellfish poisoning (PSP) were rare prior to about 1970 (Mulligan 1975), but have become virtually annual events in the past three decades. Based on analyses of diatom skeletons preserved in sediment cores, blooms of the diatom *Pseudo-nitzschia* spp. in the Gulf of Mexico were also rare prior to the 1950s, but have increased significantly in frequency and cell numbers since then, concomitant with increases in nutrient loading (Dortch et al. 2000).

In some cases, oscillations in species dominance may be related to long-term climatic variations—such as the North Atlantic Oscillation and the El Niño-Southern Oscillation (Maclean 1989)—but examples where such oscillations can specifically be related to HAB dynamics are few. In Narragansett Bay, however, where mean water temperatures increased 3°C between 1959 and 1998, major changes in bloom species and timing have also occurred (Borkman and Smayda 2003). Climate controls many fundamental properties regulating cell growth, from water temperature to precipitation and light.

There is a wealth of evidence that the expansion of HABs may also be related, in whole or in part, to many other global change phenomena. The past several decades have witnessed dramatic changes in the globe, many of which could have direct or indirect impacts on HAB species distribution and abundance. In addition to changes in climate, there have been demonstrable changes in human population size, eutrophication, agriculture and aquaculture practices and impacts, fishing pressure, and transport of species via ballast water. Human activities have changed the nutrient regimes of coastal waters tremendously, primarily as a result of increased applications of synthetic fertilizers. The export of phosphorus to the coastal zone has increased at least three-fold since

"In the past, these harmful algal blooms appeared in only a few scattered coastal areas in the United States. Without doubt, there has been a major worldwide expansion in the frequency, geographic extent, and magnitude of harmful algal bloom events and in the number of species that trigger such events. In the United States, the past 25 years reflect a marked increase in the number of algal toxins, affected areas, impacted fisheries and higher economic losses. In addition, the number of algal species known to be toxic has increased from about 20 species a few years ago to at least 85 identified toxic species as of 1998."

Ms. Ellen M. Athas, Director and Program Counsel, Clean Oceans Program, The Ocean Conservancy

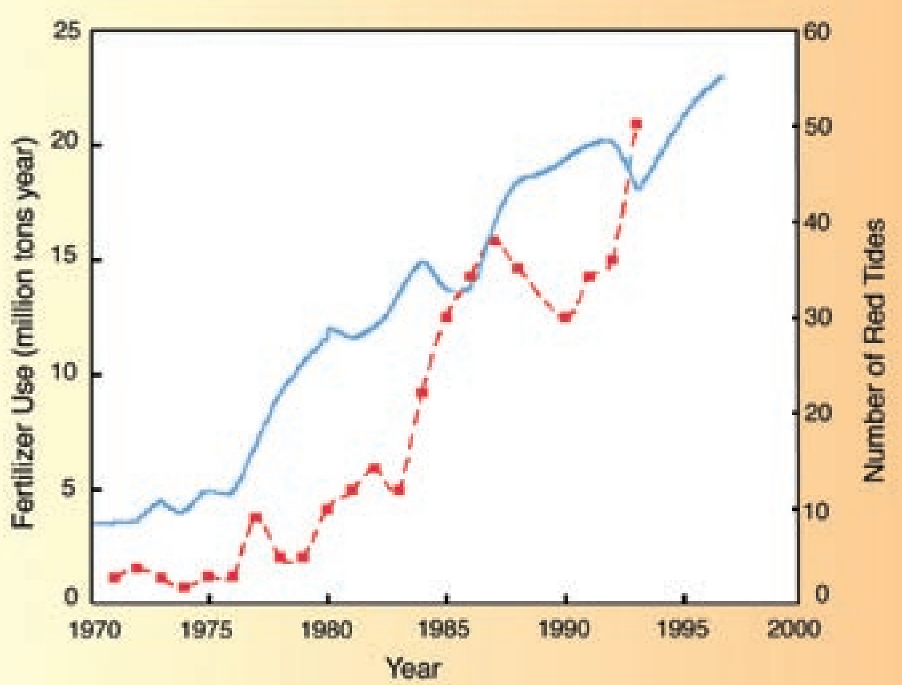
Written Testimony for Legislative Hearing on H.R. 1856, a bill to reauthorize the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 Subcommittee on Fisheries Conservation, Wildlife and Oceans Committee on Resources, February 26, 2004 US Commission on Ocean Policy Final Report, Chapter 2, p. 25.

pre-industrial times, while export of nitrogen has increased to an even greater degree (Caraco 1995; Smil 2001; Seitzinger et al. 2002). There are now a number of clear examples where alterations in nutrient quality and composition can be related to increases in HABs (reviewed by Anderson et al. 2002). Another significant alteration in nutrient loading to the coastal zone comes from the increase in aquaculture activities. From cultured salmon in Norway—which has grown from less than 10,000 tons/yr in 1970 to more than 500,000 tons—to shellfish culture throughout Europe, Asia, and elsewhere, these industries have altered ecosystems through movement of stocks and input of feed and feces or removal of plankton through feeding. Lastly, fish harvesting in general has altered ecosystems, leading to alterations in food chains. Together with increases in nutrients, removal of top grazers may contribute to the proliferation of HABs.

HAB Impacts

Algal blooms cause harm through two primary mechanisms. The first category of impacts is the production of toxins. Toxins may kill fish or shellfish directly, or may cause one of several human illnesses following ingestion of contaminated seafood. The second category of impacts is high biomass accumulation, which, in turn, leads to environmental damage or degradation. These effects can include light attenuation, clogging of fish gills, or depletion of dissolved oxygen upon decay of the algal cells. Some HABs can even kill fish because of their physical shape, lodging in gill tissues and causing a physiological response leading to death.

The effects of HABs are thus quite diverse and can range from human health and economic impacts to fundamental changes in ecosystem structure and function. Specific effects of toxic species in coastal waters include illness and/or mortality of humans as well as fish, sea birds, and marine mammals; closures of wild and farmed shellfish harvesting; and economic losses related to factors such as lost tourism revenues, clean-up costs following fish kills, and medical expenses due to toxin exposures. Impacts due to freshwater HABs are similar, but do not include shellfish toxicity.



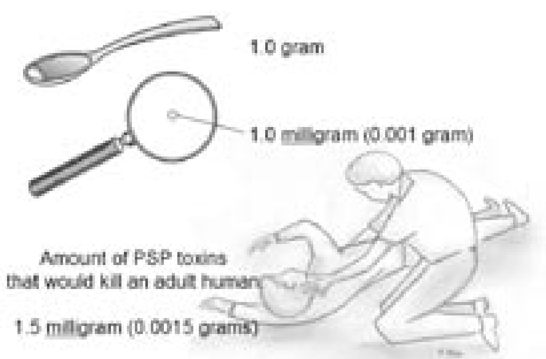
The global increase in fertilizer use over the past several decades correlates with the increase in number of red tides observed in Chinese coastal waters. Similar relationships are now being demonstrated for various parts of US coastal waters as well.

Source: D. Anderson et al. 2002.

There have been enormous advances in our understanding of HAB impacts, the toxins that may be involved, and the economic and societal effects of such outbreaks. A brief synopsis of the state of our understanding of each of these aspects, much of it gained in the past decade from dedicated research efforts, is given below.

Poisonous Seafood

Although only some HAB species are directly toxic, their impacts are the most significant in terms of human illness and death. This can occur when toxic phytoplankton are filtered from the ocean as food by shellfish such as clams, mussels, oysters, or scallops, accumulating the algal toxins to levels that can cause illness or even be lethal to shellfish consumers including humans (reviewed in Shumway 1990; Ahmed 1991; Landsberg 2002). Fish can also become poisonous, either through the direct ingestion of toxic algae and their grazers or via food web transfer of the toxins through multiple trophic levels.



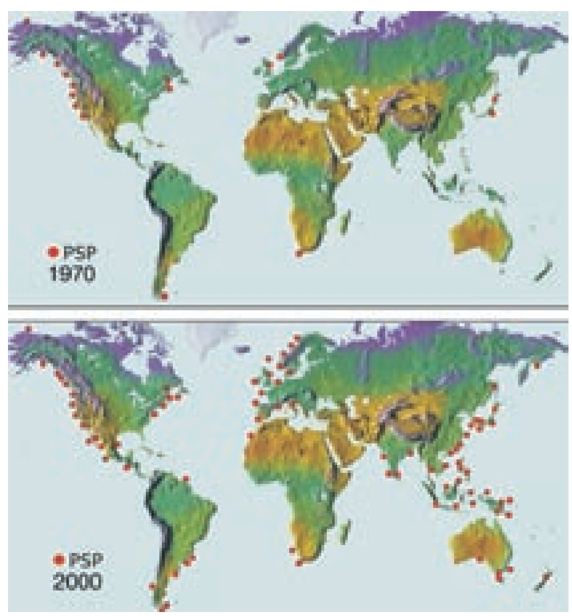
Source: J. Ramsdell.

The shellfish poisoning syndromes have been given the names paralytic, diarrhetic, neurotoxic, azaspiracid, and amnesic shellfish poisoning (PSP, DSP, NSP, AZP, and ASP), reflecting the symptoms that are caused by specific toxins. Except for ASP and AZP, all are caused by biotoxins synthesized by a class of marine algae called dinoflagellates. The source of the recently described AZP toxins is the heterotrophic dinoflagellate *Protoperidinium crassipes.* ASP is produced by diatoms that, until recently, were all thought to be free of toxins and generally harmless (Bates et al. 1989), yet now are known to produce toxins at least under some growth conditions. A sixth human illness, ciguatera fish poisoning (CFP) is caused by the production of a toxin by a specific group of dinoflagellates that grow on seaweeds and other surfaces in coral reef communities (Lehane and Lewis 2000). Herbivorous fish consume the seaweeds, accumulating the fat-soluble toxins from the associated microalgae, and pass the toxins on to carnivorous predators such as barracuda, grouper, and other commercially important fish.

Algal toxins are among the most potent biological agents known to man. For example, saxitoxin, the responsible agent for PSP, is banned under the Chemical Weapons Conventions and regulated under the Public Health Security and Bioterrorism Preparedness and Response Act of 2002. In 2002, saxitoxin was linked for the first time to toxicity events associated with puffer fish.

All shellfish poisoning syndromes, except AZP and DSP, are known problems within the US and its territories, affecting large expanses of coastline. PSP occurs in all coastal New England states, extending to offshore areas in the northeast, and along much of the west coast from Alaska to northern California. A recent bloom in 2005 in New England highlights the serious economic impacts of PSP outbreaks, as both Massachusetts and Maine issued disaster declarations and the Secretary of Commerce catagorized the event as a Commercial Fishery Failure, making the states eligible for federal assistance. Overall, PSP affects more US coastline than any other algal bloom problem.

Karenia brevis occurs annually along Gulf of Mexico coasts, with the most frequent outbreaks along western



Paralytic shellfish poisoning (PSP) is a toxin syndrome caused by consumption of seafood contaminated by certain HAB species. The above maps show the cumulative global increase in the recorded distribution of the causative organisms and the confirmed appearance of PSP toxins for the years 1970 and 2000.

Source: D. Anderson and Geohab 2001.

SPOTLIGHT

Ciguatera Food Poisoning

In the ocean, the most significant fish toxicity is associated with ciguatera fish poisoning, or CFP. More than 400 different fish species are involved in CFP including grouper, barracuda, jack, snapper, mackerel, and triggerfish. However, the true public health impact of this disease is significantly underestimated because reporting to the US Centers for Disease Control is voluntary and there is no confirmatory laboratory test.

Globally, it is estimated that as many as 200,000–1,000,000 individuals are poisoned by CFP annually with estimated incidence rates of 500 to 2,500 per 100,000 population (GESAMP 2001). In the Virgin Islands, nearly 50% of the adults are estimated to have been poisoned at least once. CFP occurs in virtually all sub-tropical to tropical US waters (i.e., Florida with isolated events from Texas to the Carolinas, Hawaii, Guam, Virgin Islands, Puerto Rico and many Pacific Territories). CFP is a particular risk to US tourists to these regions and is not restricted to endemic regions as a consequence of modern transportation networks and global trade in fish products. Seafood consumers from San Francisco to Chicago to Vermont have been poisoned.

Source: Hawai'i Department of Health.

Map depicting areas in Maine, New Hampshire, and Massachusetts that were closed to mussel harvesting during the 2005 New England HAB.

Source: MA Division of Marine Fisheries, NH Department of Environmental Services, and the ME Department of Marine Resources.

Florida and Texas, where some of these outbreaks have led to NSP. Louisiana, Mississippi, North Carolina, and Alabama have also been affected intermittently with *Karenia* blooms, causing extensive losses to the oyster industry and killing birds and marine mammals. ASP has been a problem for all of the US Pacific coast states, and the causative toxin has also been detected in northeast waters in the Gulf of Maine as well as in the Gulf of Mexico.

Toxic Air and Water

In addition to their accumulation in shellfish, some HAB toxins can be released directly into the water or air, either naturally, or following cell disruption by turbulence or through human activities such as water treatment processing. This can lead to mortality of aquatic organisms and animals of all types, as well as impacts to human health. One example of released toxins that cause human health problems occurs in the Gulf of Mexico, where neurotoxins from *Karenia brevis* can be delivered to local residents and beachgoers via sea spray. This leads to respiratory irritation, coughing, and other ailments. Ongoing studies are examining whether repeated exposure to this route of intoxication has long-term impacts.

Examples of toxic effects from exposure to water into which toxins have been released can also be found among the freshwater HABs. Excessive growth of freshwater cyanobacteria, especially taxa from the genera *Anabaena, Aphanizomenon, Microcystis* and *Cylindrospermopsis*, can lead to blooms that cause severe neuro-, cyto- and hepatotoxicity in a variety of mammals (including humans and farm animals), birds, fish, and invertebrates (including

Mortalities of domestic fauna can occur when toxic algae bloom in fresh, brackish, or marine waters.

Source: W. Carmichael.

A bloom of the toxic cyanobacterium *Microcystis* in the Potomac estuary. Cyanobacterial blooms can threaten wildlife and farm animals, human health, and human recreational activities such as swimming or boating.

Source: Aloft Inc. Aerial Photography.

zooplankton). Harmful cyanobacteria blooms are potential public health threats in nearly every state in the US due to their presence in drinking and recreational waters. The extent of this threat is not well known. Exposure to these toxins can cause an array of adverse health effects ranging from rashes, to allergies, to devastating liver damage in susceptible populations. The public health threat is potentially intensified when standard water treatment technologies do not effectively remove these toxins. In some cases, water treatment can exacerbate the problem, not alleviate it. For example, the use of copper sulfate as an agent to control a bloom may, in fact, disrupt cells and release toxins into the water. However, it is not known how often toxin-producing blooms occur in drinking water sources and publicly accessible ponds, or if most standard drinking water treatments reduce toxin concentrations sufficiently to protect public health. It is also unclear whether the public is being routinely exposed to very low levels of these toxins in drinking or recreational waters or what the long-term impact of these exposures might be. For these reasons, and because cyanobacterial toxins are extremely potent, the US Environmental Protection Agency (EPA) has included cyanobacteria and cyanobacterial toxins on their Contaminant Candidates List. This requires data solicitation to assess the occurrence of these toxins in drinking water sources and finished drinking water, the health effects associated with these exposures, and analytical methods for detecting these toxins in water.

Wildlife Mortality Events

Although human health impacts are of prime importance, another societal concern is the massive mortalities of wild animals that are caused by HABs. Wild animal mortality events, such as fish kills, bird kills, or strand-

SPOTLIGHT

Cyanobacteria in Fresh Water

Harmful algal blooms are not limited to marine waters. Recent years have seen an expansion of toxic blooms in freshwater ecosystems. These include not only the small 'farm-ponds' but also large bodies of water such as the Laurentian Great Lakes: Lake Erie and Lake Ontario. Since their original reappearance in Lake Erie in 1995, toxic cyanobacteria of the genus *Microcystis* have returned annually to Lake Erie's western basin. They can produce potent hepatotoxins called microcystins. The World Health Organization has set an advisory limit of 1 microgram microcystin-LR equivalents per liter of drinking water and the toxin levels in Lake Erie have routinely exceeded this threshold during the late summer. The Great Lakes contain almost 10% of the world's freshwater and serve as a source of drinking water for an estimated 22 million people. Protection of this and other freshwater resources is an important priority.

This photograph of a toxic cyanobacterial bloom has the typical appearance of a thick pool of green oil paint. This bloom occurred in 1981 and was found to consist of species in the genus *Microcystis*.

Source: W. Carmichael.

Characteristics of Human Illnesses and Conditions Caused by HAB-toxins Known or Suspected In US Waters

Toxin	Vector	Occurrence	Short-term Health Consequences	Long-term Health Consequences	Susceptible Populations	Susceptible Regions
Ciguatoxins	Reef fish	High	**Ciguatera Fish Poisoning:** Abdominal pain, nausea, vomiting, diarrhea, paresthesias, temperature dysthesia, pain, weakness, bradycardia, hypotension	Recurrent symptoms from months to years of chronic depression	Islanders subsistent on local fisheries, tourists	Florida Keys, Caribbean, Hawaii, Pacific Islands
Okadaic Acid	Shellfish	Low	**Diarrhetic Shellfish Poisoning:** Nausea, vomiting, diarrhea, abdominal pain accompanied by chills, headache, fever	Gastrointestinal tumor promoter in laboratory animals	Recreational shellfish harvesters	Northeast
Yessotoxins Pectenotoxins	Shellfish	Unknown	Not documented as toxic in humans, but co-occur in DSP shellfish and are highly toxic to mice	Unknown	Unknown	Unknown
Azaspiracids	Shellfish	Unknown .	**Azspiracid Shellfish Poisoning:** Nausea, vomiting, severe diarrhea, stomach cramps	Unknown	Unknown	Unknown
Brevetoxin	Shellfish	Low	**Neurotoxic Shellfish Poisoning:** Numbness of lips, tongue, and throat, muscular aches, fever, chills, muscle pains, abdominal cramping, nausea, diarrhea, vomiting, headache, reduced heart rate, pupil dilation	Unknown	Recreational shellfish harvesters	Gulf of Mexico
	Inhalation	High	Acute eye irritation, respiratory distress, asthma exacerbation	Unknown	Lifeguards, beach-goers, asthmatics	Gulf of Mexico
Saxitoxins	Shellfish	Low	**Paralytic Shellfish Poisoning:** Tingling, burning, numbness, drowsiness, incoherent speech, respiratory paralysis leading to death	Unknown	Children, recreational harvesters	Alaska, Northeast, Florida, Northwest, California
Domoic Acid	Shellfish	Low	**Amnesic Shellfish Poisoning:** Vomiting, diarrhea, abdominal pain, confusion, disorientation, memory loss	Anterograde memory deficit, seizures leading to coma and death	Elderly, children, kidney disease, subsistence and recreational harvesters	Northwest, North-east, Gulf of Mexico, California
Microcystins	Drinking water Swimming Dietary supplements	High	Abdominal pain, vomiting and diarrhea, liver inflammation and hemorrhage, acute pneumonia, acute dermatitis	Hepatocellular carcinoma, liver failure leading to death	Children, dialysis patients, liver disease, water recreation	Great Lakes, Continental US, ponds & lakes
Cylindro-spermospins	Drinking water Swimming	Medium	Abdominal pain, vomiting and diarrhea, liver inflammation and hemorrhage, acute pneumonia, acute dermatitis	Malaise, anorexia, liver failure leading to death	Children, liver disease, water recreation	Great Lakes, Continental US, ponds & lakes
Anatoxin-a	Drinking water Swimming	Low	Tingling, burning, numbness, drowsiness, incoherent speech, respiratory paralysis leading to death	Cardiac arrhythmia leading to death	Water recreation	Great Lakes, Continental US, ponds & lakes
Cyanobacterial LPS	Drinking water Swimming	Medium	Abdominal pain, vomiting and diarrhea, acute dermatitis	Unknown	Water recreation	Great Lakes, Continental US, ponds & lakes

Domoic acid intoxicated sea lion chewing on its flipper.

Source: F. Gulland.

> "The deaths of one million menhaden in North Carolina's Pamlico Sound in 1991, 150 endangered Florida manatees in 1996, and 400 California sea lions along the central California coast in 1998 have all been attributed to harmful algal blooms (McKay and Mulvaney 2001). They disrupt aquaculture, wild fisheries, and coastal tourism. In the past two decades, their effects have expanded from a few scattered coastal areas to nearly all coastal states (Burke et al. 2000)."
>
> *Pew Oceans Commission Final Report, Part 1, p. 6.*

ings of manatees and whales, have enormous impacts on local communities.

Many fish kills are associated with HABs. Some deaths occur from direct impacts, such as release of toxins into the water, or by physical clogging of the gills, leading to suffocation in the fish. Other fish kills are caused by HABs indirectly, following the development of low oxygen conditions from the decay of a large-scale HAB event, or even from disease, which may infect fish that have become stressed by interactions with HABs. Fish kills can be spectacular in size and duration, killing millions of fish over large areas. Associated impacts to benthic communities, including corals, also occur but are poorly quantified.

As algal toxins accumulate in the food web, turtles, dolphins, manatees, and other marine mammals can be affected. As techniques for detecting algal toxins in animal tissues have advanced, so has our appreciation of the number of marine mammal deaths linked to HABs. In fact, more than 50% of the unusual marine mortality events are now associated with HABs. Sea lion mortalities are now almost annual events along the southern California coastline and many of these have been conclusively linked to the ASP toxin, passed through the food web. The recent deaths of 19 massive humpback whales near Georges Bank in the Gulf of Maine is another such event associated with domoic acid poisoning. In freshwater systems, the impacts extend to birds and possibly alligators and other animals.

Aquaculture Losses

Impacts from HABs also affect freshwater and marine aquaculture industries. In the ocean, large numbers of salmon and other farmed fish can be killed in just a few hours, succumbing either to toxic algae or to species that kill in other ways. For example, in 1987, phyto-

SPOTLIGHT

Florida Panhandle Dolphins Dead from Brevetoxin Poisoning

Between March and April 2003, 107 bottlenose dolphins (*Tursiops truncatus*) were found dead together with hundreds of fish and marine invertebrates along the Florida Panhandle. Despite the absence of a concurrent bloom of *Karenia brevis*, high levels of brevetoxin were measured in all stranded dolphins examined (tissues and stomach contents), as well as in their fish prey (undigested menhaden recovered in dolphin stomach contents). Although brevetoxins were suspected in a dolphin mortality event in the same area in 2000, this was the first time that brevetoxin involvement was unequivocally confirmed in all tested animals and that the role of vectors in the poisoning was unambiguously identified. This event has indicated that lethal doses of brevetoxin can be transferred through the food web and that marine mammal mortalities can occur in the absence of a bloom.

Mass stranding of dolphins.

Source: R. Hardy, Gulfworld.

SPOTLIGHT

Prymnesium parvum Blooms Kill Fish in Brackish Water Systems

Fish killed by golden alga—Lake Granbury, Texas.

Source: Texas Parks and Wildlife Department © 2004.

An emerging problem in the US is the impact from golden-algal blooms caused by *Prymnesium parvum*, a species that thrives in brackish water typical of rivers and reservoirs in parts of Texas, Oklahoma, and Wyoming. Fish kills attributed to *P. parvum* were first documented in the US in 1985 in Texas. Since that time, 41 different fish kills have been linked to *P. parvum* in Texas, killing over 18 million fish worth an estimated $7 million. The majority of major kills have occurred since 2000 as this toxic alga has been found in an increasing number of river basins in the state. Local communities have experienced huge financial losses as tourists stay away and fishing guides lose their customers. *P. parvum* poses a threat to cultured as well as native fish in rivers and lakes. In the 1940s, it caused significant fish mortality in Israeli aquaculture ponds. It continues to pose a threat to cultured fish. In 2001, *P. parvum* killed the entire year's production of striped bass at Texas' Dundee State Fish Hatchery with over 5 million fish lost.

Expansive blooms of several *Caulerpa* spp. occurred off the Florida coast in 1997 and 2001. *Caulerpa* spp. can grow year-round and have transformed some reefs into "*Caulerpa* meadows" where more than 70% of the reef surface is now dominated by these macroalgal HAB species.

Source: B. LaPointe.

plankton blooms of the non-toxic diatom *Chaetoceros convolutus* were linked to the mortality of 250,000 Atlantic salmon valued at over $500,000 (Rensel et al. 1989). The diatoms lodged in the gill tissues, causing excessive mucus production, suffocation, and death. Blooms of the toxic raphidophyte *Heterosigma akashiwo* have caused even more extensive farmed-fish mortalities in Washington State. Freshwater aquaculture operations are also subject to risks from cyanobacteria and other HABs producing toxins that kill the fish or accumulate in tissues.

Ecosystem Impacts

Ecosystem impacts of many different types can also be linked to toxic and non-toxic HABs. The effects can be visible and easily documented or can be subtle and difficult to quantify. Ecosystem impacts include loss of shellfish, loss of habitat, seagrass die-backs, and altered food web interactions that decrease preferred higher trophic level species. An example of a species causing such impacts is the microalga *Aureococcus anophagefferens*, the cause of the mid-Atlantic brown tide, and the related species, *Aureoumbra lagunensis*, the cause of brown tides along the Texas coastline. These species have had substantial ecosystem impacts that include a reduction in light penetration, a reduction in the extent of seagrass beds, and a reduction in the growth rates of hard clams. Brown tides have also caused mass mortalities of mussel populations in Rhode Island and in Long Island waters. Recurrent blooms have had a severe impact on bay scallops, affecting more than 80% of New York's commercially valuable harvest (Cosper et al. 1987).

Estimated Annual Economic Impacts from Harmful Algal Blooms (1987–1993 estimates, reported in 1999 dollars)

	Low	High	Average	% of Total
Public Health	$ 18,493,825	$ 24,912,544	$ 22,202,587	45%
Commerical Fishery	$ 13,400,691	$ 25,265,896	$ 18,407,948	37%
Recreation/Tourism	—	$ 29,304,357	$ 6,630,415	13%
Monitoring/Management	$ 2,029,955	$ 2,124,307	$ 2,088,885	4%
TOTAL	$ 33,924,471	$ 81,607,104	$ 49,329,845	100%
15 Year Capitalization Impacts (discounted at 7%)	$308,981,162	$743,270,485	$449,291,987	

CENR. 2000. National Assessment of Harmful Algal Blooms in US Waters. National Science and Technology Council Committee on Environment and Natural Resources, Washington, DC, pg 12.

In a similar manner, blooms of opportunistic macroalgae (e.g., seaweeds such as red algae *Laurencia intricata* and *Spyridia filamentosa*; brown algae, *Dictyota* spp. and *Sargassum filipendula*; and green algae, *Enteromorpha* spp., *Codium isthmocladum,* and *Halimeda* spp.) have caused problems in many coastal regions. These species out-compete, overgrow, and replace seagrass and coral reef habitats, resulting in reduced light availability to bottom communities, lower productivity, habitat loss from low oxygen conditions, and eventual die-off of sensitive species. Some macroalgal blooms have been linked to nutrient enrichment of coastal waters (Lapointe et al. 1994). Some invasive macroalgae pose a double-edged problem: not only are they able to out-compete seagrass and more desirable species, but some may also be toxic, such as *Lyngbya majescula*, and can lead to skin rashes or other serious problems for humans or animals exposed to them.

Economic Impacts

A preliminary and highly conservative nationwide estimate of the average annual costs of HABs is approximately $50 million (Anderson et al. 2000; Hoagland et al. 2002). Public health is the largest component, representing nearly $20 million annually, or about 42% of the nationwide average cost. The effect on commercial fisheries averages $18 million annually, followed by $7 million for recreation and tourism effects, and $2 million for monitoring and management. The actual dollar amount of these estimates is highly uncertain due to a lack of information about the overall effect of many HAB events and a difficulty in assigning a dollar cost to those events that we do understand. While many expenses may be difficult to quantify, there is little doubt that the economic effects of specific HAB events can be serious at local and regional levels.

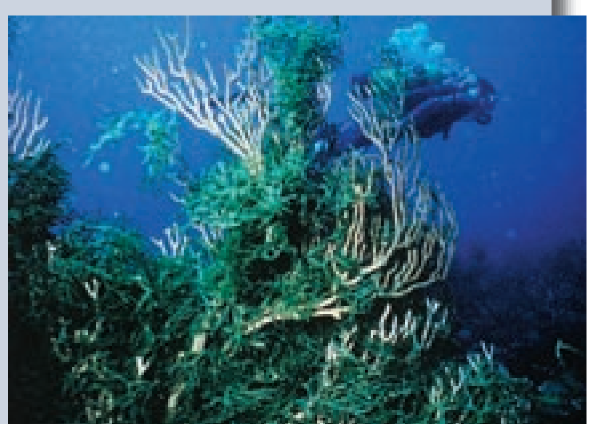
Separate from the national average, massive losses from isolated, individual events underscore the severity of the problem. A recent PSP event in New England caused estimated losses of $12 to $20 million in Massachusetts alone, with additional losses in New Hampshire

SPOTLIGHT

Macroalgal HABs Overrun Coral Reefs

Macroalgal HABs have impacted coral reefs off southeast Florida in recent decades. These phenomena began during a regional drought in 1990–1991 when massive blooms of the native green seaweed *Codium isthmocladum* formed summer blooms on deep reef communities in eastern Florida. The excessive biomass of these HABs resulted in hypoxia and anoxia in near-bottom waters, causing die-off of hard and soft corals, sponges, and other reef biota, and an overall decrease in abundance and diversity of reef fishes. This was followed by expansive blooms of several *Caulerpa* spp. in 1997 and 2001.

Although summertime upwelling can provide natural nutrient subsidies to these macroalgal HABs, stable nitrogen isotope and water column nutrient data suggest a linkage to land-based discharges of both wastewater (septic tanks, injection wells, ocean outfalls) and agricultural runoff.

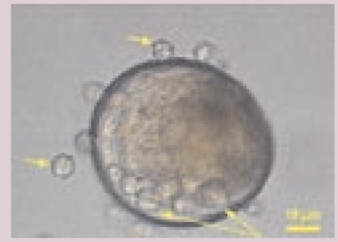


Source: B. LaPointe.

SPOTLIGHT

The Cost of *Pfiesteria*-Related Fish Kills

The economics of HAB outbreaks are extremely hard to quantify accurately. The financial impacts of HABs range from loss of marketable product, costs of maintaining measures necessary to monitor, mitigate, and manage events, and human health impairment, which translates to medical costs and lost wages and earnings (Anderson et al. 2000). During the 1997 outbreak of fish kills in Maryland, which were associated with the dinoflagellate *Pfiesteria piscicida*, it was estimated that the direct cost was at least $43 million dollars, based solely on the decline in seafood sales (Lipton 1999). When losses to tourism, recreational fisheries, and increased costs of monitoring and analysis are factored in, the economic impacts of this event were staggering. This event further demonstrated that despite the use of educational materials indicating that waters were subsequently safe, consumers were very slow to resume consumption of the impacted product leading to prolonged losses to the seafood community.



***Pfiesteria piscicida* zoospores (~10 μm in diameter) shown swarming around (short arrows), penetrating, and consuming (long arrows) a live eastern oyster larva.**

Source: J. Burkholder.

and Maine (D.M. Anderson, unpub. data). Continual PSP intoxication in Alaskan shellfish is one factor blamed for the lack of development of a commercial, wild shellfish industry, estimated to be worth $6 million annually (Anderson et al. 2000). Blooms of one of the brown tide organisms, *Aureococcus anophagefferens*, devastated the bay scallop industry in Long Island, estimated to be worth $2 million annually (Kahn and Rockel 1988). Outbreaks of *Pfiesteria*-like organisms in 1997 in Chesapeake Bay tributaries resulted in a collapse of seafood sales and boat charters, with losses to watermen, seafood dealers, and seafood restaurants approximating $43 million.

Social and economic costs also result from limited resources and costly methods for monitoring. For example, fisheries management decisions are often made without complete and timely HAB toxin data. This has led to closure of some fisheries and delayed opening of those already closed.

HABs that cause shellfish toxicity can significantly impact the livelihood of commercial shellfishermen, owners of restaurants, and seafood markets. Recreational clammers are also affected.

Source: S. Gladu.

Societal Impacts and Stakeholders

A subtle, but important impact of HABs is the effect they can have on recreation, tourism, and local aesthetics by diminishing the quality of the coastal environment. This can manifest in a variety of ways in different regions of the country. Some examples are massive fish mortalities that result in fish accumulating on beaches, the closure of recreational fisheries, respiratory ailments experienced by beachgoers from aerosolized toxins, unsightly and noxious piles of macroalgae that accumulate and decompose on beaches, the discoloration of water, as well as mortalities of protected species and modification of their habitats. HAB occurrences affect consumer perceptions of the safety of uncontaminated shellfish, reducing the demand for shellfish in general and affecting the fishing and aquaculture industries even where there is no contamination. Freshwater HABs can similarly affect the perception of drinking water safety, impacting decisions by consumers and public utilities. Although many experts argue that the effects of HABs on recreation, tourism, and aesthetics are important and potentially large, there are few available data describing their magnitude (Hoagland et al. 2002).

Estimating the full range of societal impacts of HABs is as difficult as estimating human behavior in response to a traumatic event. Working patterns can be disrupted

when fishermen seek alternative occupations or sources of income and restaurants seek alternate suppliers for their seafood. Charter boat reservations and pier attendance for recreational fishermen in Florida can be reduced during HAB events because of fish kills, respiratory irritants, and misinformation about HABs. Vacations can be ruined, and some may never visit an impacted region again. People who have retired to coastal or lake shore homes may find their property values are adversely affected when HABs frequently occur.

HABs can impact living resources and public health of local communities and beyond. Each HAB event that results in animal mortalities, fisheries closures, public health alerts, loss in work days, clean-up costs, lost revenue, and general public concern, has created stakeholders at various levels of organization, from local residents to seafood consumers both local and afar.

There are many user and advocate groups involved with HABs nationwide. These groups can be divided into four general categories: those interested in aquatic food and living resources, those interested in recreational activities and uses of public waters, those responsible for public health, and others. The economic and societal impacts of HABs on fish and shellfish harvesters, producers, and processors are direct. Their livelihoods are at risk when HABs threaten the fishery resource on which they depend. Less recognized is the impact on community volunteers, stranding and salvage networks, federal and state regulators involved in recovery or management plans, veterinarians, sea bird sanctuaries, environmental advocates, scientists, concerned citizens, biodiversity observers, database managers, and others.

Public health personnel are an essential part of the impacted community. They include medical professionals such as epidemiologists investigating an intoxication incident, family physicians treating patients

SPOTLIGHT

Domoic Acid Closes Recreational and Commercial Harvests of Shellfish in Washington and Oregon

Source: Washington State Department of Fish and Wildlife.

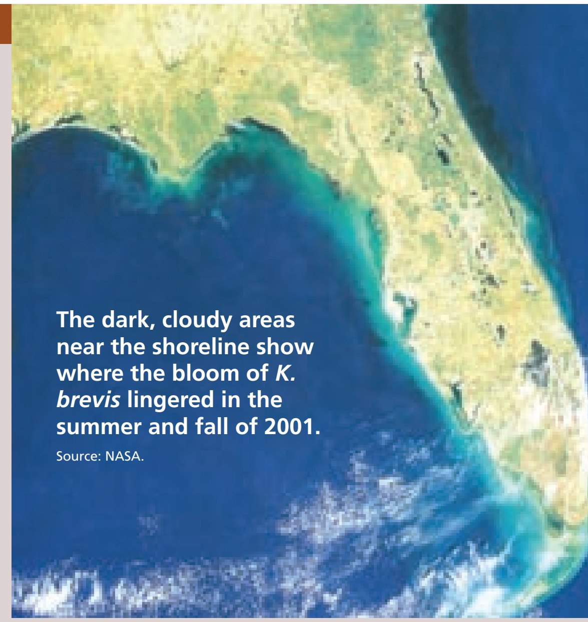
Tens of thousands of visitors are drawn to Washington and Oregon coastal communities to harvest razor clams recreationally. The economic contribution of these visitors is especially important to small coastal communities during the quiet fall, winter, and early spring months. Since 1991, high levels of domoic acid have resulted in three, year-long closures of these fisheries (1991–92, 1998–99, and 2002–03). The economic impact in terms of reduced recreational spending of the most recent of these closures has been estimated to be between $10 and $12 million (D. Ayres, pers. comm.). In addition, the Native American coastal tribes who possess fishing rights for razor clams have also been heavily impacted by the closure of their commercial and subsistence fisheries. The coastal Dungeness crab, another key commercial fishery, has experienced disruptions with closures in portions of the fishing grounds, and continues to face the real threat of future closures over much wider areas.

SPOTLIGHT

Living and Breathing Brevetoxins on Florida Beaches

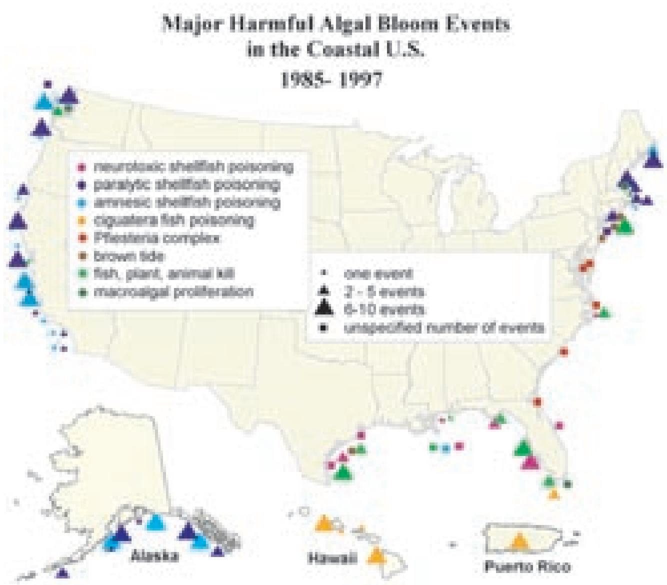
Many HABs cause human health problems before they are visible by satellite or the human eye. In the case of Florida's common *Karenia brevis* blooms, respiratory distress can occur when cells are present at about 1,000 cells/liter and fish kills begin at about 100,000 cells/liter, but visible discoloration of the water requires orders of magnitude more cells.

We know a considerable amount about the biochemical and neurophysiological activities of brevetoxins as shellfish poisons. However, we know much less about human health effects from environmental exposures, such as those from aerosols along beaches. Preliminary results suggest aerosols can have adverse effects on respiratory and lung function, particularly among the elderly and those with chronic respiratory illnesses.



The dark, cloudy areas near the shoreline show where the bloom of *K. brevis* lingered in the summer and fall of 2001.

Source: NASA.



There are very few areas of the US coast that are unaffected by HABs. This graphic shows not only the geographic areas that are affected, but the frequency of those events. Larger symbols denote more frequent occurrences, and colors denote the different HAB impacts.

Source: D. Anderson.

exposed to toxic shellfish, and emergency room physicians treating patients exposed to ciguatera fish poisoning. HABs thus affect quality of life through jobs, food, health, and recreation. As the risk increases, the user groups expand to include decision-makers at the individual, community, regional, state, federal, and tribal levels.

Another aspect of public health and HABs is the risk of cyanobacterial blooms in freshwater reservoirs. Water treatment plants have to be aware of these blooms and the toxins that they can produce. Treatment protocols are available but their effectiveness would be enhanced by early detection of cyanotoxins, application of the best treatment methods, and knowing when the protocol has to be implemented to protect public drinking water at the tap. Another public health aspect of cyanobacterial blooms is exposure to toxins or bioactive compounds that cause dermatitis in the recreational user.

The impact of HABs extends to other user groups as well, including shipping companies, database managers, importers/exporters, grassroots citizen groups, councils, commissions, the media, conservancies, parks and reserves, life guards, and city or county clean-up crews. **HABs are clearly a serious and growing problem in the coastal ocean—one that requires the interplay of all oceanographic disciplines, as well as others such as resource management and public health.**

CHAPTER 2

Coordinating with Agencies, Partners, and Stakeholders

The diverse nature of HAB phenomena is a significant challenge to the development of a coordinated national program. The multidimensional nature of HAB issues was recognized at the time of the 1993 National Plan and has resulted in a range of programs and agencies that address specific aspects of HABs, i.e., ecology, toxicology, monitoring, mitigation, human health, and education. Many of these programs are described below. As HARRNESS develops to resolve the next decade of challenges, it must take maximum advantage of current programs where they exist, engage new partners, and work within state, national, and international opportunities. Improving the coordination among the research community and the facilitating partners and stakeholders is an important goal of HARRNESS.

One of the important goals of HARRNESS is to improve the coordination among the research community, facilitating partners, and stakeholders.

National HAB Communication Program

The US National Office for Marine Biotoxins and Harmful Algal Blooms

The US National Office for Marine Biotoxins and Harmful Algal Blooms is located at the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts. Established in 1995, one of its initial roles was to assist in the development of an integrated, national HAB research agenda based on technical evaluations of research efforts, workshop activities, and federal and state agency efforts to prevent, control, and mitigate HABs. In subsequent years, the role of the National Office has expanded, as it now serves as a focal point for HAB research and management by organizing and providing for community access to the latest research developments, workshop reports, research strategies, and related data and information. The National Office also coordinates the interests of, and fosters collaboration and partnerships among, the many stakeholders in HAB research and mitigation. These include federal agencies with responsibilities to address HAB issues, the academic research community, and regional and local resource managers. The office also facilitates coordination and information exchange between the US and international HAB research and management communities. An important strength of this office is that it is located in an academic environment and is independent of the control or restrictions of government agencies.

National HAB Funding Programs

ECOHAB: The Ecology and Oceanography of Harmful Algal Blooms

The ECOHAB Program was initiated nearly a decade ago as a "scientific program designed to increase our understanding of the fundamental processes underlying the impacts and population dynamics of HABs" (Anderson 1995). This competitive, peer-reviewed research program is supported by an interagency partnership.

The federal partners participating in the ECOHAB program have different research foci related to HABs.

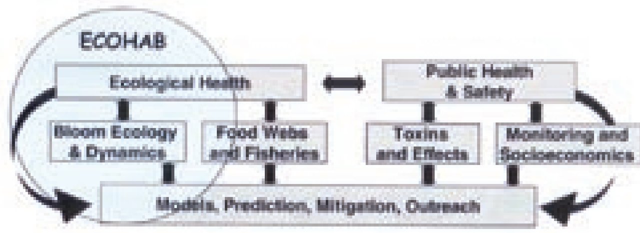
NOAA Focus – NOAA's interest in ECOHAB is in developing a general understanding of HABs and their relationships to the surrounding environment. Additionally, interest includes development and application of effective techniques for prevention, control, and mitigation to assist in reducing the impacts of HABs on coastal ecosystems (living marine resources and coastal habitats) and public health, and ensuring that the information is delivered to the public and the coastal management community in a timely and effective manner. NOAA also supports efforts to determine the socioeconomic impacts of HABs and their resulting effects. Multidisciplinary investigations of regional factors responsible for development of recurrent blooms along the US coast continue to be a major area of emphasis and include development of possible HAB forecasts for early warning in this area.

EPA Focus – EPA seeks to support the development of detection, control, and mitigation technologies to protect the integrity of ecosystems that are affected by HABs. EPA also supports studies examining relationships among nutrient loading, HABs, and food web dynamics. Of particular interest are integrative approaches to analyzing food webs and key trophic components or pathways altered by HABs, and nutrient loading thresholds affecting these alterations. Studies examining the ecological consequences resulting from the introduction of non-indigenous HABs via invasive species pathways such as ballast water are also of interest.

NSF Focus – Many aspects of species-specific dynamics of plankton, macroalgal populations, and species succession that contribute to bloom formation are poorly understood. NSF's interest in ECOHAB is in increasing our understanding of the direct and indirect causes of HABs in our coastal regions and their ecological consequences through research on the physiological and ecological bases for bloom formation, the physical and chemical attributes of coastal oceans that facilitate them, the population attributes of bloom species, and the long-term consequences of ecosystem changes.

ONR Focus – Plankton blooms resulting from complex coupled physical–biological processes strongly affect the physical, optical, and acoustical properties of the coastal ocean. ONR's interest in ECOHAB is in characterizing and forecasting these properties of blooms to improve the capability of the fleet to operate effectively within coastal environments worldwide.

NASA Focus – NASA is interested, through ECOHAB, in developing remote sensing techniques that could be applied to the detection or tracking of HABs, as well as the physiological status or taxonomic classification of bloom organisms in nearshore coastal environments.



The ECOHAB program has largely been focused on the ecology and dynamics of phytoplankton and the oceanographic conditions and processes that contribute to natural blooms.

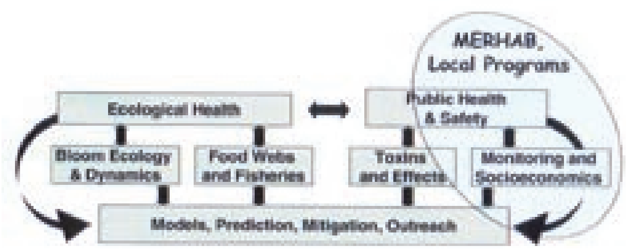
The ECOHAB Program identified three major research themes that encompass priority issues of national importance. These include: 1) *Organisms*—with a goal of determining the physiological, biochemical, and behavioral features that influence bloom dynamics; 2) *Environmental regulation*—with a goal of determining and parameterizing the factors that govern the initiation, growth, and maintenance of these blooms; and 3) *Food web and community interactions*—with a goal of determining the extent to which food webs and trophic structure affect and are affected by the dynamics of HABs. Information in these areas, in turn, supports a critical goal of the ECOHAB program—and the development of reliable models to forecast bloom development, persistence, and toxicity.

The federal partners in ECOHAB are the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), the Environmental Protection Agency (EPA), the National Aeronautics and Space Administration (NASA), and the Office of Naval Research (ONR). Each agency brought its own unique interests and missions into this coordinated research program.

Projects funded through ECOHAB include regional studies on the biogeochemical, ecological, and physical processes that contribute to bloom formation and maintenance, as well as individual targeted studies that examine specific biological and physical processes that regulate the occurrence of specific HABs. Regional ECOHAB studies have been undertaken in the Gulf of Maine for *Alexandrium* and paralytic shellfish poisoning, the Gulf of Mexico for *Karenia brevis* and neurotoxic shellfish poisoning, the shallow bays and lagoons of eastern Long Island for *Aureococcus anophagefferens*, the mid-Atlantic states for *Pfiesteria* and related organisms, and, more recently, the US west coast for *Pseudo-nitzschia* and domoic acid poisoning. Each of these efforts has resulted in a wealth of new knowledge that is leading, through collaboration with other programs, to enhanced ability to detect, monitor, predict, mitigate, control, and prevent HABs.

MERHAB: Monitoring and Event Response for Harmful Algal Blooms

Initiated in 1999 by NOAA, MERHAB seeks to develop products generated by ECOHAB and other basic science programs to help communities mitigate HAB impacts. The principal focus is to build the capabilities of local, state, tribal, and private sector interests for regular and intensive measurement of HAB parameters, making existing monitoring programs more efficient



The MERHAB program has been focused on building capabilities and technologies to improve HAB monitoring and to create science-management partnerships.

while providing for better coverage in time and space. MERHAB, like ECOHAB, is a competitive, peer-reviewed program. MERHAB regional projects engage scientists and managers to conduct rigorous field testing of state-of-the-art technology and incorporate new methods of detecting, tracking, and predicting HABs into existing monitoring programs. MERHAB targeted projects focus on advancing HAB-related technologies that have promising user-driven applications.

NIEHS-NSF Oceans and Human Health Initiative

The National Institute of Environmental Health Sciences (NIEHS) and the NSF have funded four Oceans & Human Health Centers, each having a focus on a different class of HABs. The objective is to elucidate underlying mechanisms that govern relationships between marine processes and public health. These Centers for Oceans and Human Health (COHH) seek to provide linkages between members of the ocean sciences and biomedical communities through the support of interdisciplinary research in areas where improved understanding of marine processes and systems has potential to reduce public health risks. COHH is expected to create an environment conducive to interdisciplinary and reciprocally beneficial collaborations among biomedical scientists (e.g., epidemiologists, pharmacologists, toxicologists, microbiologists, and cell and molecular biologists) and ocean scientists (e.g., biological and physical oceanographers, geochemists, and ecologists) with the common goal of improving our knowledge of the impacts of the ocean on human health.

NIEHS views "oceans and human health" as both an opportunity and a challenge. Oceans have become conduits for a number of environmental threats to human health. At the same time, oceans harbor diverse organisms that show great promise for providing new drugs to combat cancer and fight infectious diseases.

NOAA Oceans and Human Health Initiative

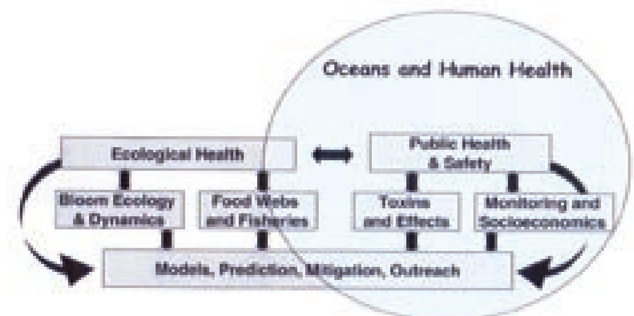
The National Ocean Service (NOS) operates the NOAA Oceans and Human Health Initiative (OHHI) which was initiated in 2004. The scope of the OHHI research portfolio includes pathogens, HABs, sentinel species as environmental or human health indicators,

NIEHS/NSF Centers for OHH

- Pacific Northwest Center for Human Health and Ocean Sciences, University of Washington
- Pacific Research Center for Marine Biomedicine, University of Hawaii
- Woods Hole Center for Oceans and Human Health, Woods Hole Oceanographic Institute
- Center for Subtropical and Tropical Oceans and Human Health, University of Miami

NOAA Centers for OHH

- NOAA Center of Excellence in Oceans and Human Health at the Northwest Fisheries Science Center, in Seattle, Washington
- NOAA Center of Excellence in Oceans and Human Health at the Hollings Marine Laboratory, in Charleston, South Carolina
- NOAA Center of Excellence for Great Lakes and Human Health at the Great Lakes Environmental Research Laboratory, in Ann Arbor, Michigan



The Oceans and Human Health programs of both NSF and NOAA are aimed at elucidating the relationships between marine processes and public health.

marine toxins, marine biomedicine, and pharmaceuticals, along with a view to integrate these into an ecosystem framework. Initial efforts are aimed at establishing three NOAA Centers of Excellence in Ocean and Human Health that focus attention and scientific expertise on key ocean and health issues, creating an internal competition to foster collaboration across NOAA, developing an external peer-reviewed grants program to engage the academic and non-governmental communities, and creating opportunities for scientists to develop and share scientific expertise by forming a distinguished scholars and training program. NOS is working closely with other parts of NOAA, NSF, NIEHS, and the academic community to ensure that the programs developed build on NOAA's strengths and complement on-going activities in this area.

National Sea Grant College Program

The National Sea Grant College Program sponsors a variety of marine research, outreach, and education projects, primarily through the 30 state Sea Grant Programs. The program has also established a series of National Strategic Investments which have a national focus and are intended to enhance Sea Grant's network-wide capabilities to respond to high priority issues and opportunities. Sea Grant has supported research and outreach dealing with public health and economic impacts of *Pfiesteria*, brown tides, and other HABs; the root causes of hypoxia; and the impacts of metropolitan sewage outflows on coastal waters. Sea Grant priority research supported under themes in Seafood Science and Technology and Ecosystems and Habitats has made significant contributions toward resolving HAB issues.

HABs are one of the three Sea Grant national priority areas. As a partnership between the nation's universities and the NOAA, there is a Sea Grant program in every coastal state. Sea Grant Programs provide research, education, and outreach on all coasts, for all age groups, for government, private businesses, and citizens, and on issues ranging from biology to economics to the physical sciences.

EPA Science to Achieve Results (STAR) Program

This program funds research grants and graduate fellowships in numerous environmental science and engineering disciplines through a competitive solicitation process and independent peer review. The extramural program complements EPA's own intramural research program and those of partners in other federal agencies. In addition, through this same competitive process, the National Center for Environmental Research (NCER) periodically establishes research centers in specific areas of national concern. At present, estuarine and coastal ecosystems form one focus of these centers.

Centers for Disease Control and Prevention (CDC)

In response to the events related to identifying *Pfiesteria piscicida* in the Chesapeake Bay, CDC was given Congressional funding to support state-based surveillance for human illnesses associated with exposure to this organism. Over time, HAB-related projects in the CDC have expanded to include investigating the public health impacts of aerosolized brevetoxins during Florida red tides, supporting development of a diagnostic method for ciguatera and assessing human exposure to blue-green algal toxins in drinking water.

National HAB Research and Response Programs

National Laboratories for HAB Research

National laboratories of the NOAA Ocean Service and NOAA Fisheries provide critical HAB research and services to the nation. The Ocean Service laboratories include the Marine Biotoxins Program located at the Center for Coastal Environmental Health and Biomolecular Research and the Hollings Marine Laboratory in Charleston, SC, and the Phytoplankton Ecology and Physiology Team at the Center for Fisheries and Habitat Research in Beaufort, NC. These laboratories coordinate with sponsored research (ECOHAB and MERHAB) programs through the National Centers for Coastal Ocean Science. The NOAA Fisheries Science laboratories include the Harmful Algal Blooms Program at the Northwest Fisheries Science Center in Seattle, WA and the Northeast Fisheries Science Center in Milford, CT. The purpose of these NOAA research laboratories is to provide scientific guidance, research, and community service on issues involving marine toxins and harmful algae to promote effective management of our coastal ecosystems and the health of the animals and people who live in the coastal zone.

The US Food and Drug Administration has a vigorous seafood research program that supports the agency's regulatory mission. FDA research forms the basis for the Agency's understanding of the extent and severity of hazards, for risk assessment, and for risk management. Seafood research is carried out at FDA's Gulf Coast Seafood Laboratory at Dauphin Island, AL, the Seafood Products Research Center in Washington State, as well as in the Beltsville Research Facility in Laurel, MD.

State HAB Information Resources

NORTHEAST	
Maine	• *Maine Red Tide Information System*: Interactive access to red tide closure data • *Maine Department of Marine Resources*, *Bureau of Resource Management*: Redtide and shellfish sanitation status information
Maryland	• *Maryland Department of Natural Resources*: Reports of HAB events in Maryland • *Eyes on the Bay*: Interactive access to Chesapeake monitoring station data including HAB events • *Maryland Department of the Environment*: Notices of shellfish closures and fishing advisories
Massachusetts	• *Massachusetts Division of Marine Fisheries*: Protocols for monitoring, harvesting closures, and other regulatory information • *Massachusetts Department of Public Health*: Permit procedures and food safety
New Jersey	• *New Jersey Department of Environmental Protection, Division of Marine Water Monitoring*: Procedures for water quality and shellfish monitoring and status • *New Jersey Department of Environmental Protection, Division of Science Research and Technology*: Brown tide status and general information • *Brown Tide Monitoring*: Maps of brown tide events in coastal New Jersey
New York	• *New York State Department of Environmental Conservation*: Shellfish closure information
SOUTHEAST	
North Carolina	• *North Carolina Department of Environment and Natural Resources*, *Division of Water Quality*: Monitoring data and fish kill maps for area rivers • *North Carolina Department of Environment and Natural Resources*, *Division of Marine Fisheries*: Shellfish closure status
South Carolina	• *South Carolina Department of Health and Environmental Control*: Monitoring and shellfish closure status
Virginia	• *Virginia Institute Department of Environmental Quality*: Procedures and regulations for water quality monitoring
GULF OF MEXICO	
Florida	• *Florida Marine Research Institute*: Current red tide status for the Florida coast, including maps • *Mote Marine Red Tide Update Page*: Local conditions for the southwest Florida coast • *Florida Department of Agriculture and Consumer Services*: Shellfish closure status
Mississippi	• *Mississippi Department of Marine Resources*: Shellfish closure status
Texas	• *Texas Parks & Wildlife Department*: Texas coast red tide status reports • *Texas Department of Health*: Shellfish closures due to red tide
WEST COAST	
Alaska	• *Alaska Department of Environmental Conservation*, *Division of Environmental Health*: Monitoring procedures for paralytic shellfish poisoning and status of shellfish closures
California	• *California Department of Health Services*, *Division of Drinking Water and Environmental Management*: Advisories and reports for marine biotoxin monitoring
Oregon	• *Oregon Department of Human Services*, *Environmental Services*: Beach monitoring programs and fish advisories
Washington	• *Washington State Department of Health*: Interactive map of recreational shellfish beach closure status • *Washington State Department of Health*, *Division of Environmental Health*: Monitoring program information and biotoxin bulletins • *Washington Department of Fish and Wildlife*: Shellfish harvesting regulations and status

Programs listed by region can be found at www.csc.noaa.gov/crs/habf/resources.html.

National Laboratories and Centers within EPA's Office of Research and Development have undertaken research to improve methods of detection for HABs and to better understand the effects of HAB toxins. Research on cyanobacteria is beginning to assume higher priority, owing to the increasing prevalence of cyanobacteria and the growing threat they pose to drinking water supplies.

National HAB Event Response Programs

The National HAB Event Response Program is comprised of a number of separate initiatives. In response to the 1987–88 Florida dolphin mortality event, NOAA established the Marine Mammal Health and Stranding Response Program, and within it, the Working Group on Unusual Marine Mammal Mortality Events. The Working Group is made up of members from academia, conservation organizations, and state and federal natural resources agencies that bring a wide variety of expertise, including: biology, toxicology, pathology, ecology, and epidemiology. Its primary role is to determine when an unusual mortality event is occurring and then to direct responses to such events. Since 1987, the Working Group has consulted on 20 marine mammal mortality events worldwide (12 in the US).

The NOAA Analytical Response Team (ART) was established within NOAA's Marine Biotoxins Program to provide a formal framework through which coastal managers can request immediate, coordinated assistance during HABs, related health incidents, and marine animal mortality events. This program's combined expertise in algal taxonomy, toxicology, and toxin chemistry supplies accurate information in a timely manner, allowing managers to make informed decisions involving shellfish harvests, life support for marine mammals, beach closures, and remedial actions. Since 1993 the Analytical Response Team has provided analyses for 50 different investigations related to algal blooms and algal toxins, including their impacts on fish, marine mammals, and birds, as well as human exposures.

NOAA's Ocean Service formed an event response program linked closely with MERHAB and ECOHAB's sponsored research programs as a means of connecting the HAB research community with managers responding to HABs to ensure timely access to cutting-edge science in support of immediate event management. NOAA and its partners in the community have provided managers access to the latest HAB detection and tracking technology and analytical expertise housed within the nation's top university and government research facilities. Researchers have been called upon to assist managers with a variety of tasks, including determining correlations between marine animal disease or mortality events and HABs, and whether algal toxins pose risks to human health. The recent response program benefits the HAB knowledge base by ensuring proper scientific documentation of the often unpredictable and ephemeral blooms.

The Health Studies Branch (HSB) of the (CDC's) National Center for Environmental Health (NCEH) is responsible for developing and evaluating strategies for preventing human exposure to environmental hazards and disasters, and for minimizing the effects of such exposures when they do occur. To accomplish this mission, HSB investigators conduct epidemiologic rapid response and research activities in cooperation with federal, state, local, and international health agencies. The goal of HSB is to provide environmental health leadership, science, and service for all major categories of environmental hazards including HABs in the US and the growing threat they pose to drinking water supplies.

State HAB Research and Monitoring Programs

There are numerous state activities, but efforts vary depending on the specific HAB problem that dominates in the state. Some states are just developing their programs, while others have had a long established record on monitoring in the interest of human health. Many state and non-governmental agencies carefully monitor HABs and provide high quality information to the public. A listing of such resources is given in the table on page 25. Many states are now recognizing that the diversity of HAB species in their waters may be increasing, and programs originally established to monitor for the presence of one species or toxin must be expanded.

International HAB Initiatives and Related Programs

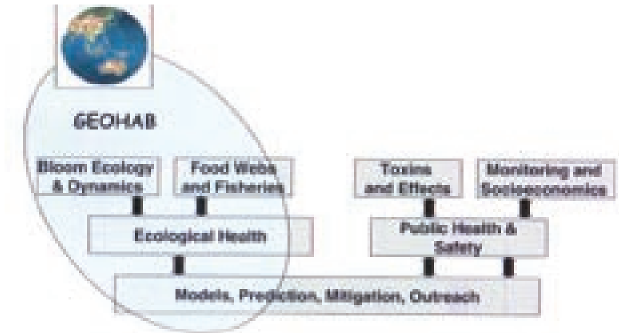
EUROHAB: European Harmful Algal Bloom Programme

Within the European community, it has also been recognized that the problems of HABs are increasing, and that these problems know no national borders. A HAB problem in one country may have been initiated through nutrient delivery or other source from another country. Furthermore, the transport of species and water via currents and shipping poses additional mechanisms by which these problems spread from one country to another. The European Commission (EC) has, over the past decade or more, funded numerous individual projects related to harmful algae and there are many efforts devoted to monitoring and research on a local scale in several European countries. However, until recently there have been no cooperative efforts aimed at understanding harmful algae in European waters in a coordinated, comprehensive fashion. In 1998, an international workshop organized by the EC and the University of Kalmar, Sweden, was held to develop a directed scientific initiative, resulting in the EUROHAB Programme (EUROHAB 1999). The following were identified as important research areas: 1) algal-produced toxins accumulating in the food web; 2) fish-killing species; 3) high biomass HABs; 4) cyanobacterial blooms and toxins; 5) field studies of physical-biological interactions; 6) tools and technology development; and 7) mitigation. Under the subsequent EUROHAB Initiative, projects were undertaken on the role of eutrophication and biological control of HABs, importance of organic matter from terrestrial sources in HAB formation, transfer and fate of HAB toxins, development of predictive systems, and most recently, a project on the socioeconomic impact of HABs (EUROHAB 2002). The EUROHAB effort is now, like ECOHAB, evolving to include a new phase of research priorities.

GEOHAB: Global Ecology and Oceanography of Harmful Algal Blooms

The GEOHAB Programme is an international, multidisciplinary program under the auspices of the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC).

The GEOHAB Science Plan (GEOHAB 2001; available online at http://www.GEOHAB.info) defines five program elements that serve as a guide to research priorities. Although HABs also pose critical problems



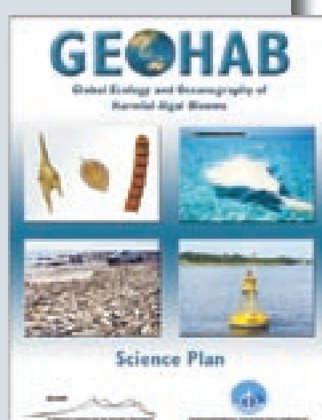
The GEOHAB program assists in the multi-national coordination of HAB research on ecology and population dynamics and oceanographic processes, and is supported by advanced observational and modeling techniques.

SPOTLIGHT

The GEOHAB Programme: Global Ecology and Oceanography of Harmful Algal Blooms

GEOHAB is an international, multidisciplinary program that will assist investigators from different disciplines and countries to exchange technologies, concepts, and findings to address issues related to the global ecology and oceanography of HABs. The emphasis is on comparative studies that include observational and modeling components. In 2001, GEOHAB published the Science Plan that identifies the following overarching questions.

- Biodiversity and Biogeography. What are the factors that determine the changing distribution of HAB species, their genetic variability, and the biodiversity of associated communities?
- Nutrients and Eutrophication. To what extent does increased eutrophication influence the occurrence of HABS and their harmful effects?
- Adaptive Strategies. What are the unique adaptations of HAB species and how do they help to explain their proliferation or harmful effects?
- Comparative Ecosystems. To what extent do HAB species, their population dynamics, and community interactions respond similarly under comparable ecosystems?
- Observation, Modeling, and Prediction. How can we improve the detection and prediction of HABs by developing capabilities in observations and modeling?



In 2003, the GEOHAB Implementation Plan was published, outlining the mechanisms by which GEOHAB Core Research Projects will be initiated and how GEOHAB will develop various networking, coordination of resources, data management, and interactions with other programs. Through Open Science Meetings held worldwide, GEOHAB is inviting the global participation of scientists in these activities.

International Agencies and Programs with Interests in HABs

IAEA The International Atomic Energy Agency supports technical cooperation projects on HABs at the national, regional, and inter-regional scale. These projects lead to transfer of toxin detection methods throughout the world and production of radiolabeled toxin standards.

APEC The Asia-Pacific Economic Cooperation established a major program on Red Tides in 1999 to coordinate the monitoring and management of HABs within the 21 APEC economies in order to facilitate a free flow of goods and services, and in particular, shellfish and fish products, which can potentially be contaminated with algal toxins.

AOAC The Association of Official Analytical Chemists responds to the global need for improved testing methods for these marine and freshwater toxins through the design and implementation of official validation of toxin methods. These activities are managed by the Task Force on Marine and Freshwater Toxins, which has a strong and practical commitment to the development and validation of methods for detection of toxins.

IUPAC The International Union of Pure and Applied Chemistry serves to advance the chemical sciences worldwide and to contribute to the application of chemistry in the service of mankind. IUPAC has supported the International Symposium on Mycotoxins and Phycotoxins since 1973 as a forum to advance understanding of toxins, occurrence, assay proficiency, toxicology, and risk assessment from a global food safety perspective.

WHO\FAO The World Health Organization and the Food and Agriculture Organization of the United Nations develop global standards for seafood safety, drinking water, and recreational water safety. WHO/IOC and FAO review the current Codex guidelines and provide advice on maximum levels in shellfish for shellfish toxins, guidance on methods for analysis of each toxin group, guidance on monitoring of harmful algae and shellfish, and information on the geographical distribution of HAB species.

GEF The Global Environment Facility is a financial framework for the Convention on Biological Diversity and the UN Framework Convention on Climate Change. GEF supports the Global Ballast Water Management Programme (GloBallast) which assists developing countries to reduce the transfer of harmful aquatic organisms and pathogens in ships' ballast water.

GOOS The Global Ocean Observing System is designed to monitor the ocean and develop sufficient understanding of environmental variability to achieve the goals of sustainable development and integrated management of the marine environment and its natural resources. GOOS provides an essential platform to enhance HAB forecasts and predictive models.

IOOS The Integrated Ocean Observing System constitutes the US contribution to GOOS. IOOS is a coordinated national and international network of observations, data management, and analyses and is intended to provide the data and information required to achieve a number of goals, including the reduction of public health risks and protecting and restoring healthy coastal marine ecosystems. IOOS provides great opportunity to observe, monitor, and predict HABs.

LOICZ The Land-Ocean Interactions in the Coastal Zone project's primary focus has been to collect information on material fluxes from the land to the ocean in order to construct flux estimates related to diverse environment types. Information and techniques available from LOICZ can be important for HAB research and prediction activities.

IMBER The Integrated Marine Biogeochemistry and Ecosystem Research Program is becoming the focal program for IGBP and SCOR in the area of ocean biogeochemistry and ecosystems. Some of IMBER-proposed research areas include phytoplankton dynamics, making this project a likely partner in HAB research.

GLOBEC The primary focus of the Global Ocean Ecosystem Dynamics program is to investigate how the physical environment affects the productivity of zooplankton and fish in marine ecosystems. One strength of GLOBEC is research in upwelling regions, which can be extremely productive and can experience severe HABs.

in freshwater ecosystems, the focus of GEOHAB will be on the manifestation of blooms in marine and brackish waters.

The mission of GEOHAB is to foster international cooperative research on HABs in ecosystem types sharing common features, comparing the key species involved and the oceanographic processes that influence their population dynamics.

GEOHAB is not a funding program or agency; rather, research is supported by national funding agencies that must respond to national scientific priorities utilizing nationally based facilities, resources, and expertise. GEOHAB will combine the resources of many countries and expertise of many individual scientists in the study of complex processes of HAB population dynamics.

GEOHAB is thus an international program that coordinates and builds on related national, regional, and international efforts in HAB research within an ecological and oceanographic context. GEOHAB applies combined experimental, observational, and modeling approaches, using current and innovative technologies in a multidisciplinary approach consistent with the multiple scales and oceanographic complexity of HAB phenomena. Through such efforts, the emergence of a truly global synthesis of scientific results should be attained.

The EU–US Scientific Initiative on Harmful Algal Blooms

A joint EU–US workshop on HABs was held in 2002 and a joint funding mechanism between the EC and the US NSF for HAB-related research was established in 2003. The EU Collaborative Program on Harmful Algal Blooms is a new initiative to support collaborative, international research. For decades, HABs have been studied in relative isolation on both sides of the Atlantic. National and regional programs such as EUROHAB in Europe and ECOHAB in the US have funded research on HABs, but these efforts have not included significant international collaboration. In recognition of the importance of scientific exchange among nations, the NSF has entered into an implemention arrangement with the EC in support of environmental research, including research on the ecology and oceanography of HABs.

IOC Harmful Algal Bloom Programme

The overall goal of the IOC HAB Programme is to foster the effective management of, and scientific research on, HABs in order to understand their causes, predict their occurrences, and mitigate their effects. There are three major divisions: educational, scientific, and operational. The educational program element is separated into two branches: information networks and training and capacity building. The scientific program element is separated into three branches: ecology and oceanography, taxonomy and genetics, and toxicology and toxin chemistry. The operational program element is divided into three branches: resource protection, monitoring, and public health and seafood safety. There are many interactions between the subjects and actions, e.g., fisheries management benefits from knowledge of the ecology and dynamics of blooms; monitoring is based on ecological, oceanographic, taxonomic, and toxicological information.

International Agencies

Multiple international agencies and programs have interests directly in HABs or related to HABs. The chart on page 28 identifies many such programs that actively engage the US HAB community or offer new opportunities to leverage resources to meet common goals.

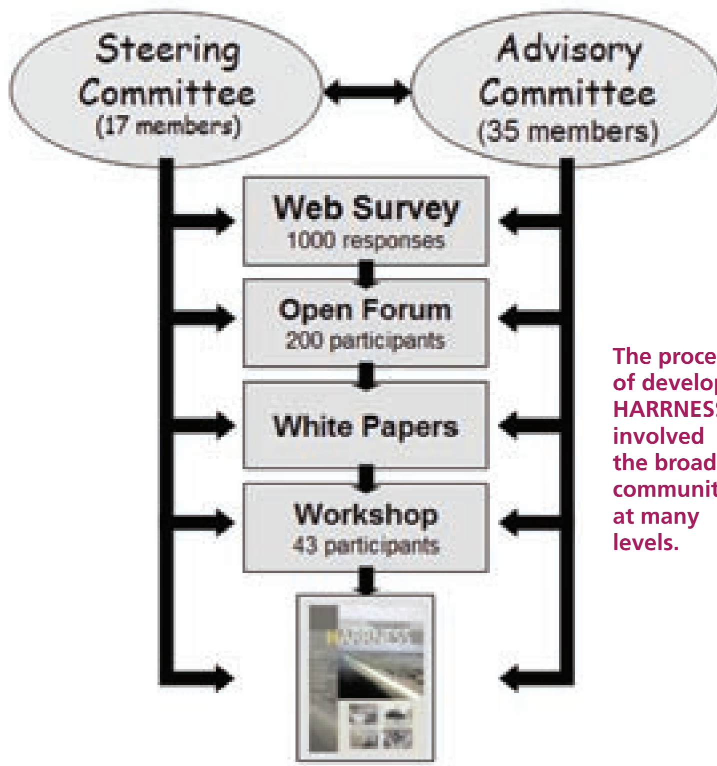
The Need for HARRNESS

The science, management, and decision-making necessary to manage the threat of HABs currently involves a complicated array of scientists, managers, and agencies at various levels. The preceding review of programs demonstrates the diversity of state, national, and international programs that have interests in HAB research, monitoring, and management activities. This review serves to demonstrate the current difficulty in coordinating such a diverse and large group of agencies and programs. **The HARRNESS program has been designed to provide this coordination and oversight, and to keep the US HAB program productive and effective over the next decade.**

Developing HARRNESS, the New National HAB Plan

The US Commission on Ocean Policy stated that "A strong and effective national ocean policy needs to be supported by a foundation of high quality ocean education that promotes lifelong learning, an adequate and diverse workforce, informed decision making, science literacy, and a sense of stewardship." Recent reauthorization of the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA) renews and expands federal efforts to combat HABs. These recent actions demonstrate concern by Congress and the Administration about the threat of HABs. Instilling a sense of stewardship is essential to sustaining Earth's resources, their interconnectivity, and our quality of life.

The 1993 *US National Plan for Marine Biotoxins and Harmful Algae* was a successful planning document that served as a springboard for multiple research agendas, funding guidance documents, and programs for research and management of HABs. Capabilities and resources to detect and monitor HABs and their toxins have vastly improved in the past decade. Despite these efforts, the nature and extent of the US HAB problem changed with the emergence of several new poisoning syndromes, the expansion of known problems into new areas, and the identification of a variety of new HAB impacts and affected resources (Chapter 1). Additionally, management of the threat of HABs currently involves a complicated array of scientists, managers, agencies, and legislatures operating at various governmental levels. Support for their activities is guided by a diversity of national and international programs (Chapter 2). The HAB community recognizes that it is now time to re-define the magnitude and diversity of the HAB problem, strengthen coordination with agencies, partners, and stakeholders, and unveil a new shared vision to significantly reduce problems from HABs in the US. **To realize this vision, the HAB community engaged in a consensus process that produced a new organizational structure and new set of shared priorities presented in the new National Plan, *HARRNESS, Harmful Algal Research and Response: A National Environmental Science Strategy 2005–2015*.**

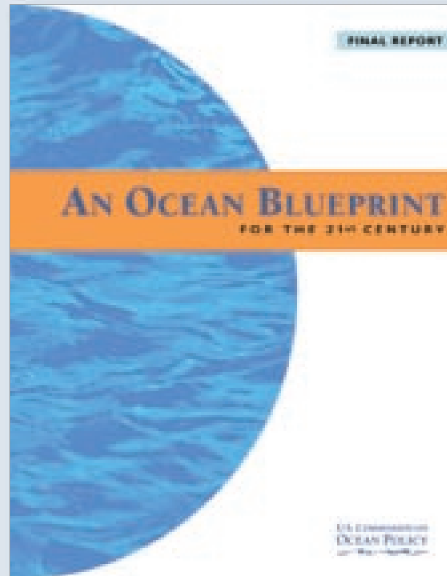


The process of developing HARRNESS involved the broader community at many levels.

The process of developing this new National Plan was initiated through a charge from NOAA's National Centers for Coastal Ocean Science to its Center for Sponsored Coastal Ocean Research. To achieve this end, a National Plan **Steering Committee** of 17 researchers and managers was selected (Appendix I). Administrative assistance was provided by the Ecological Society of America (ESA) as well as the US National Office for Marine Biotoxins and Harmful Algal Blooms. The Steering Committee's fundamental premise was to maintain the utmost transparency in the process of developing the revised plan and to offer frequent and meaningful

The US Commission on Ocean Policy

has changed the way the nation will view its oceans and protect and manage their wealth



Oceans Act of 2000 The US Congress recognized the promise of the oceans and the threats to them when it passed the Oceans Act of 2000. The resulting US Commission on Ocean Policy collected expert and public testimony indicating that major changes are needed in the management of this resource. Of great importance is the need to address the complexity and interconnections among natural systems and to update management approaches to reflect this complexity. Also noted as essential is the need for better federal support of science, infrastructure, and ocean-related education.

An Ocean Blueprint for the 21st Century The Commission delivered its Final Report, "An Ocean Blueprint for the 21st Century," to the President and Congress on September 20, 2004. The report calls for a new governance framework, more investment in marine science, and a new stewardship ethic by all Americans—all within the context of an ecosystem-based management approach—to halt the decline of this nation's oceans and coasts. The Commission's report explicitly recognized HABs and other threats to human health:

"HABs constitute significant threats to the ecology and economy of coastal areas. While the preferred course of action is prevention, effective treatments are also needed. The current availability of biological, chemical, or physical treatments is extremely limited. Better coordination would help leverage the relatively few but successful HAB research programs currently being supported by the federal government. Improved monitoring techniques are also essential in mitigating the harmful impacts of HABs. The complementary development and deployment of satellites and moored sensors will provide even greater coverage, cross-referenced ground truthing, and more frequent site-specific sampling. As more data are collected on HAB occurrences, researchers will be able to more accurately predict future outbreaks by using advanced computer models and taking into account the physical and biological conditions leading to HABs."

HARRNESS Builds on the Ocean Blueprint HARRNESS is a response to the increasing complexity and interconnections among the processes behind increased occurrence, geographical spread, and severity of HABs. It calls for invigorated investment in coordinated research, shared infrastructure, integrated observing systems, and community education. HARRNESS is also a response to the labyrinth of state, federal, and intergovernmental agencies bearing responsibility for HABs and the need to serve diverse interests spanning local to global concerns. HARRNESS takes immediate action by implementing a framework of programs, facilities, and oversight that will facilitate partners as well as stakeholders.

The Harmful Algal Bloom and Hypoxia Research and Control Act

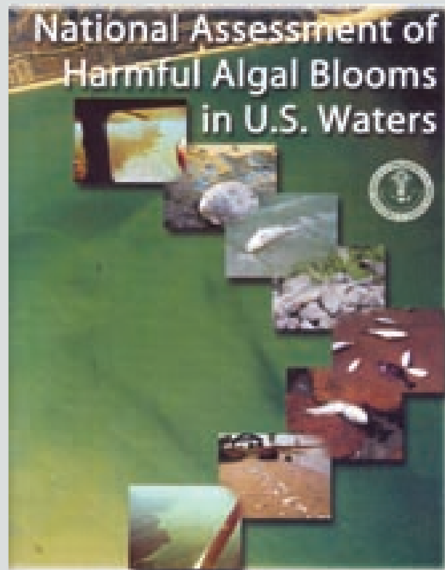
provides legislative authority for the federal government to support research, education, and monitoring of HABs

The Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA) of 1998. P.L. 105-383. The Act recognized that many of our nation's coastal areas suffer from HABs and hypoxia each year, threatening coastal ecosystems and endangering human health.

Harmful Algal Bloom and Hypoxia Amendments Act of 2004 H.R. 1856, House Rpt. 108-326 reauthorizes HABHRCA. The legislation reauthorizes the programs in the Act for Fiscal Years 2004–2006, and provides an updated research framework for addressing HABs that requires stronger consultation with local resource managers in developing the assessments and research plans.

National Assessment of Harmful Algal Blooms in U.S. Waters. The assessment, requested by Congress in the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 P.L. 105-383, compiles research and management expertise on the causes and consequences of HABs and presents recommendations for addressing their impacts nationwide. The study was a multidisciplinary effort that included input from states, Indian tribes, industry, and other coastal stakeholders. The reauthorization of HABHRCA requires a nationwide assessment of HABs once every five years.

"Harmful algal blooms are a serious threat to coastal communities that rely upon fish and shellfish," said Acting Under Secretary of Commerce for Oceans and Atmosphere, Scott Gudes. "The toxins found in harmful algal blooms can contaminate shellfish, which can cause severe illness or death when eaten. Just last summer, algal blooms are suspected of sending nine people to the hospital with paralytic shellfish poisoning in Washington State."



Freshwater HABs are now under HABHRCA Legislation. HABHRCA reauthorization requires a one-time assessment of freshwater HABs that, in the future, would be incorporated into the five-year marine HAB assessments. It also requires the development of a research plan for incorporating freshwater HAB research into the Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) interagency grant program. Research on freshwater HABs lags behind efforts addressing marine blooms and there is no comprehensive source of information on the occurrence and effects of freshwater HABs in the US. Additionally, the Great Lakes have recently exhibited an increase in the occurrence of HABs and more research is needed to understand this phenomenon.

A sampling of responses from the research and management community on HAB needs:

"The realization that HABs are affecting environmental health is more widely accepted. However, HAB activities have been more the 'shotgun' type. When there is a problem, that area spends money. Then it stops."

"We need more information about the relationship of blooms to nutrients…Even in HABs where nutrients are not the obvious cause or trigger, they are essential to the event…As coastal development continues the question of anthropogenic nutrient inputs versus natural sources is going to demand answers…"

"Health officials cannot determine the seriousness of harmful algal bloom incidents without accurate and valid human or animal exposure information. With poor exposure information, health officials can declare dangerous situations as safe, threatening the health of the public, or declare safe situations as dangerous, causing undue alarm and wasting large sums of money on needless remediation efforts."

"Models that include physical circulation and plankton bloom dynamics and link offshore processes with nearshore toxicity are essential for predicting blooms and their impacts…"

"It is my strong opinion that the success of this plan and the research that will result is dependent on how closely tied the end-users are in the process."

"It is clear that local communities are not satisfied with just better predictive abilities; they are crying for a 'fix' for these problems and their federal and state representatives are getting that message."

opportunities for stakeholders to provide the critical input necessary to develop a plan that reflects the view of the broad HAB community.

An **Advisory Committee** was next appointed to assure that the National Plan incorporated a wide range of input from stakeholders (Appendix II). This committee was composed of 35 representatives of federal and state agencies, academia, industry, and citizen groups concerned about HABs in aquatic ecosystems and their impacts on human and natural resources health, and on regional economies. The Advisory Committee reviewed and provided recommendations at three critical stages of the development of the National Plan as identified later in this chapter.

Several steps have been taken to ensure the broadest input in the process. The process of developing the National Plan began with soliciting community participation through a web-based survey and open forum discussion. The survey was sent to more than 300 individuals representing those involved in HAB research, monitoring, and management at educational institutions, state and federal offices, and laboratories. Over 1,000 specific responses were received. These responses were distilled and served as the basis for community discussion in a plenary session at the Second Symposium on Harmful Marine Algae in the US. Based on the web survey results and the community discussion at Woods Hole, MA, the Steering Committee next drafted four white papers on the topics of toxins, bloom ecology and dynamics, food webs and fisheries, and infrastructure. These white papers were then submitted to the Advisory Committee for critical review.

Following Advisory Committee review of the white papers, these documents served as the basis for discussion of a panel of 43 experts over the course of a five-day workshop that was subsequently held at NOAA's Center for Coastal Environmental Health and Biomolecular Research Laboratory in Charleston, SC. This panel of experts, selected to assure coverage of each of the 43 topics of the web-based survey, comprised the **Workshop Participants** (Appendix III). The discussions at the workshop began by analysis of the white papers and evaluation of the accomplishments and shortfalls over the last ten years. The participants decided to group the four subject areas as:

- ***Bloom Ecology and Dynamics***
- ***Toxins and Their Effects***
- ***Food Webs and Fisheries***
- ***Public Health and Socioeconomic Impacts***

The Participants next combined and integrated the different recommendations, discussed implementation of these recommendations, identified future involvement of various government agencies, and evaluated the benefits of these recommendations to users. The workshop concluded with a consensus to implement a HAB Program Framework (HARRNESS) with **a mission to represent the US HAB community at a national level**.

HARRNESS is based on the workshop products with input and review from the Workshop Participants, and the Steering and Advisory Committees. **The overall strategy resulted in this new National Plan capturing**

Web-Based Survey For Initial Community Input to the National Plan

While considering the 43 topics listed below, please use the following questions to structure your input:
1. What have been the significant advances and shortfalls that characterize the past decade's HAB activities?
2. What are future research needs, impediments, and priorities for the US HAB community?

Feel free to provide input on as many or as few of the topics as you wish. Also feel free to include topics not listed and to indicate where there has been success or failure, and where there is need for expanded activity.

TOXINS
1. Reference materials
2. Purification/Structure
3. Biosynthesis/Metabolism
4. Instrumental analysis
5. Biological assays
6. Toxicology
7. Therapeutics
8. Epidemiology/Risk assessment
9. Public Health/Surveillance
10. Human health

BLOOM ECOLOGY & DYNAMICS
11. Taxonomy
12. Cell physiology
13. Behavior
14. Community biology
15. Ecosystem dynamics & HABs
16. Genomics
17. Cell detection
18. Oceanography & observatories
19. Nutrients
20. Physical oceanography
20. Small-scale physical/biological interactions
21. Remote sensing and optics
22. Bloom mitigation
23. Modeling
24. Macroalgae

FOODWEBS & FISHERIES
25. Trophic transfer of toxins, exposure, fate
26. Impacts: Phyto-/Zooplankton
27. Impacts: Shellfish
28. Impacts: Finfish
29. Impacts: Higher vertebrates
30. Impacts: Ecosystems/benthic communities
31. Resources management
32. Resources management for public health
33. Resources health

INFRASTRUCTURE
34. Database management
35. Observing Systems
36. Education, outreach communications, training
37. Early warning, rapid response
38. Resource networking, management
39. Program oversight
40. Economic impacts
41. Repositories, collections, archives, standards
42. Volunteer networks
43. Support

and organizing the interests and input of the broadest possible cross section of the US HAB community, lending strength to its use as a guide for implementing balanced and productive HAB programs.

The following chapters outline the critical needs of the four subject areas, the program elements, and the vision of the associated HAB community to minimize the consequences of HABs to the US public and economy over the next decade via HARRNESS.

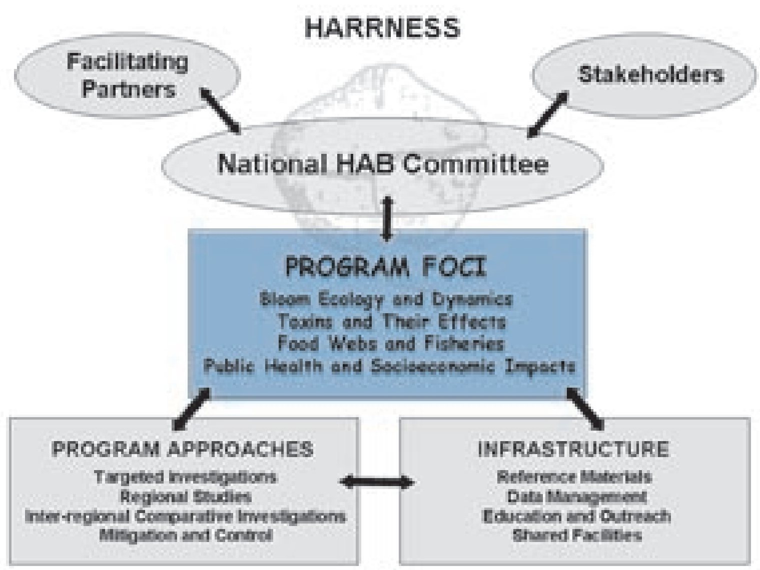
The 43 scientists and managers who participated in the HAB National Planning Meeting, held in Charleston, SC, in March 2004.

Identifying Critical Needs for HAB Research and Response

The past decade has resulted in tremendous advances in the community's understanding of HAB dynamics, from physiology and toxin production to bloom transport and economic impact on landfall. The general increase in knowledge has been matched by rapid expansion in the capability for toxin and species detection using laboratory, hand-held, and in- and above-water technologies. Advancements in both basic knowledge and in methods and tools have led to significant new opportunities for furthering understanding and for protecting human health. In the focus areas of bloom ecology and dynamics, toxins and their effects, food webs and fisheries, and public health and socioeconomic impacts, specific goals and priorities have been identified for the coming decade. These recommendations and their rationale are given in the following pages.

The opportunities for advancement in the US HAB community are many. An important goal is the development of tools to detect, analyze, predict, and manage HAB outbreaks and associated human and wildlife illnesses. Underlying this goal is the need for continually advancing methodologies in a cost-effective fashion. To attain the goals of predicting HABs, minimizing their impacts to human health and the environment, and effectively educating stakeholders and the general public, critical needs have been identified and categorized. These needs cross-cut science and management, they bridge individual agency interests, and they intersect some other US programs already in place. The critical needs described below serve also to identify these intersections with an ultimate goal of growing a greater community through collaboration.

Bloom ecology and dynamics continues to be an important, multidisciplinary field in which crucial discoveries on several HAB species and their ecological processes have been made. Yet much remains to be learned. Specific goals include improving the detection and identification of harmful algal species, assessing



their harmful status, enhancing research, monitoring and early warning strategies, and mitigating the harmful effects. Of great interest, and largely unknown for most taxa, is fundamental knowledge on their physiology, life histories, and behavior that explain fluctuations in nature. Moreover, with increasing HAB incidence, it is extremely important to enlarge our efforts to mitigate and prevent the impacts of HABs.

The effects of HAB species and their toxins on organisms around them are generally not characterized or quantified. Hence, HAB impacts on food webs is an important and largely underrepresented research area, and warrants committed resources and research if we are to fully comprehend and mitigate the increasingly frequent events in our national waters. A first priority for the coming years is to understand and mitigate impacts of HAB species on pelagic and benthic food webs and their capacity to support fisheries and ecosystem services. This will require a focus on shellfish and finfish

The HAB research community has identified four research foci.

standards and toxin-related information; developing and establishing purification methods for emerging toxins as they are discovered; defining factors regulating the biosynthesis and metabolic transformation of toxins in natural situations; providing detection and analytical methods that are suitable for field, laboratory, and clinical use; and better characterization of the adverse effects of algal toxins on living organisms with particular emphasis on susceptible populations.

Our understanding of the socioeconomics, seafood safety, and public health aspects of HABs remains rudimentary. Hence, goals for the near term include development of regional capabilities for quantifying the socioeconomic impacts of HAB events, including the estimation of costs of studying, preparing for, monitoring, and responding to HAB events. Goals also include determining regional estimates of the value of HAB forecasting programs to user groups. For consumable seafoods, much remains to be done. The nation requires seafood safe from algal toxins and an economically stable seafood industry. Inherent in this goal is protection of fresh water and marine resources from harmful algal toxins, requiring considerable investment in planning, monitoring, policy, and regulation. Finally, public health has been reasonably assured in the US in that human deaths as a result of HAB exposure have nearly been eliminated. However, illness and sublethal effects remain a national concern. Emphasis for the coming years should include programs to provide population-based estimates of human and animal exposure and illness from algal toxins, and to provide routine, readily available treatments to mitigate the adverse effects of algal toxins.

aquaculture and wild harvest. For both of these activities, it is critical to improve our capability for forecasting of HABs in order to establish an early warning system. The role of higher trophic levels in bloom dynamics is also recognized as a critical, yet often ignored, factor in most bloom studies. Therefore, focused efforts are needed to understand the role of top-down control in HAB events and how modifications in trophic structure contribute to HAB formation. Finally, HAB effects on many of our nation's important living resources often generate high public interest and threaten some of our most sensitive and limited wildlife populations. It is therefore important to understand the detrimental effects of HABs on animal species whose status is protected, threatened, or endangered, including species of marine birds, mammals, and turtles, some of which are charismatic species and often top predators.

A major limitation for the entire community has been the lack of toxin standards and reference materials and, as a result, a lack of detection capabilities for the many congeners of known toxins and new toxins. Although identified as a priority in the original National Plan (Anderson et al. 1993), there has been little national commitment to solving this large problem. Therefore, specific, high priority goals include providing infrastructure for the certification and distribution of toxin

A cross-cutting need that relies heavily on each of the four major HAB research topics is a well coordinated, national HAB event response capability that can rapidly deploy HAB scientists at a moment's notice around the country to document blooms and HAB impacts from inception to demise. One of the successes of the HAB community since the 1993 National Plan has been the documentation and analysis of major HAB mortality events. National efforts since then have focused on building mutually beneficial connections between researchers and managers of HAB impacted coastal resources that inform risk analysis decisions and advance scientific understanding of HABs. The aim of these efforts has been correctly focused on minimizing HAB-related threats to endangered marine species and, most importantly, preventing human illnesses and deaths. A clear measure of success is the increase of marine mammal mortality events confirmed for HAB toxins (9 to 50 %) since the 1993 National Plan. Several programs and many laboratories have contributed heavily to these event responses over the last decade. However, the complexity of HAB mortality events and their socioeconomic impact continues to increase as evident with *Pfiesteria* in the Chesapeake Bay in the late 1990s and more recently the 2005 New England PSP outbreak. For these reasons, a greater committment is essential for rapid identification and community-wide communications about HAB outbreaks throughout the US. It is important to identify, expand, and entrain all capabilities known to the HAB community that can be used in HAB responses, and to rapidly deploy these capabilities to impacted regions before the bloom's demise and in time to inform risk management decision-makers. A critical lesson well learned by the HAB community is the ease with which the release of incorrect data, uninformed scientific opinions, and premature conclusions to the public can produce undesirable consumer and stakeholder behavior which magnifies the economic damages and political pressures on state and federal HAB response efforts. This so-called HAB "halo" effect is excerbated by our lack of understanding about how HABs affect societal

The Detailed Recommendations from HARRNESS Share Common Themes

Reference Materials and Data Management	• Establish facilities for toxin standards, cultures, and genomic resources • Establish facilities for archiving case and clinical samples • Establish information databases
Monitoring and Surveillance	• Conduct sustained time series measurements of the biotic, chemical, and physical environments impacted by HABs • Strengthen early warning systems • Identify metabolites that contribute to animal and human illnesses and metabolic pathways for detoxification • Develop methodologies for rapid field-based detection of HABs and toxins
Algae Physiology and Molecular Biology	• Develop whole-genome sequences for selected HABs to guide physiological and behavioral studies • Identify genes linked to toxin production • Determine inter- and intra-specific variations in physiological responses • Strengthen understanding of life histories, ecophysiology, behavior, and in situ growth and death rates
Ecological Interactions and Impacts	• Trace toxin impacts and amplification through the food web • Quantify kinetics of toxin uptake, accumulation, and retention • Elucidate effects of eutrophication, over-fishing, and climate alteration on HABs
Human and Animal Health	• Establish standard reporting procedures for HAB toxin incidents • Develop new, cost-effective epidemiological methods appropriate for HABs • Identify susceptible subpopulations • Incorporate algal toxins into water quality standards for drinking and recreational waters
Models and Forecasting	• Develop food web models for fate and effects of toxins • Develop and improve species-specific models that link physical-biological models • Model long term risk of exposure to HAB toxins for individuals and populations • Develop models of socioeconomic impacts and costs of mitigation at local and regional scales
Controls and Mitigation	• Develop effective, environmentally sound techniques to control/reduce HABs and their impacts • Develop early warning systems, response plans, and methods to reduce exposure • Improve coordination of responses across local and regional scales
Training, Education, and Outreach	• Increase awareness of the effects of anthropogenic activities on HAB proliferation • Expand documentation of HAB toxins in drinking and recreational waters • Provide information on HAB toxins to medical practitioners and public health departments • Train more taxonomists in classical and molecular techniques • Develop strategies to assist aquaculturists/seafood farmers to limit crop loss

behavior and economic choices, threaten the quality of our wild and farmed seafood, and endanger human health from exposure to algal toxins.

That HABs are ephemeral and that their initiation remains largely unpredictable has further hampered development of a national program. Over the last decade the HAB community, through the federal programs, has supported the development of monitoring and response programs at sub-national levels, addressing this issue from a state or regional basis. There has been only limited success in developing a nationally coordinated HAB event response program. Highlights to date include the successful operation of event response programs that provide front-line responders the best available scientific expertise needed to assess the likelihood and severity of bloom impacts on our communities and determine whether HAB toxins are related to human and marine species illnesses or mortality events. Specific recommendations and rationales regarding each of the four program foci follow.

Summary Recommendations

The HAB community has begun tackling many of the goals and recommendations described in this chapter. Implementation of HARRNESS will strengthen the bonds already established among the scientific disciplines, allowing for continued progress in addressing bloom ecology and dynamics and their interplay in fisheries and food webs. Such interdisciplinary partnerships will advance research goals for algal toxins and their effects and provide needed attention to public health and socioeconomic impacts. **With broader support made possible through HARRNESS, the HAB community will be able to develop national initiatives, foster national coordination and oversight, and establish critical shared facilities. Over the next decade HARRNESS will allow the HAB community to contribute to and capitalize upon an expected increased pace of scientific discovery in our aquatic systems.**

BLOOM ECOLOGY AND DYNAMICS

Much progress has been made over the past several years in many aspects of bloom ecology and dynamics. In some cases, the linkages between cell physiology and toxicity have become clear. Advances have also been made in understanding the influences of physical processes and other environmental parameters integral to harmful algal expression. Yet many fundamental physiological processes remain unmeasured for most species. New methods of cell detection are becoming more readily available and progress has been made in the identification of selected genes involved in toxin production. Further understanding of the roles of nutrients—both inorganic and organic—in bloom development has been gained. Similarly, the roles of viruses and bacteria are better understood for some HABs. Yet the description of the interactions between HABs and grazers, the characterization of sublethal effects of HABs on community dynamics, and the application of these data in developing predictive models are just beginning.

Organism Detection and Assessment of Harmful Status

Accurate and timely identification of harmful species, as well as any toxins they may produce, is of fundamental importance to most aspects of HAB research and management. Historically, species have been delineated on the basis of morphology, ultrastructure, and life-stage features, as well as by pigment content. Increasingly, organisms are being compared and identified on the basis of molecular markers such as cell surface proteins, lipids, DNA sequences, and toxins, which are now being incorporated into rapid, specific assays to detect and quantify HABs. There is also an urgent and renewed demand for identifying organisms using traditional techniques so that new findings on species diversity, biogeography, and toxicology can be placed in an appropriate and historical context. In the case of toxic HABs, it is now clear that a species' toxicity can vary from high to undetectable levels according to physiological status. Therefore, the presence of cells does not necessarily equate with problematic toxin levels; the integrated detection of an alga and its toxin is essential for evaluating the harmful status of a HAB event.

Recommendations and Rationale

- *Train a new generation of taxonomists who can identify HAB species using both classical and molecular techniques (short term and career path)*

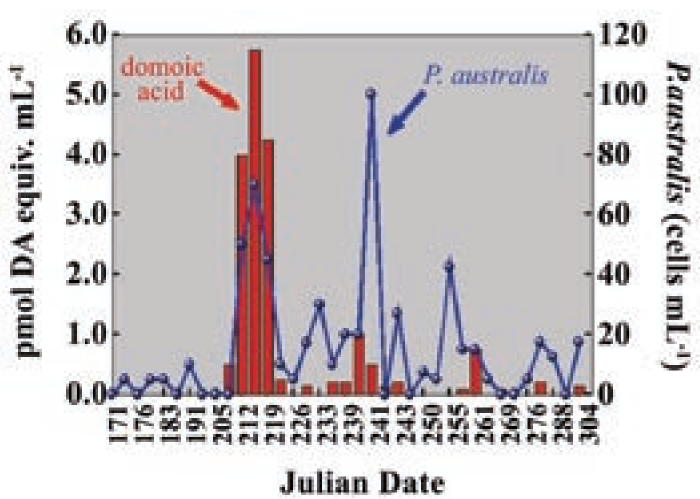
  Accurate species identifications are of fundamental importance to all facets of the ecology and bloom dynamics of HABs. There are very few individuals in the world who have this expertise, and many trained in classical taxonomy are nearing retirement.

- *Establish and provide access to reference materials, including preserved materials, live cultures, genomic data, and toxin standards*

  Reference materials are an essential component of HAB research and monitoring programs, and without access to such standards both the research and resource management communities are constrained.

- *Develop and improve methodologies for the integrated detection of species and toxins, and make them widely available*

  With very few exceptions, most rapid tests for HAB species, as well as some of their toxins, are not available commercially, limiting the extent to which these tools are applied outside of those laboratories directly involved with their development and testing. Development of new, in-water sensors for detecting species and toxins is in its infancy but nonetheless holds great promise for application on autonomous platforms.



Time course of *Pseudo-nitzschia australis* concentrations and domoic acid levels in Monterey Bay, CA during 1996, showing highly variable relationship between cells and toxicity.

Source: G. Doucette.

Harmful Algal Genetics and Physiology

Significant advances in our understanding of the physiology of harmful microalgae have been made in the past decade with regard to nutrient regulation of toxin synthesis and assimilation of dissolved organic nutrients. However, critical information required for model development, such as photosynthesis-irradiance relationships, rates of nutrient uptake, and excretion of organic matter is not available for most species. Studies of growth rates as a function of temperature, irradiance and nutrients, and their ratios are rare. Most harmful species employ a swimming strategy influenced by irradiance and nutrients in addition to ambient temperature and salinity, and these factors influence population growth and community structure in ways that we do not yet understand. The important question of how fast harmful species grow in nature remains largely unanswered. Collectively, our lack of fundamental knowledge concerning the basic physiology and behavior of most HAB species impedes our ability to develop predictive models that will ultimately aid many aspects of basic research and management.

Recommendations and Rationale

- *Develop whole-genome sequences and expressed sequence tags (ESTs) for selected HAB species to guide physiological and behavioral studies*

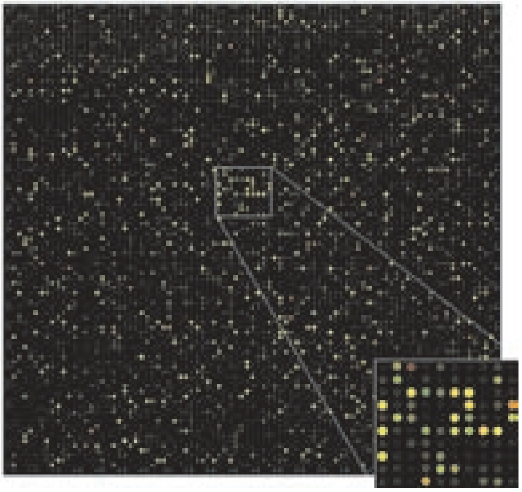
  The availability of whole genome sequences and EST libraries will fuel discovery of key genes that regulate a wide range of important cell functions, such as production of toxins and modulation of behaviors like vertical migration.

- *Determine intra-specific variations in phenotypes and genotypes of laboratory strains and field populations under changing environmental conditions*

  It is now recognized that individual species of HABs can exist in nature as distinct strains that may flourish under different environmental regimes, produce different suites of toxins, or exhibit different behaviors. Increasing our understanding of the extent of such variation is an important element of programs that are characterizing organisms linked to severe ecological and economic impacts.

- *Develop and improve individual-based models of targeted species*

  Modeling the dynamics of individual species in a controlled environment is an important step toward integrating species-specific mathematical formulations into more complex ecosystem-wide models that take into account communities of organisms and environmental forcing.



The new *Karenia brevis* DNA microarray chip enables scientists to track the expression of newly identified genes in this HAB species. As cells progress through different environmental conditions, such as sunlight to darkness, they effectively turn off or turn on the genes that will best adapt them to the current environment. In the microarray pictured above, changes in gene expression are shown as changes in color. Features with a greener coloration indicate genes that were down-regulated when moving from light to dark conditions. Red features indicate genes that were up-regulated, while features that are yellow indicate no change in expression from light to dark. Defining genes controlling development of HABs will provide indicators for bloom progression and a new source of information for accurate predictive models of bloom impacts.

Source: F. Van Dolah.

Community Ecology and Ecosystem Dynamics

HABs ultimately arise from a complex suite of interactions between the causative species and the environment, as well as their interaction with a diverse group of co-occurring organisms. While there is evidence that increasing nutrient inputs from coastal areas can lead to proliferation of some harmful algae, such simplistic 'bottom-up' controls do not adequately explain the genesis of all HABs. Indeed, many interactions involving natural modes of chemical and physical change to the water column, allelopathy, community succession, population dynamics of bacteria and viruses, and complex food web interactions also play key roles in the development, maintenance, and decline of blooms. Our understanding of such complex phenomena is limited, restricting our ability to understand fully and forecast the development of HABs.

Recommendations and Rationale

- *Evaluate the potential impacts of natural versus anthropogenic influences (e.g., climate change, nutrient over-enrichment, finfish/shellfish harvests) on HAB species dynamics, utilizing long-term datasets*

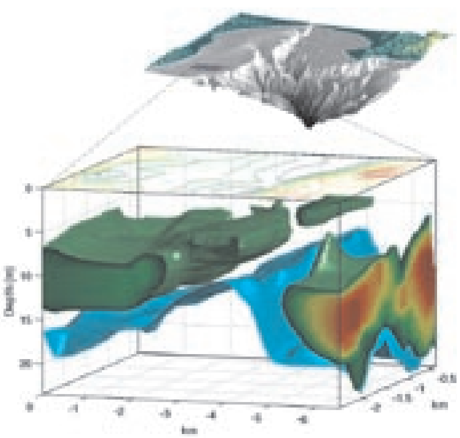
  For some areas and a variety of HAB species it should be possible to establish more robust relationships than are known at present between such factors as land-use practices, disposal of sewage effluents, and natural variations in climate and the observed frequency, duration, and geographic extent of HABs.

- *Conduct sustained time-series measurements of the biotic, chemical, and physical environment on time and space scales relevant to HABs*

  Quantitative field studies on phytoplankton community dynamics carried out over several annual cycles are required to identify recurrent patterns of HABs.

- *Synthesize diverse measurements into coupled physical/ecosystem models that incorporate species-specific growth, loss, and toxin production rates*

  Disparate data streams are now being incorporated into bio-physical models to permit estimates of HAB distributions as a function of regional flow fields and known physiological and ecological characteristics of the HAB species. As autonomous environmental observing systems become widely available and operational in the US, routine data delivery and model projection products could be realized within the next decade.



A 3-D view of a phytoplankton layer (chlorophyll fluorescence) dispersed along a density surface (internal wave; light blue) observed using an AUV survey in August, 2000, in Monterey Bay, CA. The layer of phytoplankton contained *Pseudo-nitzschia australis*, a toxic diatom linked to illness and mortality of marine wildlife. Source populations of organisms that ultimately give rise to HABs in coastal areas may occur offshore and be subsurface, sometimes in thin layers, and therefore are often difficult to detect using traditional ship surveys and even remote sensing. These blooms can be delivered to nearshore areas by physical forcing resulting in sudden increases in toxicity that are unrelated to local growth.

Source: J. Ryan, MBARI.

Prevention, Control, and Mitigation

Management strategies are needed that will prevent (avoid the occurrence of blooms or reduce their extent), mitigate (minimize HAB impacts on human health, living resources, and coastal economies when they do occur), and control (actions that directly reduce or suppress an existing bloom population). Coordinated advancements are required in all of these areas.

Recommendations and Rationale

- *Develop management strategies that incorporate knowledge of interactions between HABs and land use practices, nutrient over-enrichment, other pollutants, and fishing practices (including lack of fishing pressure in marine protected areas)*

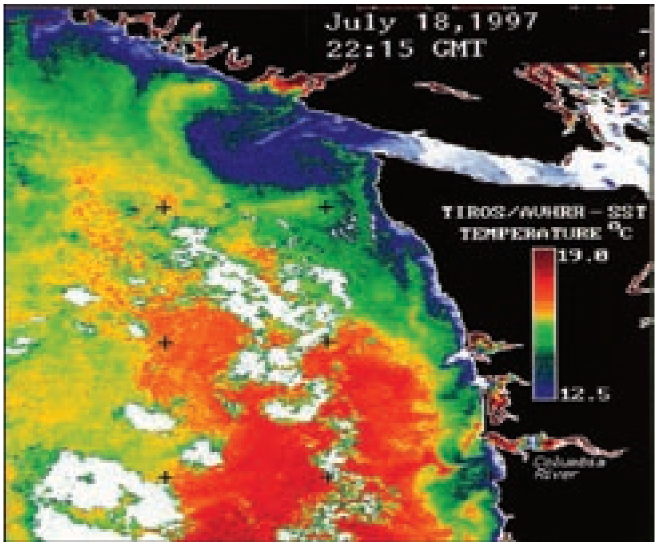
  HABs arise as a result of a complex suite of factors. Some may stem from human activities far from areas where HABs actually occur, or that on the surface appear completely unrelated to HAB phenomena.

- *Establish new and enhance existing early warning systems for detecting HABs as a foundation to minimize their impacts*

  An infrastructure must be developed to assure expanded sensor development and bloom prediction technology, and integration of these sensors with in situ observing systems. These efforts will increase opportunities for testing and refining models, data assimilation techniques, and information dissemination.

- *Develop effective, environmentally sound techniques to reduce/control HABs*

  A number of control and mitigation strategies have been explored in pilot scale studies. Larger scale, interdisciplinary investigations are now required to determine the feasibility and environmental impact of implementing such methods in nature. Assistance will be needed to minimize regulatory hurdles such as permits and impact assessments.



The Juan de Fuca eddy region, located along the Pacific coast between Washington State and British Columbia, is a site where coastal managers are given early warning of harmful algal blooms.

The Juan de Fuca eddy region is a site of persistent upwelling (nutrient enrichment) throughout the summer months. Blooms of toxic *Pseudo-nitzschia* are thought to initiate in this zone. The duration of upwelling and the timing of fall storms are factors believed to influence the levels of toxin that reach coastal razor clams.

The ORHAB partnership monitors seawater at several coastal sites for a rapid increase in the numbers of *Pseudo-nitzschia* and for toxins in seawater that may originate from the Juan de Fuca eddy. The combination of microscopic monitoring of the algae and assessment of cellular toxicity using test strips (Jellett Rapid Testing, Ltd.) has given managers an early warning of dangerous levels of toxins in razor clams.

Source: V. Trainer.

TOXINS AND THEIR EFFECTS

Purified toxins are essential to implement assays and calibrate instruments used to monitor toxins in our waters, seafood, endangered species, and citizens. These tools are required to define both an immediate mortality event, as well as to detect the 'nearly silent,' chronic effects that may affect some exposed groups. Excellent progress has been made in the development of sensitive specific assays; however, toxin standards are still lacking for many of the classes of toxins that impact US coastal waters. Furthermore, purification and characterization of the toxins is often a complicated and difficult task. The continued development of toxin standards and detection methods is needed to provide the front line tools for researchers and managers to characterize the hazards of algal toxins and monitor the extent of toxin exposure.

Establishment of Reference Material Infrastructure

The HAB field has witnessed a remarkable decade of development of new toxin detection techniques, yet the use of these techniques requires both certified reference materials, i.e., toxic matrices in which the purity and identity of the toxin have been rigorously verified, as well as calibrated standards where the concentration of the standard is known. Availability of these standards is the cornerstone for detection method development, monitoring of toxin occurrence, and determination of toxicological properties. Some specialized detection techniques may also require certified or reference material in a special form, e.g., radiolabeled saxitoxin is an essential component for the PSP receptor-binding assay. These materials need to be readily available to all investigators from a common source to ensure consistency and comparability of results between laboratories.

Recommendations and Rationale

- *Improve availability and distribution of primary toxins and their metabolites*

  Only certified reference materials assure reliable and accurate quantitative data on HAB toxins. Production of these compounds should be contracted to various laboratories with the capability and expertise to produce adequate amounts of them for the needs of the HAB community and their invested users. An authority that can administer the distribution of toxin standards needs to be identified or established.

- *Identify or establish an information database for characterization and identification of toxins and metabolites*

  Once these materials have been initially characterized, it is often possible to use the information from characterization coupled with less expensive equipment for routine monitoring, identification, and detection. The supporting information for the full chemical characterization of toxins and metabolites needs to be readily available to all.

Purified toxin reference materials such as these produced by NRC Canada are essential for other toxins found in US waters to predict the impact of HAB events on coastal communities through accurate testing methods.

Photo: K. Nowocin.

Purification of Toxin Reference Materials

Key to protecting human health and economic well-being is the ability to rapidly identify new threats as they appear. The purification of new toxins and their full structural characterization plays a key role in this identification. Historically, toxin chemists have focused on the parent molecules themselves. However, it is now apparent that metabolites of these parent compounds, produced either by the toxigenic HAB species or during the movement of the toxin through the food web, play an increasingly important role in the overall toxicity of the event.

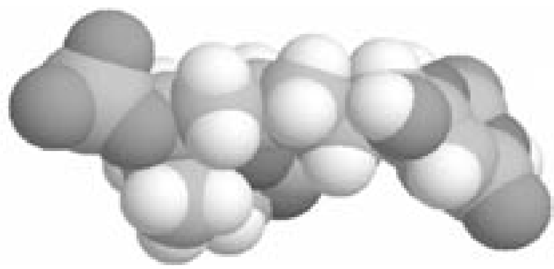
Recommendations and Rationale

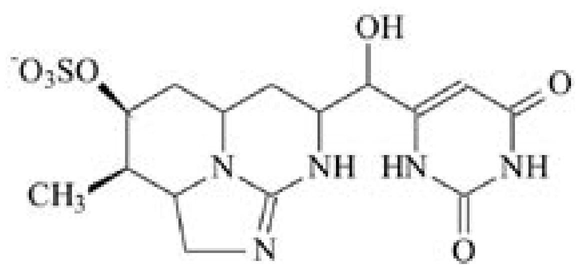
- *Elucidate new toxin compounds and their structure*

  Structure elucidation of new or emerging toxins is critical in order to minimize health and economic losses from HABs.
- *Determine the structures of toxin metabolites and their degradation products*

  Structure elucidation of metabolites will provide essential information about biosynthetic and detoxication pathways, providing biochemical bases for control and mitigation efforts.
- *Establish a facility or facilities for major instrumentation*

  The establishment of regional facilities, similar to the NSF regional Nuclear Magnetic Resonance (NMR) facilities, would help make some of the more expensive instrumentation available to individual investigators.





New Toxins, Novel Problems and Structures

Since the last National Plan, society continues to be challenged with threats from newly identified marine and freshwater toxins. Domoic acid, initially recognized as a seafood contaminant in eastern Canada, has become a major issue for protected species such as sea otters on the west coast of the US. Emerging threats include pinnatoxin which was responsible for a massive outbreak of seafood toxicity affecting over 1,000 people in eastern Asia; gymnodimine, first identified in New Zealand; and spirolides, first detected in eastern Canada. Azaspiracid, identified in the late 1990s in Ireland, had a major economic impact on the oyster and mussel industries of that country. Blooms of cyanobacteria (blue-green algae) in Florida and Australia have impacted drinking water supplies in these areas. These events underscore the constant need for monitoring and the continual development of new techniques for toxin identification.

Cylindrospermopsin, a potent hepatotoxin, currently threatens the safety of Florida drinking waters.

Source: G. Boyer.

Instrumental Analysis and Biological Assays

Our ability to detect and determine the proper response to a toxic event is only as good as our ability to measure the toxin itself. Coupled with the availability of suitable reference material, there is also a need to develop detection techniques that are suitable to the end user. For example, a west coast Indian tribe interested in protecting their members from the consumption of harmful shellfish needs a quick and easy method to determine the total level of toxins in shellfish to be harvested. Their need is very different from that of a toxicologist attempting to determine the rate of formation and effect of toxin metabolites in exposed populations. In the first case, a simple assay of total biological activity will suffice. In the latter case, an analysis of individual toxin metabolites is required. In the last decade, there has been a tremendous advance in developing biological assays to determine total toxin potency, as well as in the application of modern chemical instrumentation to the detailed analysis of algal toxins. These tools need to be transmitted from development to the application stage where they can be used to solve real-world problems.

Recommendations and Rationale

- *Develop new generation detection methods*

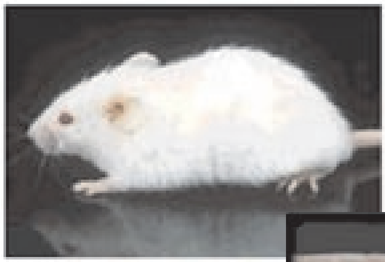
  New techniques for the detection and analysis of toxins are being developed constantly. These need to be evaluated and incorporated into both field and laboratory programs where appropriate.

- *Establish interlaboratory standard operating procedures*

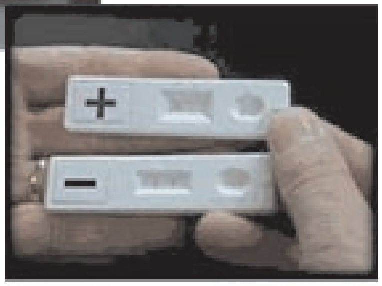
  Standard operating procedures (SOP) are required for toxin analysis in different types of species, tissues, or fluids. Utilization of SOPs will assure comparability of toxin analysis data and facilitate sharing of data during responses to HAB events.

- *Apply a two-tiered system where appropriate*

  Two-tiered systems encompass a biological assay and a confirmatory analytical technique. The initial assay is often used to screen samples for biological activity or presence of a toxin class. In the second tier, individual toxin components are unequivocally identified using a confirmatory analysis. This allows the end user to balance information, cost-of analysis and time needed.



The mouse bioassay has served as the primary testing method for PSP, NSP, and CFP for nearly 50 years.



Portable test kits are important tools used to protect the public health. Unfortunately, test kits are only available for a few of the known toxins. A major impediment to development is the availability of purified toxin standards for testing and validation.

Sources: Jellett Biotek Unlimited and Diatheva.

Biosynthesis and Metabolism of the Toxins

Algal toxins are small molecules, generally less than 1,000 daltons; however, their biosynthesis is a highly complex, multi-step process involving many poorly defined intermediates and multiple molecular species of toxins. This complexity makes it difficult to understand their biological function, and to take advantage of emerging gene-based techniques to define biosynthetic pathways. These toxins, when transmitted through the foodweb, are modified by metabolic processes that promote their elimination and which yield a wider spectrum of molecular species, many of which can have even greater toxicity than the original toxin. It is the combination of these two processes, biosynthesis and metabolism, that results in dozens of variants for a given toxin, leading to substantial difficulty for toxin detection.

Recommendations and Rationale

- *Identify the genes and biosynthetic pathways linked to toxin production*

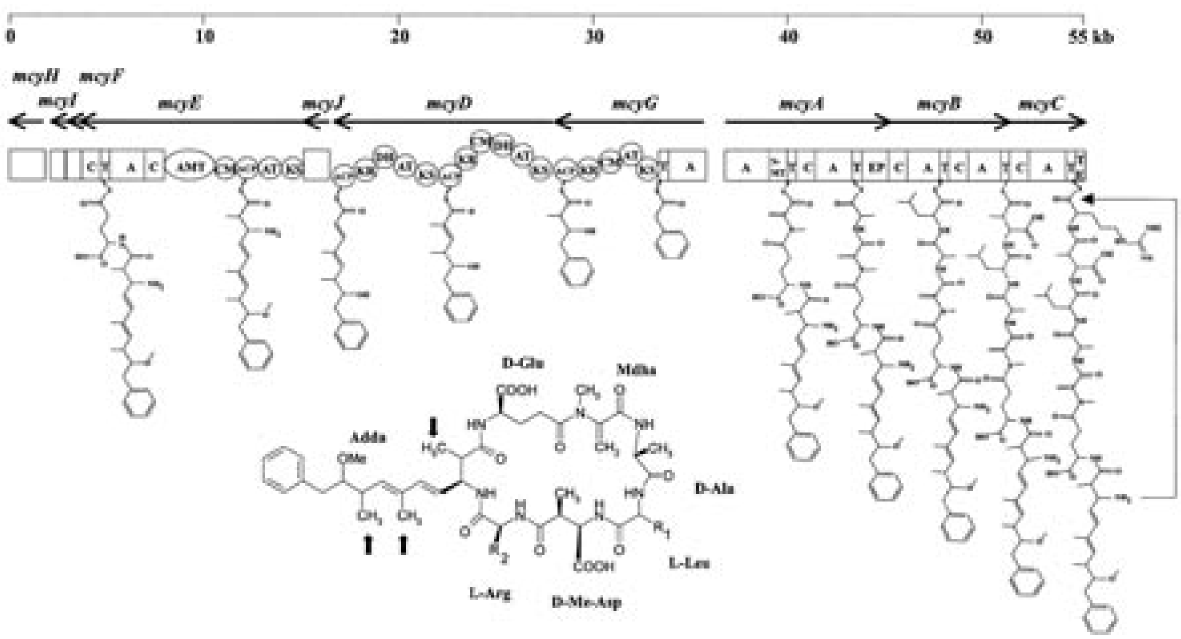
  Enhanced understanding of environmental and organismal regulation of toxin biosynthesis is critical to long-term efforts to manage and mitigate the HAB problem.

- *Identify metabolites that contribute to animal or human illness, and those useful as biomarkers for longer-term exposure*

  Seafood species are known to metabolize algal toxins to conjugated, reduced, or oxidized forms that retain toxicity towards animals and humans.

- *Provide toxicological and pharmacokinetic information on HAB toxins and metabolites*

  This will provide critical information for the development of medical intervention strategies in humans and protected species. Likewise toxicokinetic studies in seafood species will assist natural resource managers in determining algal toxin uptake, metabolism, and clearance rates for commercially important fisheries.



Most algal toxins are believed to be synthesized by a series of enzymes produced by several genes clustered closely together. This figure shows the microcystin synthetase of microcystin-LR (Rouhiainen et al. 2004). Structural variations have been reported in all seven amino acids, but most frequently with substitution of L-amino acids at positions 2 and 4, and demethylation of amino acids at positions 3 and/or 6. About 60 structural variants of microcystins have been characterized so far from blood samples and isolated strains.

Integrated Toxin Effects and Mechanisms of Susceptibility

The initial targets (i.e., ion channels, receptors, etc.) and symptoms of the major HAB toxins are well known. However, between these initial sites of action and the final symptoms, are numerous factors and interactions that modify the eventual outcome. Multiple organ systems are often involved that may lead to chronic diseases affecting health in both humans and entire populations of wildlife species. Toxins may affect the natural signaling processes leading to obvious (i.e., pain perception) and to less obvious effects (i.e., synaptic plasticity). The advent of toxicogenomics and metabolomics will expand our knowledge on the different signaling molecules and their genetic diversity and enhance our understanding of the overall effects of HAB toxins on living animals. However, toxicology must look beyond the effects on otherwise healthy individuals to those populations most likely to suffer the greatest risk. Animal models need to be developed to study susceptible populations, based upon exposure history, sex, inherited genetic traits, developmental stage, and various states of disease.

Recommendations and Rationale

- *Characterize the acute and long-term effects of HAB toxins*

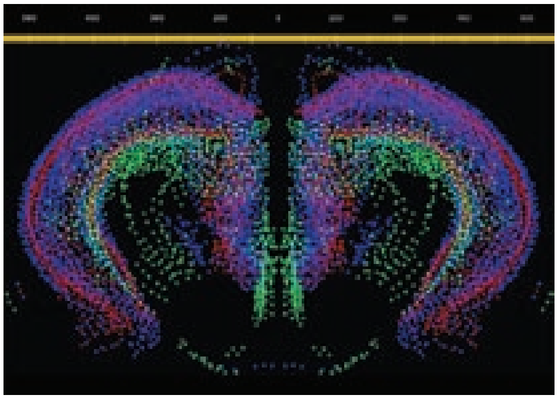
  The primary site of actions for many toxins is well known on a biochemical basis. But what is not well known is how these primary effects are translated into long-term health effects, such as cancer, cardiovascular disease, developmental defects, and neurobehavioral illnesses.

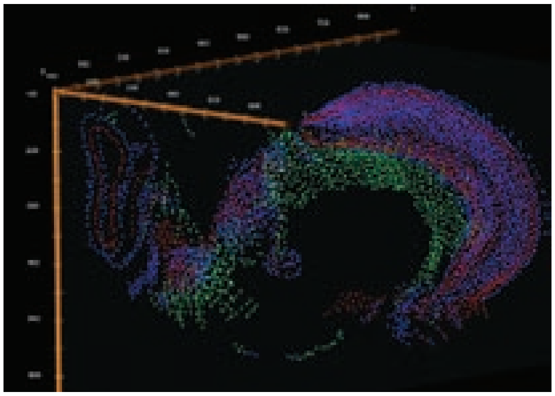
- *Define mechanisms of susceptibility*

  Studies need to be directed to identify special risk groups, such as the very old, the very young, and those with compromised health.

- *Integrate laboratory animal model data and wildlife exposure information with human exposures and disease*

  Development of cross-disciplinary investigations among toxicologists will provide important information about toxic effects. Improved coordination among scientists, veterinarians, physicians, and public health and wildlife managers is essential to predict and prevent human illness.





Domoic acid damage has been mapped in the brain. However, many questions exist on persistent effects on susceptible populations.

Damage to cell bodies (red dots), axons (green dots) and terminals (blue dots) were reconstructed from 65 maps to form a 3-D rotatational image of the mouse brain after domoic acid exposure. In addition to the traditional memory processing regions of the brain, olfactory or smell sensing regions of the brain also sustain heavy damage after exposure to domoic acid. This later effect may result in more significant effects on certain marine animal populations.

Source: J. Ramsdell.

FOOD WEBS AND FISHERIES

There are considerable gaps in knowledge concerning the impacts of HAB toxins upon natural resources, their transfer and pervasiveness in the food web, and how they influence trophic structure. While it is recognized that harmful algae and their toxins can influence ecosystems from the top-down, i.e., affecting predators and influencing grazing, and from the bottom-up, i.e., affecting plankton and benthic communities, there is little knowledge about how these factors influence the structure and stability of major fisheries and critically endangered species. Acute or chronic exposure to HABs and their toxins, either directly or through the food web, puts these populations at increased risk.

Impacts of HABs on Food Webs

Previous research has primarily focused on algal species known to produce toxins dangerous to humans. This emphasis addressed basic information needs to ensure the safe harvest and consumption of fishery resources as well as the safe recreational use of coastal and freshwater environments. By contrast, the potential impact on trophic interactions between toxic or harmful algae and the biotic communities in which they occur remains largely unexplored. Preliminary and observational information suggests that the effects upon aquatic life (including harvested and protected resource species), terrestrial animals associated with aquatic systems, or upon ecosystems are far more widespread than previously recognized. To manage these resources and the food webs that support them, this knowledge needs to be developed or improved significantly.

Recommendations and Rationale

- *Assess sublethal and chronic impacts of HABs on specific life history stages of affected aquatic species*

  The existing, quite limited data suggest differential susceptibility by stage.
- *Assess the effects of chronic exposure to HABs on food webs and economically and ecologically relevant species at the population level*

  Such studies on long-term exposure are nearly non-existent.
- *Develop a better understanding of newly identified HAB species (identification and toxin production)*

  Unexplained disease and mortality events have recently been linked to algal species previously thought to be benign.
- *Identify and quantify synergistic impacts of HABs and their interactions with other environmental stressors*

  Traditionally, HAB impacts have been assessed on a single-species basis. No data exist on synergism with other HAB species, or with environmental stressors such as contaminants and infectious disease agents.
- *Develop food web models for fate and effects of toxins*

  To date, trophic interactions and impacts of HABs on food webs have been ignored.
- *Identify and develop control and mitigation strategies and assess their environmental impacts*

  To date, mitigation and environmentally sound control strategies are limited. Few approaches have been field tested and shown to be environmentally harmless or effective over either short- or long-term scales.

Biotoxins from HABs are transferred throughout the food web when toxic algal cells are eaten by zooplankton, fish, and shellfish that are, in turn, eaten by other animals and humans. While many of these linkages have been recognized in isolated cases, they remain poorly defined and unquantified. Further, effects of the accumulated toxins on the health of marine animals are suspected but not well understood.

Source: G. Wikfors.

Impacts of HABs on Aquaculture and Wild Harvest

Adverse effects ranging from reduced growth and reproduction to mass mortalities may lead to increased occurrence and severity of disease, significant losses in harvestable resources, or to spoiled or contaminated products—outcomes that result in substantial economic damage and adverse health consequences for consumers. Aquaculture operations are particularly vulnerable to toxic and harmful algal events because of the inability to move or protect certain kinds of stock when a HAB event threatens. Information that provides a better understanding of the interactions between harmful and toxic algae and their impacts on farmed fish and shellfish will lead to management strategies that have a direct, measurable, and significant economic benefit.

Recommendations and Rationale

- *Quantify kinetics of toxin uptake, accumulation, retention, and depuration in key species*

  To date, impacts of HABs on shellfish have only been assessed for indicator species and a few commercially important species. Limited data are available for impacts of HABs on fish.

- *Identify toxic and non-toxic modes of harmful action by target HAB species*

  Multiple algal species are responsible for problems in water quality, can cause mechanical damage to animals, and impact the fitness and survival of numerous species in the food web.

- *Identify new, regulatory-appropriate sentinel species*

  Use of new species as early-warning sentinels for HAB events can expand and improve regional monitoring programs.

- *Develop management, control, or mitigation strategies, and assess potential environmental impacts, both adverse and beneficial, of these strategies*

  To date, mitigation and environmentally sound control strategies are limited. Few approaches have been field tested and shown to be environmentally harmless or effective over either short- or long-term scales.

- *Expand and assist existing state emergency response programs to facilitate rapid response (e.g., sampling, sample analysis) and information dissemination for unexpected HAB events*

  The ability to respond quickly to a HAB event is often hampered by geographic distance, knowledge of local resources, access to fresh samples, funding, and availability of knowledgeable personnel.

Different species of shellfish, such as the mussels shown here, can accumulate algal toxins to dangerous and sometimes lethal levels, both in the wild and in aquaculture facilities.

Improved Capacity for Forecasting HABs

Natural resource managers and public health officials need better tools to forecast imminent HAB events so that mitigation actions can be more effectively taken. Improving and expanding the forecasting capabilities offered by remote sensing technologies, such as offshore instrument moorings and satellite telemetry, will provide rapid and spatially broad information. This information will permit monitoring of the environmental conditions that may promote HAB formation, as well as the tracking of HABs as they transit through a region. In addition, expanding the number of sentinel species used to detect HABs and the improvement of state shellfish monitoring programs will result in regional early warning systems that will allow managers to lessen the impacts HABs have on those communities that depend on the affected resources.

Recommendations and Rationale

- *Expand and improve the efficiency and networking of state monitoring programs, including regional programs that encompass shellfish, fish, endangered species, and plankton monitoring components*

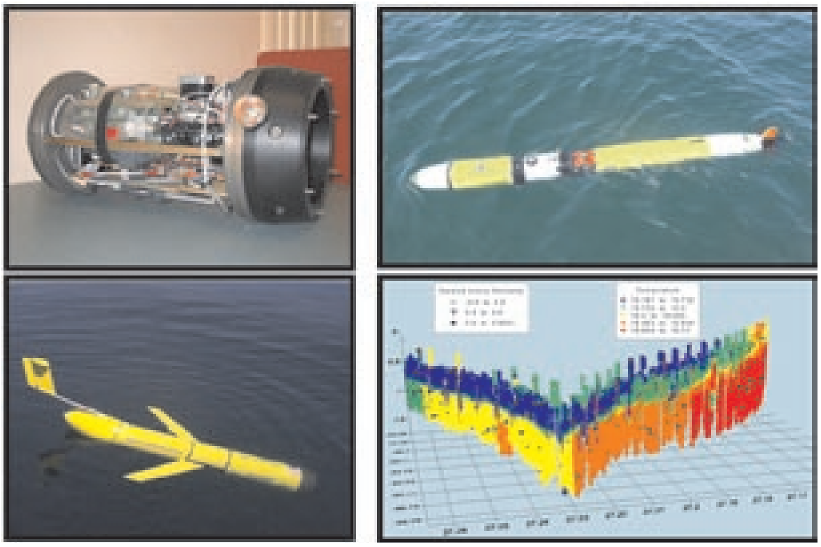
  Currently, each state monitoring program operates independently. Regional impacts can be minimized with better communication and forewarning by responsible personnel.

- *Improve coordination of monitoring/modeling efforts and data mining, both nationally and regionally, and improve use of networking technology (web-based GIS)*

  Considerable funds have been expended on data-gathering, yet the data have not been integrated or disseminated to the user community.

- *Support the development of new and improved technologies for remote cell and toxin detection, and for modeling and forecasting*

  Large-scale technology has made great progress in the detection of surface-level HABs, but improved resolution of satellite imagery, and expanded and networked automated systems for HAB cell and toxin monitoring should be developed. Models of use for predictive purpose should also be developed.



The optics-based BreveBuster (upper left) has been adapted for operation in two classes of autonomous underwater vehicles (REMUS upper right, Glider lower left). This marriage of technologies has yielded a means to conduct unattended surveys of *Karenia* spp. over time scales of days to weeks and spatial scales of meters to hundreds of kilometers. Four-dimensional (space and time) products show (lower right) the distribution of *Karenia* spp. in relation to other measured parameters (temperature and salinity).

Source: G. Kirkpatrick.

Top-down Control and Changes in Trophic Structure by HABs

It is highly likely that a combination of increases in nutrient resources (bottom-up control) and relaxation in grazing (top-down controls) contributes to the increase in the frequency and intensity of HAB events. Eutrophication changes top-down control, as well as providing bottom-up support for blooms. Changes in food web structure attributable to other human influences, including over-fishing, habitat degradation, invasive species, and climate change interact with eutrophication and contribute to global increases in HABs. Better definition of how changes in top-down control may change the occurrence and severity of HABs will provide new, previously unavailable management options for mitigation and control.

Recommendations and Rationale

- *Understand and quantify impacts of grazing, parasitism, and pathogens on various HAB species*

  The potential for biological control of HAB species through the use of pathogens and other mortality agents has not been fully explored and could be a viable option for management of HAB species.

- *Understand how trophic cascades and species interactions impact grazing on HAB species*

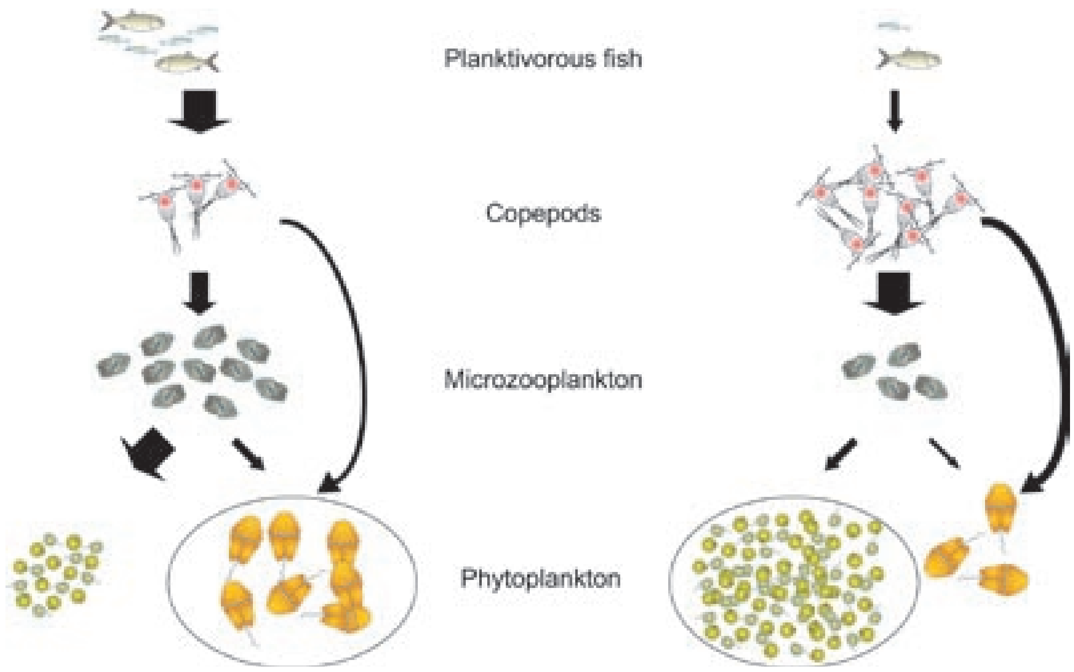
  Amplification of toxins through the food web as a result of trophic interactions is poorly understood and can result in unusual mortalities or sublethal impacts.

- *Elucidate the effects of eutrophication, over-fishing, climate change, invasive species, and habitat alteration on top-down control of HABs*

  Multiple factors are likely to affect or control top-level trophic groups and this will in turn have profound impacts on food web dynamics.

- *Formulate management strategies involving manipulation of top-down controls to mitigate or control HABs*

  An understanding of top-down controls would allow for their use as means of managing or mitigating HABs.



Conceptual diagram of top-down control and effect of trophic cascades on small and large cell-size phytoplankton. On the left, proliferation of baitfish resulting from over-fishing of top predators leads to blooms of large dinoflagellates (circled). Alternatively, on the right, removal of small fish (fishing down the food chain) can lead to blooms of small phytoplankton (circled) such as brown tide.

Source: D. Stoecker.

Impacts of HABs on Higher Vertebrates

Acute or chronic exposure to HABs and their toxins, either directly or through the food web, place certain populations at increased risk. Little information exists about the chronic, sublethal, or lethal effects of bioaccumulated or biomagnified algal toxins, the routes of exposure, and whether such effects render organisms more susceptible to disease. Microalgal toxins and their chronic effects need to be studied at all biological levels and to be recognized as major threats to animal health, sustained fisheries, endangered species, and ecosystems. Long-term effects of biotoxins on the health of aquatic animals include increased susceptibility to disease, immunosuppression, abnormal development, and the induction of tumors. Animals at all trophic levels that are exposed to biotoxins in the long term through their diet may die or display impaired feeding and immune function, avoidance behavior, physiological dysfunction, reduced growth and reproduction, or pathological effects.

Recommendations and Rationale

- *Develop improved detection methods for determination of toxins and toxin metabolites in tissues of higher vertebrates*

  Accurate assessment of the role of HABs in mortalities of higher vertebrates is hindered by the lack of tools and techniques for accurate verification of toxins in tissues.

- *Determine adverse effect levels of HAB toxins in protected, threatened, and endangered species*

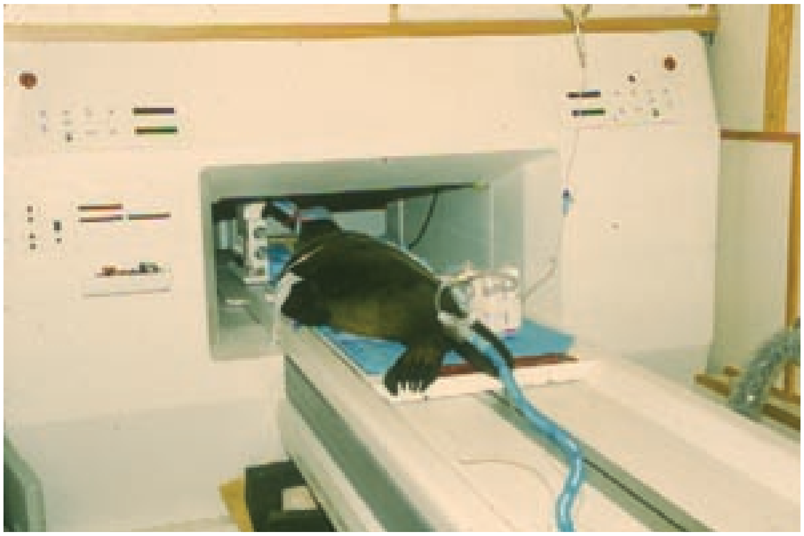
  Acute level impacts of HAB toxins are just starting to be understood; however, there is little knowledge of chronic or sublethal impacts on these populations.

- *Develop toxin-specific biomarkers of exposure and effects for assessing sub-lethal and chronic exposure*

  Animals can be exposed to multiple toxins from a number of HAB species and synergisms could be expected. Therefore, toxin-specific biomarkers can aid in recognizing and separating these stressors.

- *Assess effects of long-term risk of populations to exposure to HAB toxins*

  Currently there is no knowledge about the impacts of widespread or persistent exposure to HAB toxins, nor is there information available about how they are impacting the population dynamics of endangered species. Models need to be developed and integrated biological studies conducted about these key, but less visibly dramatic, effects of HABs.



California Sea Lion undergoing an MRI at UC Davis.

Source: Marine Mammal Center.

PUBLIC HEALTH AND SOCIOECONOMIC IMPACTS

The demand for seafood as part of a healthy diet, combined with globalization of trade and tourism, expands the geographic boundaries for human exposure and subsequent illness as well as those of economic losses beyond historically affected coastal communities. The economic and public health impacts of HABs can be profound. Research, public education, and outreach are needed to assess and address the impacts of HABs on local, national, and global economies, the safety of our seafood, public health, and drinking and recreational water quality.

Socioeconomic Impacts of HABs

Many millions of dollars are spent annually addressing the known HAB-related impacts on public health, commercial fisheries, recreation, tourism, environmental monitoring, and bloom management. Public health impacts account for the largest economic impacts, followed by commercial fisheries and tourism. Even one HAB can be extremely costly. The hidden costs to secondary industries (e.g., food processing or aquaculture suppliers), human illness (e.g., medical care for undiagnosed or chronic illnesses), and decline in consumer confidence (e.g., failure to purchase seafood in restaurants or reserve fishing charter trips) remain unknown.

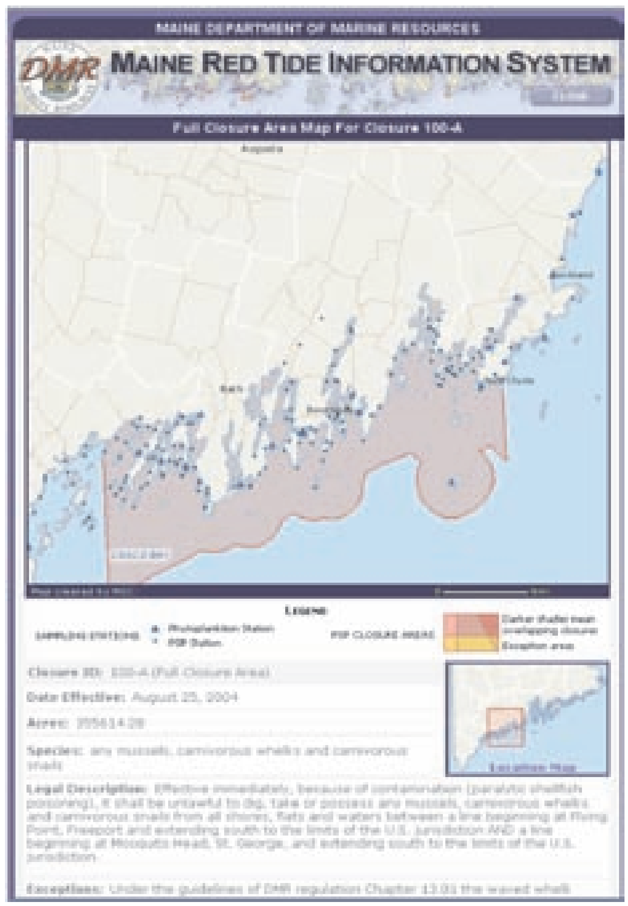
Recommendations and Rationale

- *Compile data and calculate the socioeconomic impacts of HAB events at local and regional scales*

  Data are currently compiled on an informal and non-standardized basis. Methodologies from the fields of public health and environmental and natural resource economics should be applied to estimate the economic effects of HABs and the subsequent modeling technology should be developed for use by local public health, environmental, and natural resource officials.

- *Conduct socioeconomic studies of how user groups will benefit from HAB forecasts at different temporal and spatial scales*

  Several regional models of the formation and fate of HABs are under development, utilizing an emerging network of ocean observing systems. These models will lead to the development of capabilities to forecast bloom transport and severity. Models to assess the economic benefits of these forecasts to coastal communities should be developed and shared with state and local constituencies (or public, environmental, and resource officials).



The shellfish closures in Maine during summer cover an extensive area of the coastline.

Source: http://megisims.state.me.us/dmr_redtide/.

Impacts of HABs on Seafood Safety

Seafood constitutes a significant proportion of the world food supply with more than 70 million metric tons harvested each year. Estimated seafood consumption is 9 kg per person per year in the US. Although an important and popular food source, seafood ranks third on the list of products most frequently associated with food-borne disease. Several seafood-related diseases are caused by contamination of seafood with potent neurotoxins naturally produced by marine algae associated with HABs.

Recommendations and Rationale

- *Incorporate validated and rapid field detection methods into seafood safety testing*

  Rapid field methods will enable industry and public health officials to assess seafood contamination in a timely manner appropriate to the potential hazard and the perishable nature of the food.
- *Identify and coordinate regional laboratory-based facilities that will provide timely, analytical confirmation of seafood contamination*

  Rapid detection methods are typically presumptive in nature and represent a 'first alert' warning system. Confirmatory analytical methods are essential to verify presumptive results. Provision of this service/capability is necessary to protect consumers and maintain confidence in the seafood industry.
- *Identify, expand, and coordinate seafood species identification and geographic origins databases*

  The expansion of national and international trade in seafood has progressed in the absence of information systems for accountability. Genomic or proteomic-based libraries for species identification and geographic mapping are necessary tools for resource management, public health protection, and disease outbreak control.

Ensuring seafood safety is of paramount concern.

Source: S. Shumway.

Impacts of HABs on Public Health

Documented cases of HAB-related poisonings represent only a small percentage of the actual cases that occur. Existing mechanisms for data collection are not only dependent upon the correct diagnosis, but also on reporting of the case to a disease surveillance program. Under-diagnosis and under-reporting of even well known HAB-related illnesses are common.

Recommendations and Rationale

- *Define which algal toxin exposures have long-term effects*

  Exposure to algal toxins through the consumption of food and water and the breathing of aerosols can cause acute illness in humans and animals that can be medically addressed by symptomatic treatment. However, long term health effects may be associated with chronic, low level exposures. Treatment alternatives for mitigating these long-term symptoms are limited.

- *Develop tools for clinical diagnostic support*

  Currently, there are no readily available tools or methods for diagnosing HAB-related illnesses in humans or other animals. Thus, accurate diagnosis, treatment, and prognosis are impossible.

- *Improve surveillance of human exposure and disease*

  Surveillance is the on-going systematic collection of data used to inform public health decisions. Currently, information about the extent of exposure and prevalence of HAB-related illness is limited.

- *Develop a system for archiving case and clinical samples*

  The analysis of archived animal samples has historically been used to define exposure and disease in animal populations. Similar archives of human samples will allow investigators to develop and test new techniques, identify previously uncharacterized toxins, and develop assays for exposure and biologic effect.

- *Develop new, cost-effective epidemiological methods that are appropriate to HAB issues*

  Traditional epidemiologic methods are labor intensive, expensive, and time consuming. Identifying and applying alternative methods for data collection and analysis will enhance our capacity to develop primary public health and prevention activities.

- *Identify susceptible populations based upon physiological traits, behavioral factors, socioeconomic status, and cultural practices*

  Multiple factors, including age, gender, baseline health, brain reserve capacity, psychological status, risk perception, cultural practices, genetic predisposition, collateral exposures and duration and severity of illness contribute to disease expression.

- *Develop early warning and detection mechanisms to prevent exposure*

  The ultimate goal of public health is the primary prevention of exposure and disease. Coordination and communication among the public health, fish and wildlife, and environmental communities can improve our capacity for timely public health action.

Based on mortality figures from recent outbreaks, children are more likely to be poisoned by saxitoxin than adults. The effects of saxitoxin and other shellfish toxins such as domoic acid on childhood development and learning are of great concern to local communities.

Photo: Government of Canada.

Recreational and Drinking Water Impacts

Cyanobacteria are a component of freshwater and marine ecosystems. The abundant growth of cyanobacteria in reservoirs contributes to significant practical problems for water supplies. Moreover, many of the known cyanotoxins (e.g., microcystins, saxitoxins) have been associated with deleterious human health effects. The full impact of the presence of these toxins on contaminated water bodies remains unknown.

Recommendations and Rationale

- *Expand and improve documentation of the occurrence of algal toxins in drinking and recreational waters*

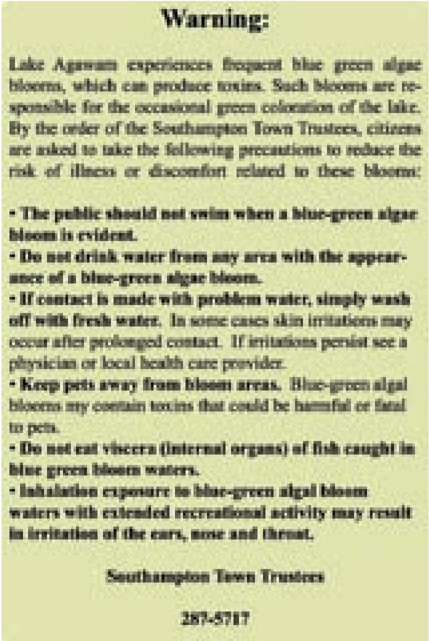
  Surveys conducted in the US have identified algal toxins in drinking water and recreational waters. However, there is no on-going systematic monitoring program in place to identify high-risk areas.

- *Develop short-term response plans for algal toxin-contaminated water to protect public health*

  There is very limited information about both the occurrence of algal toxins in water and their health impacts. However, water-quality related decisions still need to be defined, particularly on a local level.

- *Incorporate algal toxins into water quality standards for drinking and recreational waters*

  Water utility managers and those responsible for recreational water quality do not have water quality standards on which to base decisions for safe levels and practices. Therefore, water users are not necessarily protected from exposures and subsequent related health effects. Water resource managers need water quality guidelines that, based on the current scientific knowledge, protect public health.



Warning signs such as this posted at a lake on Long Island, NY caution local communities of frequent blooms of cyanobacteria that turns the lake waters green and produces toxins that endanger recreational users.

Source: C. Gobler.

CHAPTER 5

Moving Forward: 'HARRNESSing' the Resources and Energies of the HAB Community

The HAB scientific and management community now envisions a new structure to ensure that research and management activities are coordinated and responsive to the changing nature of HABs. This new strategy incorporates the recommendations of HAB scientists, managers, and educators. It integrates the needs and input from groups ranging from scientists to coastal residents to our government's decision-makers. It fosters multidisciplinary investigations, products, and services responsive to the national priorities. And it integrates with initiatives outside the HAB field.

HARRNESS is a proposed organization of HAB-related initiatives and programs that identifies and addresses current and evolving needs associated with HABs and their impacts. HARRNESS is a framework, not a funding program. It allows for multiple levels of participation and involvement. While identifying and highlighting disciplinary priorities and requirements, it lays out the multiple pathways by which these priorities may be achieved.

HARRNESS is envisioned to function with a number of distinct components. Some of these components, such as research funding mechanisms, are in place, but may require additional funds or new directions. Other components will need to be established for this purpose.

HARRNESS wll be coordinated by a National HAB Committee; the research will be conducted at a range of scales and investments will be made in infrastructure.

The National HAB Committee

A core component of HARRNESS is a National HAB Committee (NHC). The NHC will be a rotating, interdisciplinary group of individuals representing priority research areas. The mission of the NHC is to facilitate coordination and communication of activities for the US HAB community at a national level. Desirable characteristics of the composition of the NHC are that it is (1) community based, (2) recognizable to the agencies, (3) knowledgeable about organizational issues, and (4) scientifically and technically credible.

It is recommended that the initial composition of the NHC consist of the members of the HAB National Plan Workshop Steering Committee. The NHC will then establish procedures for appointment of a chair, an executive body, and rotation of members. One of the initial tasks of the NHC will be to set up a plan for regular meetings and to establish a presence on the world wide web.

Facilitating Partners

The fragmentation, and in some cases isolation, of agencies, programs, or scientific disciplines involved in HAB research can limit overall progress within the field. The NHC will facilitate implementation of the

HARRNESS plan among the many agencies, groups, disciplines, and initiatives with shared HAB goals and objectives.

The NHC of HARRNESS must vigorously communicate with the federal, state, and international agencies, and with programs outlined in Chapter 2. One important mechanism will be through representation (ex officio or otherwise) of personnel from federal agencies involved in HAB research, such as NOAA, NSF, EPA, USDA, NASA, ONR, FDA, DOI, NIH, and CDC, on the National HAB Committee. Also of interest and importance is the identification and inclusion of groups currently responsible for proactive program development; for example, initiatives that will link land and watershed observations to biophysical responses in receiving waters of rivers, estuaries, lakes, and the coastal ocean, such as GOOS, ORION, NEON, CLEANER, and CUAHSI. Still others include initiatives focusing on micro- and nanotechnology development where assays and detection are being miniaturized to such an extent that huge detection arrays may now be possible with hardware developed less than a decade ago. International initiatives specific to HABs, such as the EU–US Program and GEOHAB, must also be represented.

Another role of the NHC will be to solicit input from, and to provide feedback to, the broader group of state and local governments involved in HAB issues. In some cases, direct representation on the NHC may be appropriate; in other cases, clear lines of communication, such as via the web or targeted listservers, may suffice.

The NHC should ensure that non-public interests are also considered. The HAB community will depend on academic-private partnerships in the development, testing, and application of new instruments and technologies. Industrial expertise may be necessary on the NHC, or may be sought through other channels.

Stakeholders

As a coordinating body, the NHC must also consider the needs of those who require or seek HAB-specific information for a range of purposes. These stakeholders range from well-established national bodies to local citizen groups. Efforts must be made to ensure that monitoring efforts in water quality and public health are engaged as HARRNESS develops. At the national level, direct communication with organizations such as the Interstate Shellfish Sanitation Conference (ISSC) may be required. In other cases, outreach efforts to societal organizations may suffice. These may turn out to be regional organizations like the Chesapeake Bay Foundation or HAB-specific citizens' groups like START in Florida. They could also be industries with specific resource or water quality interests, such as aquaculture or mariculture corporations, water intake processors (for drinking or cooling), or animal husbandry/agricultural organizations interested in effluents or loadings from their operations. Through compilation of regional priorities on HAB impacts, stakeholder participation will be identified and their interests represented.

Activities of the NHC

1. Facilitate implementation of HARRNESS and garner support among all stakeholders;
2. Foster communication between all components of the HAB community;
3. Interface with related national and international initiatives, such as GEOHAB, IOOS, GOOS, CUAHSI, CLEANER, NEON, and ORION;
4. Form ad hoc technical advisory committees as needed to address issues or requests; and
5. Raise the visibility and understanding of HAB issues nationally.

Program Foci

In recognition of the multiple research objectives previously described in Chapter 4, HARRNESS will focus on four primary areas:

- ***Bloom Ecology and Dynamics***
- ***Toxins and their Effects***
- ***Food Webs and Fisheries***
- ***Public Health and Socioeconomic Impacts***

Achieving the goals of the program foci will require:

- Targeted Investigations
- Regional Studies
- Inter-regional Comparative Investigations
- Mitigation and Control

Program Approaches

Each of the Program Foci shares a need for a suite of Program Approaches—a set of management and research activities. Program approaches are directed at various scales of the HAB problem, from highly focused studies, to regional and inter-regional scale investigations, to policy-making and resource management activities. These approaches provide a network for integrating the expertise represented by the different Program Foci, and for ensuring a more cohesive response to the HAB problem both nationally and internationally than was possible previously.

The integration of Program Foci, and the assurance that these efforts respond to the needs of the Stakeholders, will require investigations at multiple levels with a range of objectives. The full plan for implementation will require further community input.

Infrastructure

Coordinated HAB community development and progress in HARRNESS is assured through an **infrastructure** element that includes activities and services required by all program foci. The HAB community is committed to providing the research, management, and education communities with the necessary resources, including reference materials to data-visual products and shared facilities. Toward this end, several critical community-wide activities must be established:

1) **Provision and quality assurance of reference materials.**
2) **Access to data management and data visualization tools.** As a national research program, HARRNESS must be able to effectively manage its own data as well as provide access to other related information about bloom species and events.
3) **A national education and outreach effort.**
4) **Shared facilities.** The HAB research community has developed many regional capacities to collect HAB and HAB-related information but sustained support for these facilities is required.

In-depth discussion of these four infrastructure components follows at the end of this chapter.

Implementation: Next Steps

To accomplish the objectives and recommendations of the HAB community and this proposed National Plan, a combination of existing, restructured, and new programs will be required. New or modified agency partnerships will clearly be required, as the priorities of some agencies have changed over time. A few examples of program modification and development are given here, along with some recommendations for further action. These are offered as suggestions, recognizing that other mechanisms may be developed that accomplish the same goals.

Existing Programs

At its inception a decade ago, the focus of the ECOHAB program was ecology and oceanography. Over time, the coverage has expanded and now includes topics such as mitigation and control of HABs, toxin chemistry, and economic impact analysis. This evolution reflects in part the changing mandates of some of the agency partners. A re-evaluation of the direction and priorities of this program within the context of other HAB programs and needs is thus recommended. One possibility is to have ECOHAB emphasize some of the priorities of the international GEOHAB program, such as regional and inter-regional comparative studies of upwelling systems, eutrophied systems, and fjords and embayments, or the development of instrumentation and modeling capabilities in support of HAB research and monitoring.

The NOAA National Center for Coastal Ocean Science created the Monitoring and Event Response for Harmful Algal Blooms (MERHAB) program to help coastal states respond to HABs by partnering with regional management and scientific institutions. MERHAB projects are enhancing existing water and shellfish monitoring programs with new technology allowing for proactive detection of coastal HAB events. This program fills an important niche that is not covered by ECOHAB, and thus should continue without major modifications.

The new Oceans and Human Health (OHH) initiatives of NIEHS/NSF and NOAA are being enthusiastically received by the scientific, management, and public health communities. As described in Chapter 2, the OHH initiatives fill another important niche by addressing the public health aspects of HABs. Although it is too soon to evaluate the efficacy of these programs, it is noteworthy that program resources are sparsely divided. For example, the NOAA OHH program focuses on marine toxins and infectious diseases, chemical pollutants, coastal water quality and beach safety, seafood quality, and sentinel species as indicators of both potential human health risks and human impact on marine systems and marine natural products. In addition to funding centers, the NOAA OHH Initiative includes an External Grants Program, Internal NOAA Awards Program, Distinguished Scholars and Traineeship Programs and Outreach and Community Building Activities. A number of recommendations have been suggested by the HAB community to further enchance the OHH efforts. These include: 1) Increase the number of OHH centers through the NIEHS/NSF program; 2) Expand NIEHS/NSF HAB research funding to allow individual investigators to obtain independent funding to work with existing centers or on OHH issues without any center affiliation; and 3) Enhance coordination between NOAA OHH centers, the NOAA extramural OHH research program, and the NIEHS/NSF COHH program.

New Programs

Even with such actions, a number of the recommendations of HARRNESS are not adequately addressed by existing programs. As a result, the HAB community needs to work with Congressional staff and agency program managers to create new programs where appropriate.

For example, a separate program on HABs and food web impacts could focus resources on this important topic area in a way that is not presently possible through ECOHAB. Chemistry and toxicology of HABs, the basis of the adverse consequences from HABs, receives only piecemeal funding through support of other HAB efforts and requires focused attention and perhaps its own targeted funding initiative. Likewise the practical aspects of HAB prevention, control, and mitigation are presently inadequately included in ECOHAB. A separate program can be justified that does not draw funds from or compete with important, fundamental studies of ecology and oceanography. Recognizing this, Congress has mandated a separate program for prevention, control, and mitigation in the legislation reauthorizing the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA). The strong Congressional support behind this program element is further seen in a section of HABHRCA that directs NOAA to "identify innovative response measures for the prevention, control, and mitigation of harmful algal blooms and identify steps needed for their development and implementation." Focused programs on these topics are thus recommended in support of HARRNESS.

With the exception of the Great Lakes, which fall under NOAA's jurisdiction, freshwater systems that are impacted by HABs have not been comprehensively addressed in ECOHAB, MERHAB, or the OHH HAB programs. These phenomena are, however, an important focus within the HABHRCA reauthorization, and within HARRNESS, and therefore targeted funding initiatives are recommended. Once again, these need to be separate initiatives that do not compete with funds or resources from the marine HAB programs.

In this context, it is clear that the US National Office for Marine Biotoxins and Harmful Algal Blooms will need to address freshwater HAB issues at all levels. A new name for the office will also be needed to account for this expanded purview.

The coordinating structure, research foci, and infrastructure of HARRNESS will require considerable discussion among the community to fully implement the recommendations put forth. **The detailed steps required for program implementation are beyond the bounds of this report. As a result, the NHC will be charged with preparation and distribution of an Implementation Plan for HARRNESS. The Implementation Plan will further prioritize the recommendations of HARRNESS and specify the steps and associated funding mechanisms to accomplish these goals.**

Reference Materials

Repositories or facilities where collections of resources are deposited for safekeeping and can be retrieved represent an essential infrastructure element to support the entire HAB community. A portfolio of integrated repositories is required for the next decade. Such facilities should maintain clonal cell isolates, genetic material, animal and human tissue samples, purified toxins and reagents, and informational databases on toxins and the organisms that produce them. These repositories may exist at different physical locations and could consist of several databases linked by a common search engine. Each repository will need sustainable funding support in order to maintain consistency and availability of resources.

These reference materials would be used by researchers, managers, and educators to characterize toxins, develop molecular probes, and train volunteers to recognize different HAB species. HARRNESS promotes the development of new facilities, like the following widely recognized examples, to broaden community access to reference materials.

A repository of probes for specific HABs should provide certified nucleic acids for identification of algal species. Such a repository would maintain samples of lectin, antibody, and nucleic acid probes, as well as provide certified living HAB cultures, preserved field specimens, and preserved and lyophilized clonal cell isolates. The repository would continue refinement of probes and assays for use on biogeographically dispersed strains to eliminate potential cross-reactions with non-target species and non-reactions with intended target species.

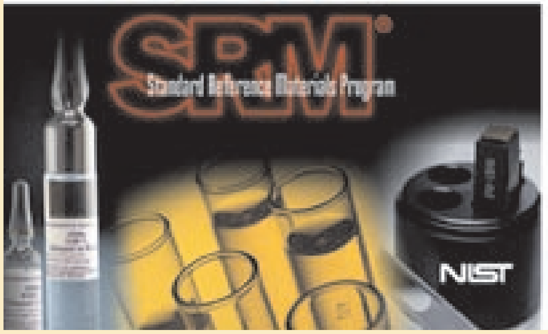
A HAB tissue bank is needed to house frozen and preserved biological samples from HAB events, e.g., tissues and body fluids from marine mammals, birds, and fish. The bank would retain both intoxicated and uncontaminated control samples. These tissues are critical to verify new techniques, to detect and quantify toxins, and will allow retrospective analysis of HAB events as technology improves.

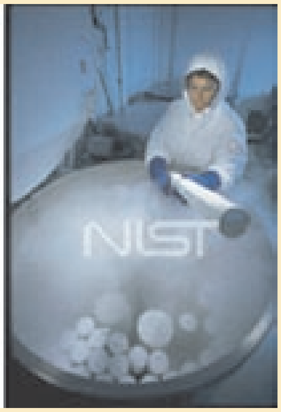
A toxin reference material repository would meet the widely recognized and critical need for readily available and certified toxin standards. This repository would provide certified reference material for methods development and instrument calibration, as well as coordinate with the HAB tissue bank to provide toxin standards in sample matrices. The toxin reference material repository would also link with the integrated databases to provide up-to-date information on protocols and methods for toxin analysis, as well as information on metabolite formation and pharmacokinetics. Resources and reference materials must extend beyond just the primary toxins to include metabolites and their variants.

The National Institute of Standards and Technology offers opportunity for establishment of repositories for HAB reference materials.

NIST supports accurate and compatible measurements by certifying and providing over 1,300 Standard Reference Materials with well-characterized composition or properties, or both. These materials are used to perform instrument calibrations in units as part of overall quality assurance programs, to verify the accuracy of specific measurements, and to support the development of new measurement methods.

Source: http://www.nist.gov/.





The NIST Biomonitoring Specimen Bank stores thousands of tissue samples, including human, shellfish, seabirds, and marine mammals for monitoring long-term pollution and health trends.

Data Management

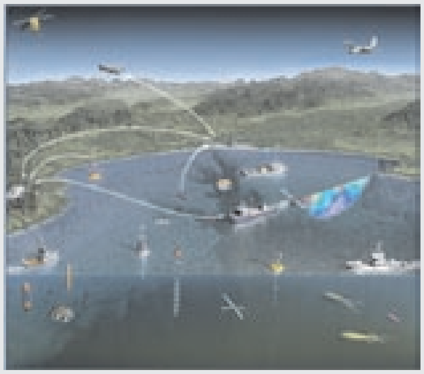
Easy exchange of data is a key to the building of strong and successful relationships between the HAB community and its **Facilitating Partners**. Data management plans known as Data Management and Communications (DMAC) (http://dmac.ocean.us/dacsc/imp_plan.jsp) should be adopted by the HAB community as a central part of its data management activities. The developing DMAC structure for information reporting and distribution provides the integration capabilities needed by collectors and users of HAB data.

The HAB community should engage in developing the DMAC plan to ensure that its needs are met by developing data conventions and accessibility functions. The following planned DMAC elements require HAB community input: assembling metadata opportunities using Federal Geographic Data Committee formats (FGDC descriptions) and expanding opportunities such as search capacity (data discovery); transporting data, assuring seamless access and retrieval; on-line browsing for data assessment; a data visualization/interaction capability permitting virtual applications (e.g., ArcIMS); and data archives for secure storage and retrieval.

The DMAC provides immediate benefits to the HAB community. First, DMAC provides a formal data management strategy for the HAB community and a solid information technology foundation for future national and international data distribution and access. It also insures credibility of the HAB research and data products within the larger oceanographic and Integrated Ocean Observing System (IOOS) communities. IOOS also benefits substantially through broadening the types of information it supports in that basic suites of oceanography and meteorology measures are simultaneously assembled to help explain/define potential mechanisms for HAB initiation, transport, and landfall. Such information is ideal for users along the coasts protecting living resources, local economies, and public health.

In the Gulf of Mexico, an effort involving the HAB and IOOS communities provides a case study that should be replicated in other regions or expanded to meet the needs of the US HAB community. The Gulf of Mexico HAB community and the developing IOOS regional associations in the Gulf of Mexico and the Southeastern US have an existing infrastructure in the Harmful Algal Blooms Observing System (HABSOS). The modular approach of HABSOS includes data requirements for each of the following disciplines: oceanography, meteorology (buoys and coastal weather), remote sensing, model output, river gauges, HAB cell counts, aquatic mortalities, public health, shellfish management, volunteer sampling, event reports, and foundation and state specific data.

Ultimately, integrated databases should be made available to users. Databases should include HAB species profiles, such as geographic origin, isolator, growth medium or media, salinity and temperature tolerances, light microscopy and scanning electron microscopy images; chemical information on toxin standards, toxin structures, metabolites, and pharmacokinetics; and genetic information including HAB species genomes, unique identifying sequences for species identification, toxin production, and markers for bloom dynamics. These databases should provide multidimensional graphical viewing of data and should be integrated with search engines and online workrooms.



Several regions now have IOOS systems in place. Future regions are planned. Such IOOS coverage would be of great benefit in observing, monitoring, and ultimately predicting HABs in these regions.

Source: MBARI, MUSE 2000.

The Integrated Ocean Observing System (IOOS), the US components of the Global Observing System, combines global/basin scale observations from satellites with more local efforts, focused on observing and quantifying land-based inputs, more and different variables, and greater spatial and temporal resolution of observations.

Education and Outreach

A primary goal of the National HAB Educational Outreach Program is to **maintain and disseminate information** about HABs to ensure accurate knowledge, attitudes, and perception. At present, the US National Office for Marine Biotoxins and Harmful Algae, located at the Woods Hole Oceanographic Institution, has provided a national focal point of HAB education materials for more than a decade. The US National Office serves as a central clearinghouse for HAB-related information, maintains national directories of experts, and organizes national workshops and symposia. Sea Grant provides outstanding regional support with programs in the 30 coastal states that work with universities and state agencies and has HABs as a priority topic for outreach and education activities. Sea Grant extension officers facilitate outreach to many HAB scientists and research projects and offer education programs for undergraduate and graduate students, teacher training, K-12 curriculum development, and career-building fellowships.

With HARRNESS, efforts on education and outreach should produce even greater community awareness of HABs and a resurgence of stewardship of coastal ecosystems. Information should be developed in forms that are easily accessible and understandable to a variety of age and interest groups. This information must also be provided in formats that the community can use in meaningful ways. Finally, community experiences should be integrated and shared through regional centers and networked nationally and globally. The National HAB Educational Outreach Program will:

- Promote active participation of community and school groups in volunteer phytoplankton monitoring projects and ocean education stewardship programs;
- Work with teachers to better understand public school curricula at different grade levels to develop teaching sourcebooks and activities that promote understanding of algae, toxins, food webs, and health;
- Work with industry representatives and regulatory agencies to enhance public awareness of health benefits that foster accurate perceptions of seafood/shellfish safety to reassure consumers of the quality of the seafood products being marketed;
- Develop and distribute easily accessible information about HABs environmental impact and health risks; and
- Provide multiple layers of communication on these subjects spanning local to global communities.

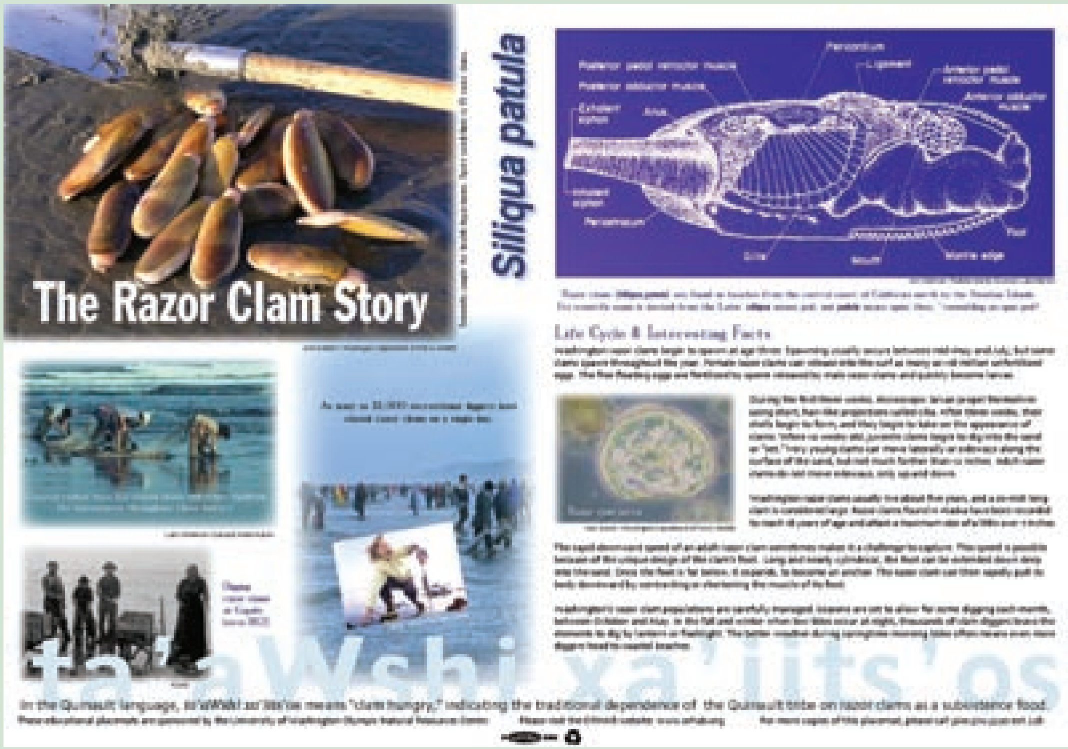
The National HAB Educational Outreach Program should **assure inclusion of traditionally under-represented groups.** HABs most often impact select populations of US residents: those subsistent on local seafood, recreational harvesters, recent immigrants, and those located in remote regions lacking active surveillance programs. Within these populations, the very young, the very old, and those with existing health problems are at the greatest health risk. Small, local coastal communities without diversified incomes are those most likely to suffer the greatest economic hardship. The National HAB Educational Outreach Program will:

- Implement special language or culturally sensitive educational procedures for delivering health messages to underserved or culturally or socioeconomically isolated communities;
- Develop communications focused on unusually susceptible populations such as different age groups, health status, and geographic distribution;
- Provide resources and monitoring programs to communities subsistent on local resources where other options may not be readily available; and
- Listen closely to the needs of small coastal communities to provide quality information and resources to their schools, local organizations, and businesses.

The long-term success of the National HAB Educational Outreach Program requires enhanced teaching and training opportunities to maintain a core of experts and professionals. The Program will promote development of new experts and enhance training of professionals by:

- Working with medical schools and associations to improve physician education in the diagnosis, management, and reporting of HAB related illness;
- Working with universities to maintain support through training and fellowships for traditional taxonomic classification of toxic algae, analytical chemistry of algal toxins, and epidemiologic-based studies of human intoxications; and
- Providing resources for workshops or symposia at national HAB meetings to improve the skills of laboratories, physicians, and public health researchers to educate the media, public health officials, and local communities.

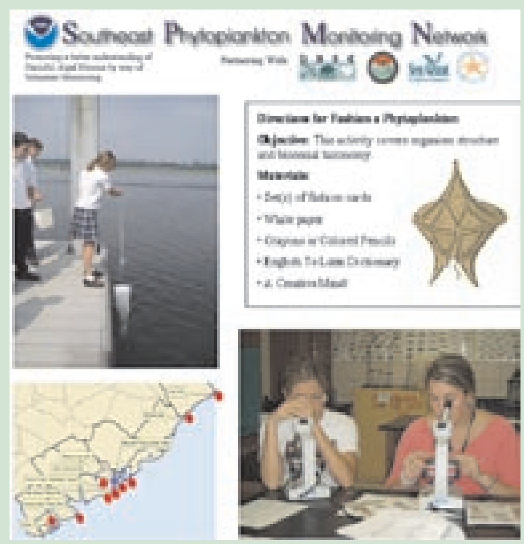
Education and Outreach (CONTINUED)



Washington State's HAB monitoring program has had great success in educating the public about HABs and the need for sustained monitoring and research. One of a series of popular placemat-style posters in high demand by local restaurants, hotels, libraries, and schools.

Source: Olympic Natural Resources Center.

The Bigelow Laboratory for Ocean Sciences hosts an informative HAB educational website: http://www.bigelow.org/hab/index.html.



Although many excellent educational tools and websites are now available, such as this one by NOAA's Southeast Phytoplankton Monitoring Network (www.chbr.noaa.gov/CoastalResearch/SEPMN/), more are needed. Through HARRNESS, new educational materials will be developed and will reach multiple audiences, from students to public health officials and local citizens.

Source: W. Wenke.

Shared Facilities

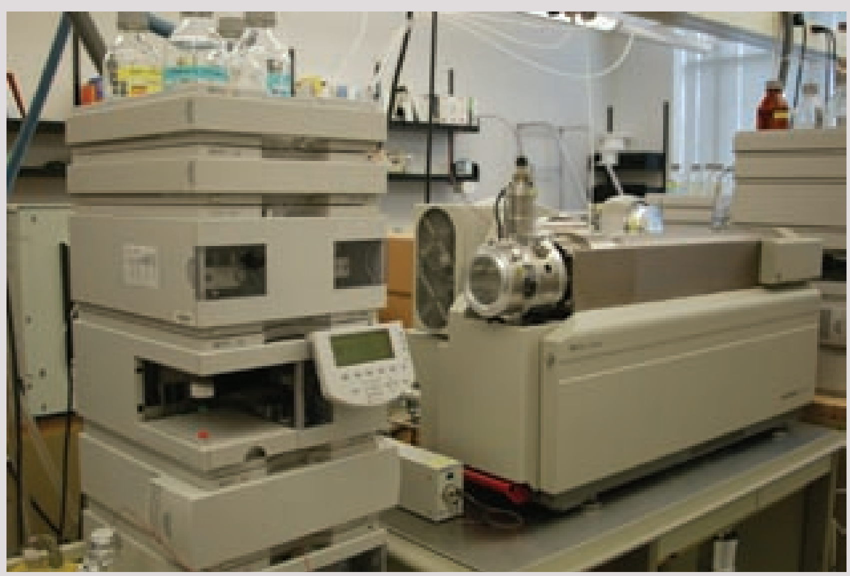
Cultures of HAB species must be readily available and easily distributed among all HAB workers.

Source: CCMP:Bigelow.

The HAB research community has developed many detection and tracking capabilities specific to physical conditions in a regional-scale area, to unique characteristics of individual species, or to particular HAB toxins. Additional and sustained support is needed to expand and link these capabilities beyond their species, toxin, or location-specific purposes. Those laboratories with specific expertise for one or more techniques, species, or toxins must be considered national resources; it is impossible to provide these capabilities for each and every state experiencing HAB events. The identification of the capacities and technologies that can be shared through loans, collaborative efforts, or leases should become an integral part of the infrastructure that supports HARRNESS.

There is overwhelming support for this approach, as resources for acquiring these capacities are limited. Initial discussions have formulated specific needs and mechanisms for assuring development and distribution of standards, reagents, kits, assays, and expertise. In March, 2002, a segment of the HAB community met with state resource managers and private industry representatives to discuss development, application, and commercialization of HAB sensors and techniques for general use by coastal states. Recommendations were made to assure distribution of standardized, at-cost HAB and toxin detection methods to local monitoring efforts (Alliance for Coastal Technologies 2002). This was followed by a meeting of international researchers and managers at the 10th International Conference on Harmful Algae where initial steps were formulated for moving this effort forward.

Additional discussions on options, progress, and community acceptance were held in June, 2003, at the HAB-WATCH Meetings in Villefranche-sur-Mer, France, and at the Second US National HAB Symposium in Woods Hole, MA, in December, 2003. The community desire is for a national capability to identify priority research areas, develop and distribute standard reagents and protocols for community-accepted assays and probes, provide national taxonomic expertise, and assure availability of detection equipment sufficiently expensive to prevent purchase in routine public monitoring programs. Experts identified by the larger community should be available for consultation on individual taxa, toxins, or impacts. Further, developing technologies and their application in regional IOOS field efforts should be a critical Shared Facilities activity to assure routine and inexpensive application of detection methods for user groups. All of these distributed capacities from US laboratories could serve as national resources through a network of HAB Shared Facilities. This network will be the foundation and formal structure that can electronically link recognized, regional HAB institutions, laboratories, and researchers, and enable access to all national resources and experts.



Not all agencies and institutions can afford the equipment necessary for detailed toxin analysis. Central and shared facilities will enable all workers to benefit from new detection techniques.

Source: K. Nowocin.

The US HAB community needs a sustained supply of certified toxin standards and reference materials.

Source: K. Nowocin.

CHAPTER 6

Envisioning the Benefits of HARRNESS

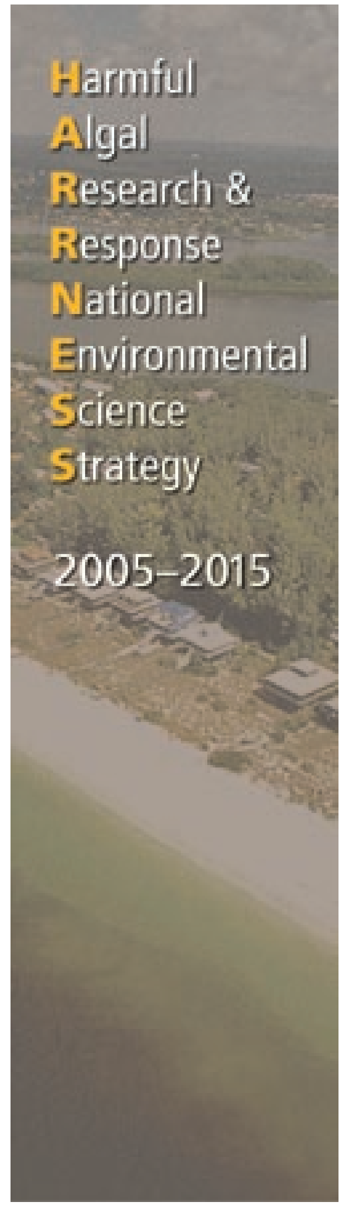
This document has outlined the growing impacts of HABs in the US and the world. It has described the process by which the scientific and public health communities came together to identify the range of needs for research and management. And it has presented the conceptual structure of HARRNESS, the National Plan for HABs for the next decade. The National Plan is not simple, and will require substantial investment. The socioeconomic costs of not addressing these needs, however, greatly exceed the initial investment.

Much has been accomplished since the National Plan of 1993; however, the complexity of the HABs, the toxins they produce, and the increasing number of bloom events are becoming more difficult challenges for managers, and there are more noticeable socioeconomic consequences as populations continue to inhabit our coastal regions. Personal statements from managers and stakeholders are provided throughout this chapter to substantiate the needs to address the challenges that HABs will pose over the next decade.

HARRNESS will address the needs of managers and stakeholders. Benefits range from specific aspects of the currently impaired ecological health of our aquatic ecosystems to threatened public health and economic prosperity of coastal communities. This will be accomplished by the cross-linking of science and management, yielding improved mitigation, control, prevention, and education. This chapter describes eight areas of benefits that address the urgency expressed by managers and stakeholders.

The outcome of these benefits is a future with noticeable improvement in the quality of our coastal environment and the health and prosperity of our coastal residents. HARRNESS has arrived at a time when the leaders of our nation have realized the promise of the oceans and the threats to them and have acted through legislation to build a new governance framework, increase investment in marine science, and instill a new stewardship ethic in all Americans. Accordingly, this chapter concludes with a vision for the future after full implementation of HARRNESS.

Improved Ability to Detect HAB Species and Analyze HAB Toxins



HARRNESS calls for the development of accurate and rapid tests for cells and toxins because they are essential in monitoring and assessing the risks of HABs. HARRNESS also calls for developing sources of toxin standards, cell and tissue repositories, and trained personnel and centers to provide crucial support and data management.

Cell repositories will provide scientists and educators with reliable reference materials. Tissue repositories will provide the required clinical samples from humans and animals for pathologists, veterinarians, and toxicologists, and certified toxin standards will be available for validation of toxin detection methods. From validation of intervention methods to understanding causal relationships and their impacts, the current lack of reference materials has impeded progress. Rapid progress will be made when the infrastructure is in place for shared resources.

What Managers and Stakeholders Are Saying

"We are still in need of reasonably priced, quick, and relatively easy to perform testing methods for real and potential toxins in Maine (ASP and DSP)."

Laurie Bean, Scientist
Maine Department of Marine Resources

"Treatment technologies exist to remove toxins but they are expensive. To minimize that expense, it is necessary to establish the level of treatment needed to protect health. A simple, rapid, inexpensive methodology to measure toxin concentrations must be available to treatment facilities in order to monitor source waters for early detection of toxins and to measure the effectiveness of treatment."

Bruce MacLeod, Water Treatment Plant Superintendent
Bradenton, FL

"From personal experience I can say that in dealing with the sudden onset of a HAB event it is critical to be able to quickly and unambiguously identify the nature and source of the HAB toxin. For maximum effectiveness these crucial first steps rely completely on the availability of certified toxin standards, coupled with detection methods and tests based on the newest technologies. Currently we are badly lacking in some of these areas."

Jeffrey L.C. Wright,
Marine Chemist and Professor of Marine Science
University of North Carolina at Wilmington

"The HAB community has developed a suite of molecular probes, toxin and toxicity assays, and new in-water detection capacities that offer the larger monitoring community new and relatively inexpensive detection and therefore early warning capabilities. Providing these tools and the reagents and operating procedures at cost to this community obligated to protect our coastal residents and living resources is a high priority for the research community. One means of undertaking this effort would be through national centers for harmful algae where the distribution of recently developed and tested detection methods and tools is insured to provide this early warning capacity for regionally specific bloom species…. Much has been done but the momentum for even more rapid development is integral to the community now."

Kevin Sellner, Executive Director
Chesapeake Research Consortium

"Progress has been made on the physical circulation modeling of many of the geographies that have frequent HAB events. These models often operate on regional scales and have an offshore emphasis. They have performed well with regard to simulating and even forecasting circulation events; however there are very few models that routinely and accurately incorporate phytoplankton bloom dynamics into the output, and frequently the models are less accurate in the coastal waters where the shellfish harvesting areas are located. This is important because the coastal waters are where the state management agencies are most concerned about effective monitoring for HABs and models, particularly forecasts, are valuable assets to directing sampling efforts and increasing mitigation options."

Mary Culver
NOAA/NOS/Coastal Services Center

"For the past 11 years that I have been a clam farmer and clam processor in Charlotte County, the cornerstone of my business plan has been water quality and consumer safety. Rapid testing and monitoring are very important tools in that they would allow me to make harvesting strategies that would let me keep a consistent supply of product flowing to my distributors. A faster test would mean shorter closures. Better monitoring would give me enough warning to harvest from some of my other leases that may not be affected by a particular HAB event."

Dan Leonard
Bull Bay Clam Farm, FL

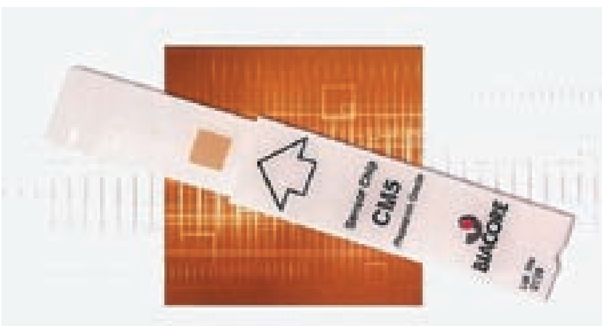
"The more 'tools' we have as managers of these important fisheries, the better job we can do in minimizing the disruptions presented by HAB events. Clearly, the sooner we know of an impending problem with a HAB event, the sooner we can react and inform others."

Dan L. Ayres, Fish and Wildlife Biologist
Coastal Shellfish Lead
Washington State Department of Fish and Wildlife

Improved Capability for Monitoring and Forecasting HABs in a Cost-Effective and Timely Manner

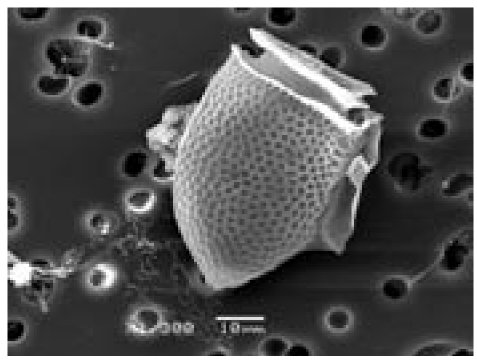
Monitoring and forecasting are especially critical in areas where HABs are an acute or chronic threat to human and ecosystem health and coastal economies. The proposed research described in this plan will utilize appropriate monitoring strategies and models for predicting HAB events and their effects. Monitoring will use emerging and new technologies, sometimes in conjunction with coastal observing systems and models, much like weather forecasts. Data and model predictions will allow planning for human and fiscal resource response and assessing causal relationships of factors leading to HABs.

It is imperative, and a proposed goal of the HAB community through HARRNESS, that HAB species and toxin detection be routine components of rapidly evolving observing systems. As multiple arrays of sensing platforms are linked to measure water and nutrient fluxes from the air, across and beneath the terrestrial environment, to receiving waters of creeks, rivers, estuaries, and the ocean, standard sensor packages will ideally include detection capabilities for HAB taxa and associated toxins.



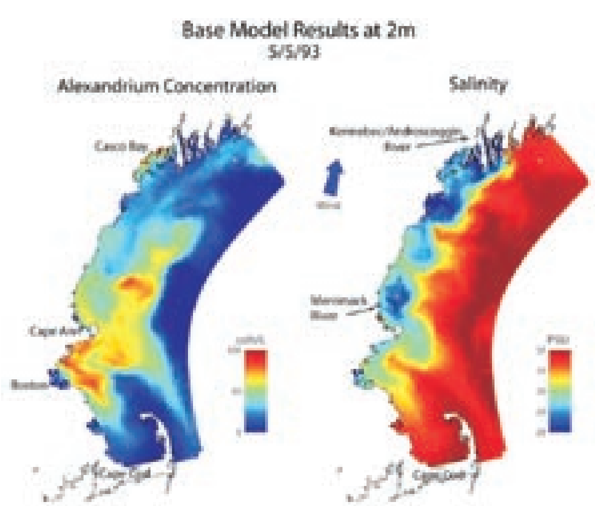
Surface plasmon resonance is a re-usable label-free surface-based detection technology. Hand-held detection devices, such as this one employing surface plasmon resonance for microcystin and domoic acid detection, show promise for further development and application.

Source: Biacore.



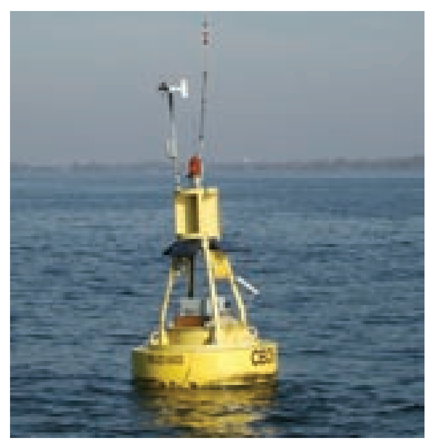
The development of environmental scanning microscopy has filled the longtime desire of scientists to view specimens and processes in their natural state, allowing greater resolution of new HAB species.

Source: S. Morton.



While models have been applied to HABs around the world, one well-studied and modelled bloom is *Alexandrium fundyense* in the Gulf of Maine. The combination of laboratory experiments, field sampling, and models has helped to generate a fundamental understanding of the dynamics underlying growth, transport and landfall of the toxic blooms. Models are being used to test hypotheses concerning bloom initiation and demise, and to explore the utility of the sampling program in generating statistically meaningful data.

Source: C. Stock.



Automated moorings can be equipped with sensors to continuously monitor the temperature and salinity of the water column. The corresponding optical properties can be related to the constituents of the water, including phytoplankton and dense HABs.

Source: www.CBOS.org.

What Managers and Stakeholders Are Saying

"It is imperative that public health officials have the necessary tools to evaluate health threats from exposures to HABs and methods to reduce associated illnesses. These include greater understanding of their toxicology, routes of exposure, and a recognition of high risk groups. We also need educational materials for health care providers and the general public that are accurate, pertinent and understandable."

Andy Reich, Aquatic Toxins Program Coordinator
Florida Department of Health

"It is extremely important that we understand mechanisms of susceptibility of humans to domoic acid poisoning as this will help us understand the magnitude of risk for consumers eating shellfish and will allow us to be more proactive in predicting the potential for and preventing permanent neurotoxicological health impacts."

Elaine M. Faustman, Ph.D. DABT, Professor and Director
Department of Environmental and Occupational Health Sciences
University of Washington, Seattle, WA

"The people in the Caribbean, specifically in the US Virgin Islands, are very much aware of the presence and threat of ciguatera in our waters and fish. It affects the health of our residents as well as that of our visitors, thus potentially injuring our first industry: Tourism. Research and monitoring programs are needed to help control the threat that ciguatera represents to our health and to our economy."

Norma Villaneuva, M.D., J.D., Emergency Room Physician
Roy L. Schneider Hospital and Community Medical Center
St. Thomas, USVI

"As a manager of the Quinault people's shellfish resources, I am most concerned about the human health aspects of these toxins. Without a HAB plan that really pays attention to this remote part of the US, we are left without the invaluable assistance of new research, science and technologies that may help save lives, resources and economies."

Joe Schumacker, Shellfish Biologist
Quinault Indian Nation
Taholah, WA

"In view of the role of harmful algal blooms in marine mammal mortality and morbidity, research is needed to identify and implement management strategies to prevent their occurrence or at least mitigate their effects."

Report on the Consultation on Future Directions in Marine Mammal Research, Marine Mammal Commission, 2004, p. 36.

"A better database and more information on lethal and non-lethal impacts, movement through the food web, role of anthropogenic influences on development of blooms, and biotoxins would better allow federal agencies to develop biological opinions, and prepare better status reviews, environmental impact statements, and recovery/conservation plans. The information is needed to fulfill the Marine Mammal Protection Act and Endangered Species Act."

Teri Rowles
Office of Protected Resources
NOAA NMFS

"Almost certainly, restoration of benthic habitats and grazing communities that include HAB-resistant species will help to mitigate the severity of HABs in some regions. These recovery programs will be much more effective if based upon knowledge gained through directed research than if they proceed by trial and error."

John Boreman
NE Fisheries Center, NOAA NMFS

"We need to begin the difficult task of putting our knowledge to use to reduce HAB events. My amendment requires that an action plan to reduce the frequency and intensity of HAB events be developed cooperatively with the coastal states. This is a difficult task, however the sooner we begin to tackle the problem the sooner we will be able to solve it…. People in my home state of Washington cannot wait for every research question to be answered before action is taken."

Prepared statement by US Representative Brian Baird
Proceedings of the Markup by the Subcommittee on Environment, Technology, and Standards on H.R. 1856, Harmful Algal Bloom and Hypoxia Research Amendments Act of 2003

Improved Protection of Human Health

Accurate knowledge and awareness of fish, shellfish, and water-related illnesses amongst the general public and medical communities will provide a foundation for increased public confidence in the seafood industry. Implementation of HARRNESS will lead to improved medical and epidemiological understanding of well-established acute syndromes, the human health impacts of chronic low-level exposure to putatively safe levels of toxins, as well as the potential impacts of new or emergent HAB related threats. The research required by this plan will delimit the mechanisms of human exposure, determine modes of action of biotoxins, and allow description of acute and chronic effects of HAB toxins on human health. Plans for rapid response to an unexpected outbreak will be available. Risk assessments and appropriate management actions to protect human health and provide treatment options will result.

On the lookout for trouble: A member of the 2001 Occupational Red Tide Survey team collects lung function and respiratory effect data from a lifeguard who worked on beaches affected by *K. brevis* red tides.

Source: B. Kirkpatrick.

Improved Protection of Endangered Species and Improved Ecological Health

Marine mammals, turtles, and other aquatic animals are increasingly threatened by HABs. Research under this plan will identify pathways and mechanisms of how HAB toxins threaten endangered living resources. This will allow analyses for risk assessment that can be used in new or revised endangered species recovery plans. Expanded and accurate analytical and forecasting capabilities that will develop under HARRNESS will allow for improved diagnoses and interpretation of the effects of HABs on living resources at the individual or population level. Improved diagnoses will be based on better understanding of known acute syndromes (e.g., brevetoxicosis), of the sub-lethal and chronic effects of exposure to toxins, and of the potential impacts of new or emergent HAB related threats. Improvements will be dependent upon collaborations between researchers in toxicology, oceanography, and bloom ecology, and researchers and practitioners in fish and wildlife management and veterinary medicine.

Researchers perform spirometry on red tide-afflicted manatees to detect respiratory effects.

Source: B. Kirkpatrick

Improved Prevention and Mitigation Strategies

Knowing the underlying causes and biology of HABs will lead to more options for intervention strategies. These will include more effective monitoring and prediction to provide early warning and possible use of physical, chemical, or biological intervention to eliminate or reduce the effects.

What Managers and Stakeholders Are Saying

"Some of the greatest impacts from HABs are spillover effects, that is effects of perception about risks that cause people to change their behavior for things such as seafood consumption or undertaking a beach vacation. Research on the costs of HABs helps identify these costs as well as the direct costs so that more efficient management strategies can be developed."

Douglas W. Lipton
Department of Agricultural & Resource Economics
University of Maryland

"…a notable shortfall has been the lack of much empirical work on the economic costs associated with HABs. Most of the work done has been to extrapolate from anecdotal estimates about the costs. More work needs to be done to rigorously measure the costs associated with HABs and better delineate these costs within the local business and residential communities where HABs occur."

Chuck Adams, Marine Economist
Florida Sea Grant, University of Florida

"…one of the concepts that we are looking at is how to use aquaculture of filter feeders to reduce phytoplankton blooms as a way to balance ecosystems."

James McVey
NOAA National Sea Grant

"Sea Grant outreach specialists work very closely with coastal community leaders, the general public, and educators. All of these groups need more information about HABs in their areas."

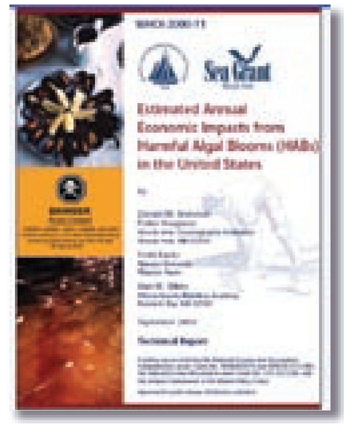
Jeffrey M. Reutter, President
National Association of Marine Laboratories
Director, Ohio Sea Grant Program

"Volunteers conducting field observations of phytoplankton and other environmental parameters can greatly improve the reliability of marine biotoxin management programs by focusing toxicity testing on the times and locations of greatest concern, and indicating which toxins should be tested for. Attaining a similar level of safety assurance using toxicity testing alone is far more expensive, and unlikely in practice. Experience with such volunteer observer networks over the last decade has shown that they are also a powerful tool for educating and enlisting the interest of the public, and for accumulating baseline data on phytoplankton populations along our coasts."

Sherwood Hall, Chief
Washington Seafood Laboratory, Division of Science and Applied Technology, Office of SeafoodCenter for Food Safety and Applied Nutrition, US Food and Drug Administration

Researchers are investigating the use of natural clays as a potential tool to mitigate harmful algal blooms, or "red tides."

Source: J. Cutler.



The HAB community has engaged social scientists and economists to expand initial efforts to define socioeconomic impacts of HABs.

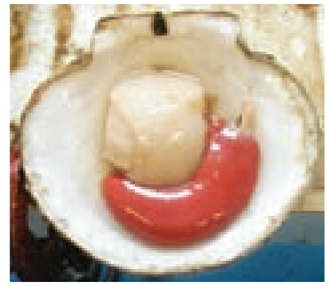
Source: D. Anderson.

Improved Economic Cost Estimates of HAB Events

HAB events are perceived to be extremely costly, but after the fact it is extraordinarily difficult to accurately assess their full impact. HARRNESS outlines research needs for developing accurate cost estimates and comparing them with the costs of appropriate management strategies.

Improved Economics for Aquaculture and Shellfish Safety

Improved information about, and management of, harmful and toxic algal-shellfish interactions will likely have a direct, measurable, and significant economic payoff. Current programs are functional and remarkably successful in protecting public health from known, recurring toxic algal outbreaks, but they are not optimized, technically or economically, and are not designed to respond to new toxic algal events. Shellfish harvest closures represent hardships for harvesters of both wild and cultured shellfish. A reliable early warning system will provide public health officials and managers with a means to focus sampling efforts more efficiently, especially in regions where shellfish harvest is in remote



Roe-shellfish offers a higher-value market for wild and aquaculture shellfish. The markets are being opened with the assistance of survey based testing for PSP and ASP in the northeast Atlantic.

Source: Silver Spring Seafood Co.

areas. With warning of an impending bloom, shellfish aquaculturists will make informed decisions to sell or move their products to avoid catastrophic losses.

Current research, management, and regulatory activities related to HAB–shellfish interactions often are regional or limited to the state level; this is appropriate because implications often occur in waters under state jurisdiction. The provincial nature of programs, however, has resulted in efforts that tend to be fragmented and poorly coordinated on a national level. Through HARRNESS, understanding and management of HAB-shellfish interactions will benefit from improved information availability, dissemination, and coordination.

An Educated and Informed Public

HARRNESS recognizes the need for education and outreach in several diverse sectors: public, educational institutions, medical profession, media, aquaculture industry, seafood industry, tourist industry, recreational and commercial fishing industry, and other water-related industries. The adage "knowledge is power" applies to all these sectors because an informed populace is a prepared one. They will know what a HAB event is, what to expect, and how to respond appropriately. Citizen monitoring networks improve the effectiveness of state monitoring programs by expanding coverage to increase data production for modeling and forecasting. An involved constituency is an informed constituency.

A better informed public will also aid in the development of improved estimates of the costs of damages that result from HABs and the costs of responding to such events. Improved societal awareness will aid the medical community in diagnoses, will aid the seafood safety community in conveying the importance of closures, and the public will have better models and forecasts on which to rely. Societal awareness also translates into better public recognition of the importance of adhering to warnings, whether they be closed shellfish beds or public water supplies that must be avoided when blooms occur.

The Beach Watchers volunteer group observes a bloom of *Noctiluca*—a non-toxic red tide alga. This group, sponsored by Washington State University, is dedicated to protect and preserve the fragile environment of Puget Sound through research, education, public awareness, and example.

Source: © M. Adams.

Phytoplankton volunteers use field microscopes to detect the presence of toxic phytoplankton associated with shellfish poisoning, providing a cost-effective early warning system.

Source: S. Hall.

HARRNESS: A Vision for 2015

This document has attempted to underscore the broad, multidimensional nature of the HAB problem. As the quotes and other examples in this chapter have indicated, the need for increased HAB research and the development of HAB response infrastructure is widely understood. This plan sets a course of action for developing a national capacity for responding to HABs, for assessing the risk to human health, living resources, and the environment, and for implementing effective prevention and mitigation measures. HARRNESS is an ambitious and comprehensive program. The recommendations and guidance in this document outline a pathway to a future that is markedly different from the present with respect to HABs and their management. Nevertheless, with foresighted coordination of activities and new, targeted funding, our 'vision' for the coming decade and beyond is realistic and achievable.

If successful, the environmental and socioeconomic scale of the HAB problem in 2015 will be discernibly different from today. HABs will still occur, but large unsightly events that impact important economic sectors of tourism and recreation will be fewer in number. The adverse impacts of poisonous seafood, wildlife mortality events, aquaculture kills, and ecosystem disruption will be carefully managed. And the general public will experience a resurgence of stewardship of coastal ecosystems. Some specific benefits and capabilities that are envisioned include:

- Healthy fisheries industries, both wild and aquaculture-based, selling seafood that is safe with respect to biotoxins, despite the continued presence of toxic algae in the waters in which these resources grow.
- Reductions in the frequency of large, unsightly, and noxious accumulations of algae that result from excess anthropogenic nutrient inputs as nutrient reduction actions are successfully undertaken.
- Ecosystems and fisheries resources that are less threatened by invasions of non-indigenous HAB species through improvements in ballast water discharge, policies, and technologies.
- Mitigation of bloom impacts of all types using a suite of practical strategies to protect and utilize threatened resources, as well as to directly intervene in bloom development (where appropriate) using economical and environmentally acceptable methods.
- Sophisticated, yet simple to operate instruments, from hand-held monitors to remotely deployed sensors that can detect toxins and other related parameters for HAB detection. Inexpensive test kits will serve multiple purposes for commercial management of fisheries, health clinics, and recreational and subsistent harvesters.
- Teams of scientists with expertise and tools such as biosensors for toxins and diagnostic markers that are indicative of toxin exposure. These teams can respond to unusual or unexpected events, whether they are unexplained marine mammal deaths, human poisonings, or other outbreaks.
- Networks of moored, automated observing systems that incorporate technologies for HAB cell and toxin detection with measurements of other critical water column properties. Early warning networks of this type will be linked to numerical models that provide forecasts of bloom transport and landfall. In addition to short-term predictions of this type, longer-term forecasts will predict years with high probability of extensive HAB outbreaks in particular regions.
- Realistic conceptual models of bloom dynamics and ecology of the major HAB species in key US habitats. Models would be based on a working knowledge of the factors that regulate these blooms, with some of these conceptual models being developed into physical/biological numerical models that realistically simulate field observations and allow for forecasts and other assessment activities.
- Satellite surveillance capability for some HAB blooms, detecting and tracking them over large distances. In some cases these results will be linked to models that allow forecasts of bloom transport and landfall.

- Improved scientific resources for the study of HABs, their toxins, and their effects, including:
  — Culture collections containing multiple strains of all of the major HAB species, each of which is characterized taxonomically, genetically, and toxicologically.
  — Reference material collections of certified toxin standards and reference materials that will assure accuracy and uniformity of analyses worldwide.
  — Genetic databases for HAB species, providing information useful for determining species relatedness or for probe-based cell detection, as well as for studies of gene expression using microarrays and other powerful molecular techniques.
  — Comprehensive epidemiological databases for HAB poisonings, with linkages between this information and data on the causative organisms and their environment or habitat.

These are but a few of the many benefits and capabilities that will derive from the planned cooperation and coordination of academic and government scientists and resource managers through HARRNESS.

Realistically, the extraordinarily diverse nature of HAB phenomena and the hydrodynamic, genetic, and geographic variability associated with outbreaks in fresh and marine waters throughout the US pose significant constraints to the development of this type of coordinated program. Nevertheless, the HAB community in the US has matured scientifically and politically and is fully capable of undertaking these challenges.

The US Commission on Ocean Policy is primed to move ocean science forward at an accelerated pace in this awakening century, and we have advanced scientific and information technologies and an unprecedented population shift to coastal areas that will define a new age of community participation and stewardship.

Americans have valued their coastal resources for generations. HARRNESS will protect coastal resources and economies from extreme natural events such as harmful algal blooms far into the future.

Source: The Raging Main.

The HAB community has joined together to develop HARRNESS and has initiated program implementation through the establishment of a National HAB Committee. It is time for the scientific community, the facilitating agencies, and stakeholders to support the development of a HARRNESS Implementation Plan, and bring this vision to reality.

HABs will still occur, but large unsightly events that impact important economic sectors of tourism and recreation will be fewer in number, the adverse impacts of poisonous seafood, wildlife mortality events, aquaculture kills, and ecosystem disruption will be carefully managed, and the general public will experience a resurgence of stewardship of coastal ecosystems.

References

Alliance for Coastal Technologies. 2002. Biosensors for Harmful Algal Blooms Workshop Proceedings: ACT-02-02, University of Maryland Technical Report Series TS-374-02-CBL and CRC Publ. No. 02-156. Solomons, MD. 21p.

Ahmed, F.E. (ed.). 1991. Seafood Safety. Committee on the Evaluation of the Safety of Fishery Products, Food and Nutrition Board, Institute of Medicine. Washington, National Academy Press. 474p.

Anderson, D.M. 1989. Toxic algal blooms and red tides: A global perspective. In: T. Okaichi, D.M. Anderson and T. Nemoto (eds.), Red Tides: Biology, Environmental Science and Toxicology. Elsevier, New York, 11–16pp.

Anderson, D.M., B.A. Keafer, D.M. Kulis, R.M. Water and R. Nuzzi. 1993. An immunofluorescent survey of the brown tide chrysopyte *Aureococcus anophagefferens* along northeast coast of the United States. J. Plankton Res. 15:563–580.

Anderson, D.M. 1995. ECOHAB–The Ecology and Oceanography of Harmful Algal Blooms: A National Research Agenda. Woods Hole Oceanographic Institution, Woods Hole, MA. 66 p.

Anderson, D.M., P. Hoagland, Y. Kaoru and A.W. White. 2000. Estimated annual economic impacts resulting from harmful algae blooms (HABs) in the United States. WHOI Tech. Rept. No. 2000-11. Woods Hole, MA.: Department of Biology and Marine Policy Center, Woods Hole Oceanographic Institution.

Anderson, D.M., P.M. Glibert and J.M. Burkholder. 2002. Harmful algal blooms and eutrophication: Nutrient sources, composition, and consequences. Estuaries 25:704–726.

Bates, S.S., C.J. Bird, A.S.W. de Freitas, R. Foxall, M. Gilgan, L.A. Hanic, G.R. Johnson, A.W. McCulloch, P. Odense, R. Pocklington, M.A. Quilliam, P.G. Sim, J.C. Smith, D.V. Subba Rao, E.C.D. Todd, J.A. Walter and J.L.C. Wright. 1989. Pennate diatom *Nitzschia pungens* as the primary source of domoic acid, a toxin in shellfish from eastern Prince Edward Island, Canada. Can. J. Fish. Aquat. Sci. 46: 1203–1215.

Borkman, D. and T.J. Smayda. 2003. Long-term patterns of Narragansett Bay phytoplankton driven by decadal shifts in phytoplankton habitat. Conference 2nd Symposium on Harmful Marine Algae in the US, 8–13 Dec 2003, Woods Hole, MA. National Office for Marine Biotoxins and Harmful Algae, National Oceanic and Atmospheric Administration, Center for Sponsored Coastal Ocean Research Coastal Ocean Program.

Burke, L., Y. Kura, K. Kassem, C. Revenga, M. Spalding and D. McAllister. 2000. Pilot Analysis of Global Ecosystems (PAGE): Coastal ecosystems. World Resources Institute, Washington, DC.

Caraco, N.F. 1995. Influence of human populations on P transfers to aquatic systems: A regional scale study using large rivers. In: H. Tiessen (ed.), Phosphorus in the Global Environment. SCOPE 54. John Wiley & Sons Ltd., New York, 235–247pp.

Cosper, E.M., W.C. Dennison, E.J. Carpenter, V.M. Bricelj, J.G. Mitchell, S.H. Kuenstner, D. Colflesh and M. Dewey. 1987. Recurrent and persistent brown tide blooms perturb coastal marine ecosystem. Estuaries 10(4):284–290.

Dortch, Q., M.L. Parsons, G.J. Doucette, G.A. Fryxell, A. Maier, A. Thessen, C.L. Powell and T.M. Soniat. 2000. *Pseudo-nitzschia* spp. in the northern Gulf of Mexico: Overview and response to increasing eutrophication. Symposium on Harmful Marine Algae in the US, December 4–9, 2000. Marine Biological Laboratory, Woods Hole, MA, 27p.

EUROHAB. 1999. European Initiative on Harmful Algal Blooms (EUROHAB): Harmful Algal Blooms in European Marine and Brackish Waters. E. Granéli, G.A. Codd, B. Dale, E. Lipiatou, S.Y. Maestrini and H. Rosenthal (eds.), European Commission, Directorate General Science, Research and Development, Brussels, 93 p.

EUROHAB. 2002. EUROHAB Science Initiative Part B: Research and Infrastructural Needs. E. Granéli and E. Lipiatou (eds.), National European and International Programmes, Office for Official Publications of the European Communities, Luxembourg, Belgium, 142 p.

GEOHAB. 2001. Global Ecology and Oceanography of Harmful Algal Blooms, Science Plan. P. Glibert and G. Pitcher (eds.). SCOR and IOC, Baltimore and Paris, 86 p.

GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/ UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). 2001. Protecting the oceans from land-based activities. Land-based sources and activities affecting the quality and uses of the marine, coastal and associated freshwater environment. Rep. Stud. GESAMP No. 71, 162 p. ISBN 82-7701-011-7.

Hallegraeff, G.M. 1993. A review of harmful algal blooms and their apparent global increase. Phycologia 32:79–99.

Hoagland, P., D.M. Anderson, Y. Kaoru and A.W. White. 2002. The economic effects of harmful algal blooms in the United States: Estimates, assessment issues, and information needs. Estuaries 25(4b):819–837.

Kahn, J. and M. Rockel. 1988. Measuring the economic effects of brown tides. J. Shellfish Res. 7(4):677–682.

Landsberg, J.H. 2002. The effects of harmful algal blooms on aquatic organisms. Rev. Fish. Sci. 10:113–390.

LaPointe, B.E., D.A. Tomasko and W.R. Matzie. 1994. Eutrophication and trophic state classification of seagrass communities in the Florida Keys. Bull. Mar. Sci. 54: 696–717.

Lehane, L. and R. Lewis. 2000. Ciguatera: Recent advances but the risk remains. International Journal of Food Microbiology, 61: 91–125.

Lipton, D.W. 1999. *Pfiesteria*'s economic impact on seafood industry sales and recreational fishing. In: B.L. Gardner and L. Koch (eds.), Economics of Policy Options for Nutrient Management and *Pfiesteria*. Proceedings of the Conference, Nov. 16, 1998, Laurel, MD.

Maclean, J.L. 1989. Indo-Pacific red tides, 1985–1988. Mar. Pollution Bull. 20:304–310.

McKay, B. and K. Mulvaney 2001. A review of marine major ecological disturbance (MMEDs). Endangered Species UPDATE 18(1):14-24.

Mulligan, H.F. 1975. Oceanographic factors associated with New England red tide blooms. Proceedings of the First International Conference on Toxic Dinoflagellate B., MSTF, Wakefield, MA.

National Plan. 1993. Marine Biotoxins and Harmful Algae: A National Plan. D.M. Anderson, S.B. Galloway and J.D. Joseph (eds.), Woods Hole Oceanographic Institution Technical Report, WHOI 93-02, Woods Hole, MA.

Rensel, J.E., R.A. Horner and J.R. Postel. 1989. Effects of phytoplankton blooms on salmon aquaculture in Puget Sound, Washington: Initial research. Northw. Environ. J. 5:53–69.

Rouhiainen, L., T. Vakkilainen, B. Lumbye Siemer, W. Buikema, R. Haselkorn and K. Sivonen. 2004. Genes coding for hepatotoxic heptapeptides (*Microcystins*) in the Cyanobacterium Anabaena strain 90. Appl. Environ. Microbiol. 70: 686–692.

Seitzinger, S.P., R.W. Sanders and R.V. Styles. 2002. Bio-availability of DON from natural and anthropogenic sources to estuarine plankton. Limnol. Oceanogr. 47(2):353–366.

Sellner, K.G., G.J. Doucette and G.J. Kirkpatrick. 2003. Harmful Algal Blooms: Causes, impacts, and detection. J. Indus. Microbiol. Biotechnol. 30: 383–406.

Shumway, S. 1990. A review of the effects of algal blooms on shellfish and aquaculture. J. World Aquacult. Soc. 21:65–104.

Smayda, T.J. 1990. Novel and nuisance phytoplankton bloom in the sea: Evidence for a global epidemic. In: E. Granéli, B. Sundstrom, L. Edler and D.M. Anderson (eds.), Toxic Marine Phytoplankton. Elsevier, New York, 29–40pp.

Smil, V. 2001. Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food. The MIT Press, Cambridge, MA.

APPENDIX I:
Steering Committee Members

Donald M. Anderson (Co-Chair)
Biology Department
Mail Stop 32, Redfield 332
Woods Hole Oceanographic Institution
Woods Hole, MA 02543-1049
Tel: 508 289-2351
Fax: 508 457-2027
danderson@whoi.edu

Greg Boyer
Chemistry Deptartment
State University of New York
College of Environmental Science and Forestry
Syracuse, NY 13210
Tel: 315 470-6825
Fax: 315 470-6856
glboyer@esf.edu

Clifford Duke
Ecological Society of America
1707 H Street, NW, Suite 400
Washington, DC 20006
Tel: 202 833-8773, ext 202
Fax: 202 833-8775
CSDuke@esa.org

Lynn M. Grattan
Neuropsychological Diagnostic and Research Laboratory
University of Maryland School of Medicine
22 S. Greene Street
Baltimore, MD 21201
Tel: 410 328-6297
Fax: 410 328-5874
LGrattan@epi.umaryland.edu

Gary J. Kirkpatrick
Mote Marine Laboratory
1600 Ken Thompson Parkway
Sarasota, FL 34236
Tel: 941 388-4441, ext 271
Fax: 941 388-4312
gkirkpat@mote.org

Judy Kleindinst
Biology Department, MS #32
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
Tel: 508 289-2745
Fax: 508 457-2027
jkleindinst@whoi.edu

Jan Landsberg
Aquatic Health Program
Florida Marine Research Institute
Florida Fish and Wildlife Conservation Commission
100 Eighth Avenue, SE
St. Petersburg, FL 33701-5095
Tel: 727 896-8626
Fax: 727 823-0166
jan.landsberg@myFWC.com

Dennis McGillicuddy
Bigelow 209b - MS 11
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
Tel: 508 289-2683
Fax: 508 457-2194
dmcgillicuddy@whoi.edu

John S. Ramsdell (Co-Chair)
Marine Biotoxins Program
NOAA–National Ocean Service
219 Fort Johnson Road
Charleston, SC 29412
Tel: 843 762-8510
Fax: 843 762-8700
John.Ramsdell@noaa.gov

Chris Scholin
Monterey Bay Aquarium Research Institute
7700 Sandholdt Road
Moss Landing, CA 95039-0628
Tel: 831 775-1779
Fax: 831 775-1620
scholin@mbari.org

Kevin Sellner
Chesapeake Research Consortium
645 Contees Wharf Road
Edgewater, MD 21037
Tel: 410 798-1283; 301 261-4500
Fax: 410 798-0816
sellnerk@si.edu

Sandra E. Shumway
Department of Marine Sciences
University of Connecticut
1080 Shennecossett Road
Groton, CT 06340
Tel: 860 405-9282
Fax: 860 405-9153
sandra.shumway@uconn.edu

Karen Steidinger
Florida Fish and Wildlife Conservation Commission
Florida Marine Research Institute
100 Eighth Avenue, SE
St. Petersburg, FL 33701-5095
Tel: 727 896-8626
Fax: 727 823-0166
karen.steidinger@myFWC.com

Marc Suddleson
NOAA National Ocean Service
CSCOR Coastal Ocean Program
SSMC4 Rm 8331
1305 East West Highway
Silver Spring, MD 20910
Tel: 301 713-3338, ext 162
Fax: 301 713-4044
marc.suddleson@noaa.gov

ESA STAFF

Rhonda Kranz
Program Manager
Ecological Society of America
1707 H Street, NW, Suite 400
Washington, DC 20006
Tel: 202 833-8773, ext 212
Fax: 202 833-8775
rhonda@esa.org

NOAA SUPPORT

Susan Banahan
Program Manager
NOAA Coastal Ocean Program, N/SCI2
1305 East West Highway, Rm 8205
Silver Spring, MD 20910
Tel: 301 713-3338, ext 148
Fax: 301 713-4044
Susan.Banahan@noaa.gov

Quay Dortch
Coordinator
ECOHAB Program
Coastal Ocean Program,
NOAA COP N/SC12 Rm 8432
1305 East West Highway
Silver Spring, MD 20910-3282
Tel: 301 713-3338, ext 157
Fax: 301 713-4044
Quay.Dortch@noaa.gov

APPENDIX II:

Advisory Committee Members

Chuck Adams
Florida Sea Grant
University of Florida
P.O. Box 110240
Gainesville, FL 32611-0240
Tel: 352 392-1826, ext 223
cmAdams@mail.ifas.ufl.edu

Dan L. Ayres
Washington State Deptartment of Fish and Wildlife, Region Six
48 Devonshire Road
Montesano, WA 98563
Tel: 360 249-4628, ext 209
ayresdla@dfw.wa.gov

Lorrie Backer
National Center for Environmental Health
1600 Clifton Road, NE, MSE-23
Atlanta, GA 30329
Tel: 404 498-1342
lbacker@cdc.gov

Daniel G. Baden
Center for Marine Science
University of North Carolina at Wilmington
5600 Marvin Moss Lane
Wilmington, NC 28409
Tel: 910 962-2408
baden@uncw.edu

Laurie L. Bean
Deptartment of Marine Resources
Biotoxin Monitoring
P.O. Box 8
W. Boothbay Harbor, ME 04575
Tel: 207 633-9555
Laurie.Bean@maine.gov

Donald F. Boesch
University of Maryland Center for Environmental Science
P.O. Box 775
Cambridge, MD 21613
Tel: 410 228-9250, ext 601
boesch@ca.umces.edu

Paula Bontempi
Ocean Biology and Biogeochemistry Programs
Office of Earth Science, Code YS
NASA Headquarters
300 E. Street, SW
Washington, DC 20546
Tel: 202 358-1508
paula.s.bontempi@nasa.gov

John Boreman
NMFS/Northeast Fisheries Science Center
166 Water Street
Woods Hole, MA 02543
Tel: 508 495-2233
Jboreman@whsun1.wh.whoi.edu

Leon Cammen
Sea Grant SSMC3 Rm 11841, R/SG
1315 East West Highway
Silver Spring, MD 20910
Tel: 301 713-2435, ext 136
Leon.Cammen@noaa.gov

Joan S. Cleveland
Environmental Optics, Office of Naval Research, Code 322OP
800 N. Quincy Street
Arlington, VA 22217-5660
Tel: 703 696-4532
Joan_Cleveland@onr.navy.mil

Mary Culver
NOAA/Coastal Services Center
2234 South Hobson Avenue
Charleston, SC 29405-2413
Tel: 843 740-1250
Mary.Culver@noaa.gov

Allen Dearry
NIEHS
P.O. Box 12233
111 T.W. Alexander Drive MD EC-21
Research Triange Park, NC 27709
Tel: 919 541-3068
dearry@niehs.nih.gov

Quay Dortch
NOAA/COP N/SC12
1305 East West Highway
Silver Spring, MD 2090
Tel: 301 713-3338, ext 157
Quay.Dortch@noaa.gov

James E. Eckman
Biological and Chemical Oceanography Program
Office of Naval Research, Code 322BC
800 N. Quincy Street
Arlington, VA 22217
Tel: 703 696-4590
James_Eckman@onr.navy.mil

T.J. Evens
USDA-ARS US Horticultural Research Laboratory
2001 S. Rock Road
Ft. Pierce, FL 34945
Tel: 772 462-5921
Tevens@ushrl.ars.usda.gov

Dave Garrison
Biological Oceanography
NSF4201 Wilson Boulevard
Arlington, VA 22230
Tel: 703 292-8582
dgarriso@nsf.gov

Dave Goshorn
Maryland Department of Natural Resources,
Living Resource Assessment
580 Taylor Avenue, D-1
Annapolis, MD 21401
Tel: 410 260-8639
DGOSHORN@dnr.state.md.us

Sherwood Hall
FDA
HFS-426 200 C Street, SW
Washington, DC 20204
Tel: 202 205-4818
shall@cfsan.fda.gov

John Heisler *(deceased December 8, 2004)*
USEPA, Oceans and Coastal Protection Division
Marine Pollution Control Branch (4504F)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Tel: 202 566-1268
heisler.john@epa.gov

Laurie J. McGilvray
NOAA Estuarine Reserves Division
N/ORM5, SSMC4 Rm 10535
1305 East West Highway
Silver Spring, MD 20910-3281
Tel: 301 563-1158, ext158
Laurie.McGilvray@noaa.gov

James P. McVey
NOAA/SSMC3 Rm 11838 R/SG
1315 East West Highway
Silver Spring, MD 20910-3282
Tel: 301 713-2451, ext160
Jim.Mcvey@noaa.gov

Mike O'Neill
CSREES Water Quality Program
USDA-CSREES
3192 Waterfront Centre 800 9th Street, SW
Washington, DC 20024
Tel: 202 205-5952
moneill@csrees.usda.gov

Neal A. Palafox
Department of Family Medicine and Community Health
John A. Burns School of Medicine
University of Hawaii
95-390 Kuahelani Avenue
Mililani, HI 96789
Tel: 808 627-3239
npalafox@uhfpres.org

Gina M. Perovich
USEPA/ORD/NCER(8723R)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Tel: 202 564-2248
perovich.gina@epa.gov

Jack Rensel
4209 234th Street, NE
Arlington, WA 98223
Tel: 360 435-3285
jackrensel@att.net

Jeffrey M. Reutter
Ohio Sea Grant College Program
FT Stone Laboratory
The Ohio State University Area 100 Research Center
1314 Kinnear Road
Columbus, OH 43212
Tel: 614 292-8949
reutter.1@osu.edu

Donald L. Rice
Chemical Oceanography, National Science Foundation
4201 Wilson Boulevard
Arlington, VA 22230
Tel: 703 292-8528
drice@nsf.gov

Teri Rowles
Office of Protected Species
Hollings Marine Lab, N/SCI4
219 Ft. Johnson Road
Charleston, SC 29412-9110
Tel: 301 713-2322, ext 178
Teri.rowles@noaa.gov

James D. Simons
Texas Parks and Wildlife Department
3000 IH 35 South, Suite 320
Austin, TX 78704
Tel: 512 912-7034
James.Simons@tpwd.state.tx.us

Karen Steidinger
Florida Fish and Wildlife Conservation Commission
Florida Marine Research Institute
100 8th Avenue, SE
St. Petersburg, FL 33701
Tel: 727 896-8626
karen.steidinger@fwc.state.fl.us

Pat Tester
NOAA/CCFHR101
Pivers Island Road
Beaufort, NC 28516-9722
Tel: 252 728-8792
Pat.Tester@noaa.gov

Juli M. Trtanj
Oceans and Human Health Initiative
NOAA Office of Global Programs
1100 Wayne Avenue, Suite 1225
Silver Spring, MD 20910
Tel: 301 427-2089, ext 134
Juli.Trtanj@noaa.gov

Jeremy Whatmough
S.T.A.R.T.
P.O. Box 8296
Longboat Key, FL 34228
Tel: 941 383-0325
info@start1.com

Kirk Wiles
Texas Department of Health, Seafood Safety Division
1100 West 49th Street
Austin, TX 78756
Tel: 512 719-0215
kirk.wiles@tdh.state.tx.us

Thierry Work
USGS, National Wildlife Health Center Hawaii Field Station
P.O. Box 50167
Honolulu, HI 96850
Tel: 808 792-9520
thierry_work@usgs.gov

APPENDIX III:
Workshop Participants

Donald M. Anderson
Biology Department
Mail Stop 32, Redfield 332
Woods Hole Oceanographic Institution
Woods Hole, MA 02543-1049
Tel: 508 289-2351
Fax: 508 457-2027
danderson@whoi.edu

E. Virginia Armbrust
School of Oceanography
Box 357940
University of Washington
Seattle, WA 98195–7940
Tel: 206 616-1783
Fax: 206 616-1570
armbrust@ocean.washington.edu

Dan Ayres
Washington State Department of Fish and Wildlife
Region Six
48 Devonshire Road
Montesano, WA 98563
Tel: 360 249-4628, ext 209
Fax: 360 664-0689
ayresdla@dfw.wa.gov

Lorraine Backer
National Center for Environmental Health
Centers for Disease Control and Prevention
4770 Buford Highway, NE
MS F-46
Chamblee, GA 30341
Tel: 770 488-3426
Fax: 770 488-3450
lbacker@cdc.gov

Greg Boyer
Chemistry Deptartment
State University of New York
College of Environmental Science and Forestry
Syracuse, NY 13210
Tel: 315 470-6825
Fax: 315 470-6856
glboyer@esf.edu

Carrie Bretz
Seafloor Mapping Lab
Institute for Earth Systems Science & Policy
California State University Monterey Bay
100 Campus Center
Seaside, CA 93955-8001
Tel: 831 582-4197
Fax: 831 582-3073
carrie_bretz@csumb.edu

JoAnn M. Burkholder
Center for Applied Aquatic Ecology
North Carolina State University
620 Hutton Street, Suite 104
Raleigh, NC 27606
Tel: 919 515-2726
Fax: 919 513-3194
joann_burkholder@ncsu.edu

Wayne Carmichael
Wright State University
Department of Biological Sciences
3640 Col. Glenn Highway
Dayton, OH 45435
Tel: 937 775-3173
Fax: 937 775-3320
wayne.carmichael@wright.edu

Robert Dickey
FDA Gulf Coast Seafood Laboratory
1 Iberville Street
P.O. Box 158
Dauphin Island, AL 36528
Tel: 251 690-3368
Fax: 251 694-4477
rdickey@cfsan.fda.gov

Quay Dortch
ECOHAB Program
NOAA/NOS/NCCOS/CSCOP/COP
N/SC12
1315 East West Highway
Silver Spring, MD 20910-3282
Tel: 301 713-3338, ext 157
Fax: 301 713-4044
Quay.Dortch@noaa.gov

Gregory Doucette
Marine Biotoxins Program
NOAA–National Ocean Service
219 Fort Johnson Road
Charleston, SC 29412
Tel: 843 762-8528
Fax: 843 762-8700
greg.doucette@noaa.gov

Clifford Duke
Ecological Society of America
1707 H Street, NW, Suite 400
Washington, DC 20006
Tel: 202 833-8773, ext 202
Fax: 202 833-8775
CSDuke@esa.org

Lora E. Fleming
Department of Epidemiology & Public Health
University of Miami School of Medicine
Highland Park Building Suite 200
1801 NW 9th Avenue
Miami, FL 33136
Tel: 305 243-5912
Fax: 305 243-3384
lfleming@med.miami.edu

Peter J.S. Franks
Scripps Institution of Oceanography
University of California, San Diego
2119 Sverdrup Hall
Mail Code 0218
La Jolla, CA 92093-0218
Tel: 858 546-0676
Fax: 858 822-0562
pfranks@ucsd.edu

Patricia M. Glibert
University of Maryland Center for Environmental Science
Horn Point Laboratory
P.O. Box 775
Cambridge, MD 21613
Tel: 410 221-8422
Fax: 410 221-8490
glibert@hpl.umces.edu

Lynn M. Grattan
Neuropsychological Diagnostic and Research Laboratory
University of Maryland School of Medicine
22 S. Greene Street
Baltimore, MD 21201
Tel: 410 328-6297
Fax: 410 328-5874
LGrattan@epi.umaryland.edu

Porter Hoagland
Marine Policy Center, MS #41
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
Tel: 508 289-2867
Fax: 508 457-2184
phoagland@whoi.edu

Rita Horner
School of Oceanography
Box 357940
University of Washington
Seattle, WA 98195-7940
Tel: 206 543-8599
Fax: 206 543-0275
rita@ocean.washington.edu

Daniel Kamykowski
1125 Jordan Hall
Department of Marine, Earth & Atmospheric Science
North Carolina State University
Raleigh, NC 27695-8208
Tel: 919 515-7894
Fax: 919 515-7802
dan_kamykowski@ncsu.edu

Gary J. Kirkpatrick
Mote Marine Laboratory
1600 Ken Thompson Parkway
Sarasota, FL 34236
Tel: 941 388-4441, ext 271
Fax: 941 388-4312
gkirkpat@mote.org

Judy Kleindinst
Biology Department, MS #32
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
Tel: 508 289-2745
Fax: 508 457-2027
jkleindinst@whoi.edu

Rhonda Kranz
Ecological Society of America
1707 H Street, NW, Suite 400
Washington, DC 20006
Tel: 202 833-8773, ext 212
Fax: 202 833-8775
rhonda@esa.org

Raphael Kudela
Ocean Sciences Department
University of California Santa Cruz
1156 High Street
Santa Cruz, CA 95064
Tel: 831 459-3290
Fax: 831 459-4882
kudela@cats.ucsc.edu

Brian Lapointe
Division of Marine Science, Harbor Branch
Oceanographic Institution, Inc.
5600 US 1 North
Ft. Pierce, FL 34946
Tel: 772 465-2400, ext 276
Fax: 772 468-0757
lapointe@hboi.edu

Thomas C. Malone
University of Maryland Center for Environmental Science
Horn Point Laboratory
P.O. Box 775
Cambridge, MD 21613
Tel: 410 221-8301
Fax: 410 221-8490
malone@hpl.umces.edu

Dennis McGillicuddy
Bigelow 209b - MS 11
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
Tel: 508 289-2683
Fax: 508 457-2194
dmcgillicuddy@whoi.edu

Ken Moore
ISSC
209-2 Dawson Drive
Columbia, SC 29223
Tel: 803 788-7559
Fax: 803 788-7576
Kmoore2@issc.org

Tim Orsi
NOAA National Coastal Data Development Center/PSI
Building 1100, Room 101
Stennis Space Center, MS 39529
Tel: 228 688-3908
Fax: 228 688-2968
Tim.Orsi@noaa.gov

Mark Poli
Toxicology Division
US Army Medical Research Institute of Infectious Diseases
Fort Detrick, MD 21702-5011
Tel: 301 619-4801
Fax: 301 619-2348
mark.poli@amedd.army.mil

John S. Ramsdell
Marine Biotoxins Program
NOAA–National Ocean Service
219 Fort Johnson Road
Charleston, SC 29412
Tel: 843 762-8510
Fax: 843 762-8700
John.Ramsdell@noaa.gov

Kelly Rein
Florida International University
Department of Chemistry
Miami, FL 33199
Tel: 305 348-6682
Fax: 305 348-3772
reink@fiu.edu

Chris Scholin
Monterey Bay Aquarium Research Institute
7700 Sandholdt Road
Moss Landing, CA 95039-0628
Tel: 831 775-1779
Fax: 831 775-1620
scholin@mbari.org

Kevin Sellner
Chesapeake Research Consortium
645 Contees Wharf Road
Edgewater, MD 21037
Tel: 410 798-1283; 301 261-4500
Fax: 410 798-0816
sellnerk@si.edu

Sandra E. Shumway
Department of Marine Sciences
University of Connecticut
1080 Shennecossett Road
Groton, CT 06340
Tel: 860 405-9282
Fax: 860 405-9153
sandra.shumway@uconn.edu

Mary Silver
Institute of Marine Sciences
University of California, Santa Cruz
Santa Cruz, CA 95064
Tel: 831 459-2908
Fax: 831 459-4882
msilver@cats.ucsc.edu

Theodore Smayda
Graduate School of Oceanography
University of Rhode Island
Kingston, RI 02881
Tel: 401 874-6171
Fax: 401 874-6682
tsmayda@gso.uri.edu

Roxanna Smolowitz
Marine Biological Laboratory
MBL Street
Woods Hole, MA 02543
Tel: 508 289-7400
Fax: 508-289-7900
rsmol@mbl.edu

Karen Steidinger
Florida Fish and Wildlife Conservation Commission
Florida Marine Research Institute
100 Eighth Avenue, SE
St. Petersburg, FL 33701-5095
Tel: 727 896-8626
Fax: 727 823-0166
karen.steidinger@myFWC.com

Diane Stoecker
University of Maryland Center for Environmental Science
Horn Point Laboratory
P.O. Box 775
Cambridge, MD 21613
Tel: 410 221-8407
Fax: 410 221-8490
stoecker@hpl.umces.edu

Marc Suddleson
NOAA–National Ocean Service
CSCOR Coastal Ocean Program
SSMC4 Rm 8331
1305 East West Highway
Silver Spring, MD 20910
Tel: 301 713-3338, ext 162
Fax: 301 713-4044
marc.suddleson@noaa.gov

Vera L. Trainer
NOAA/NMFS/ECD
2725 Montlake Boulevard, East
Seattle, WA 98112
Tel: 206 860-6788
Fax: 206 860-3335
Vera.L.Trainer@noaa.gov

Frances Van Dolah
Marine Biotoxins Program
NOAA–National Ocean Service
219 Fort Johnson Road
Charleston, SC 29412
Tel: 843 762-8529
Fax: 843 762-8700
Fran.Vandolah@noaa.gov

Gary H. Wikfors
NOAA/NMFS/NEFSC
212 Rogers Avenue
Milford, CT 06460
Tel: 203 882-6525
Fax: 203 882-6517
Gary.Wikfors@noaa.gov

Jeffrey L. C. Wright
University of North Carolina at Wilmington
Center for Marine Science
One Marvin Moss Lane
Wilmington, NC 28409
Tel: 910 962-2397
Fax: 910 962-2410
wrightj@uncw.edu

HARRNESS: Harmful Algal Research and Response
A National Environmental Science Strategy, 2005–2015

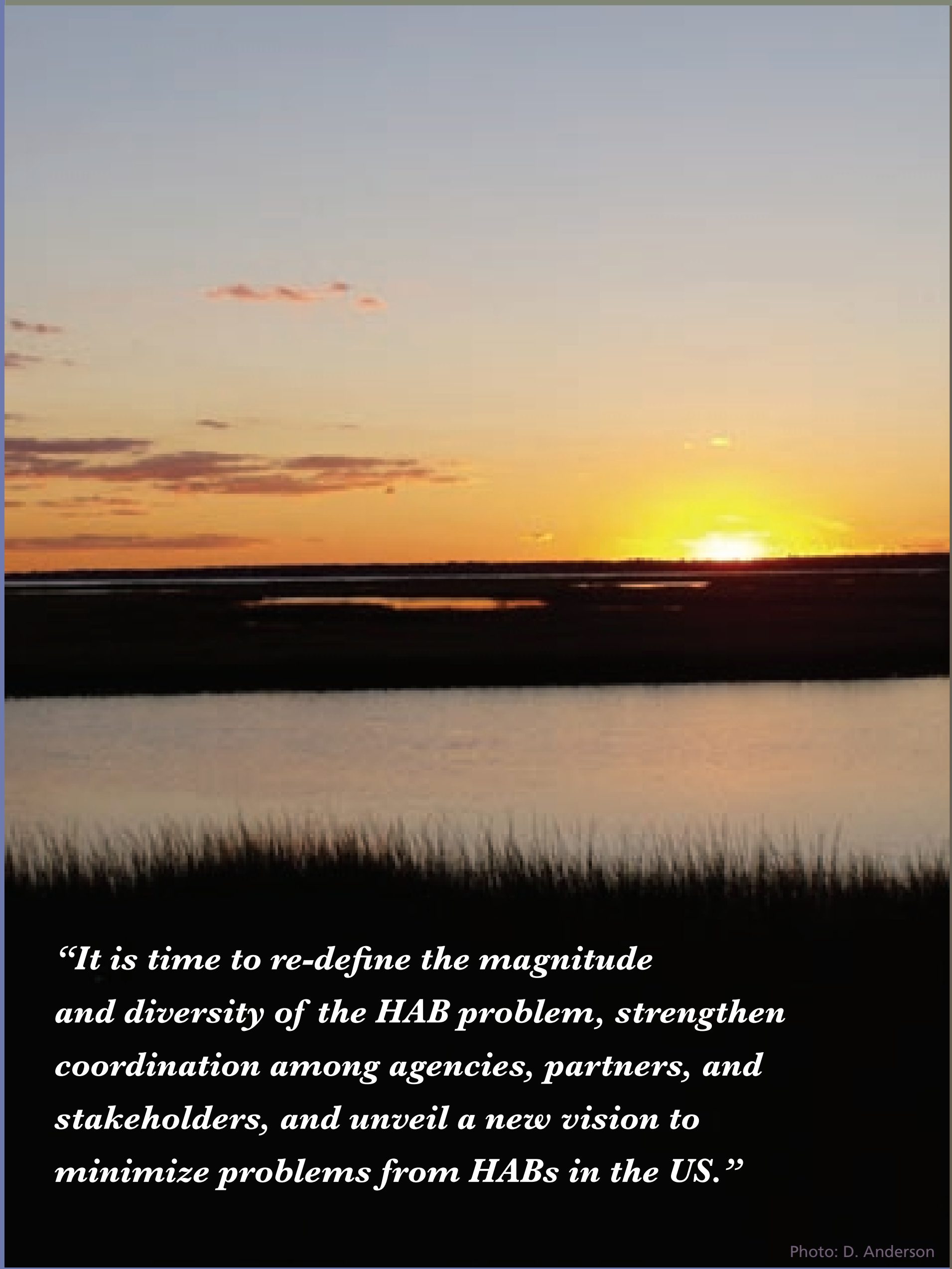


Photo: D. Anderson

For additional copies or information, please contact the National Office for Marine Biotoxins and Harmful Algal Blooms at Woods Hole Oceanographic Institution (508 289-2745) or visit ***http://www.whoi.edu/redtide/nationplan/2005nationalplan.html.***