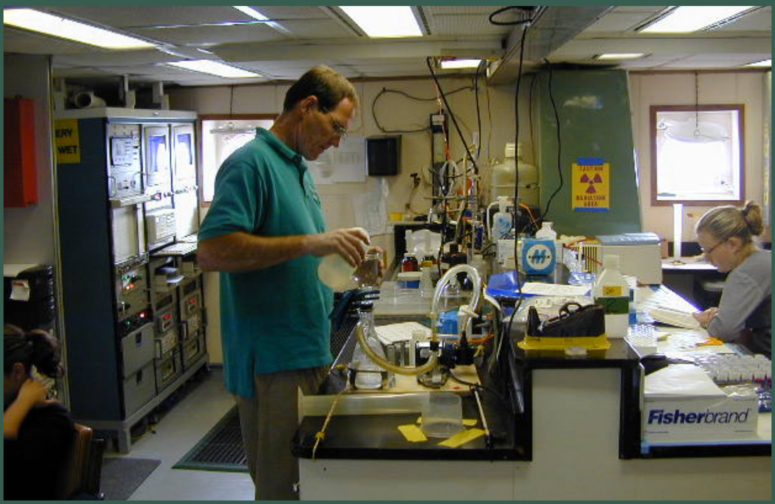
# Harmful Algal Bloom Management and Response: Assessment and Plan

Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health

September 2008

This document should be cited as follows:

Jewett, E.B., Lopez, C.B., Dortch, Q., Etheridge, S.M, Backer, L.C.  2008. Harmful Algal Bloom  Management and Response: Assessment and Plan. Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology. Washington, DC.

## Acknowledgements

Many scientists and managers from Federal and state agencies, universities, and research institutions contributed to the knowledge base upon which this assessment depends.  Many thanks to all who contributed to this report, including Lynn Dancy of NOAA National Centers for Coastal Ocean Science who providing a thorough copy editing.

### Cover Photo Credits

*Background center: Cochlodinium polykrikoides* bloom in Virginia. Photo courtesy of Christy Everett, Chesapeake Bay Foundation.
*Upper left*: Fish kill due to *Prymnesium parvum* bloom on Lake Granbury in Texas. Photo courtesy of Joan Glass, Texas Parks and Wildlife Department.
*Upper right*: Fish kill along Padre Island, Texas during 2006 *Karenia* bloom. Photo courtesy of Alex Nunez, Texas Parks and Wildlife Department.
*Lower left*: A mussel cage used in the Washington Department of Health's Sentinel Mussel Biotoxin Monitoring Program, photo courtesy of Liz Cox-Bolin and Frank Cox.
*Lower right*: Filtering for microcystin analysis in Lake Erie, photo courtesy of Steve Wilhelm.

**Council on Environmental Quality**
**Office of Science and Technology Policy**
**Executive Office of the President**

Dear Partners and Friends in our Ocean and Coastal Community,

We are pleased to transmit to you this report, *Harmful Algal Bloom Management and Response: Assessment and Plan***.** This document reviews and evaluates Harmful Algal Bloom (HAB) management and response efforts, identifies current prevention, control, and mitigation programs for HABs, and presents an innovative research, event response, and infrastructure development plan for advancing the response to HABs.

In December 2004, Congress enacted and the President signed into law the Harmful Algal Bloom and Hypoxia Amendments Act of 2004, (HABHRCA 2004). The reauthorization of HABHRCA acknowledged that HABs are one of the most scientifically complex and economically damaging coastal issues challenging our ability to safeguard the health of our Nation's coastal ecosystems. The Administration further recognized the importance of HABs as a high priority national issue by specifically calling for the implementation of HABHRCA in the President's U.S. Ocean Action Plan. HABHRCA 2004 requires four reports to assess and recommend research programs on HABs in U.S. waters. This document comprises two linked reports specifically aimed at improving HAB management and response: the *Prediction and Response Report* and the follow-up plan, the *National Scientific Research, Development, Demonstration, and Technology Transfer (RDDTT) Plan on Reducing Impacts from Harmful Algal Blooms*.

This document was prepared by the Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health, which was chartered through the Joint Subcommittee on Ocean Science and Technology of the National Science and Technology Council and the Interagency Committee on Ocean Science and Resource Management Integration. This report complements and expands upon HAB-related priorities identified in *Charting the Course for Ocean Science in the United States for the Next Decade: An Ocean Research Priorities Plan and Implementation Strategy*, recently released by the Joint Subcommittee on Ocean Science and Technology. It draws from the contributions of numerous experts and stakeholders from federal, state, and local governments, academia, industry, and non-governmental organizations through direct contributions, previous reports and planning efforts, a public comment period, and a workshop convened to develop strategies for a HAB management and response plan.

Given the importance of the Nation's coastal ocean, estuaries, and inland waters to our quality of life, our culture, and the economy, it is imperative that we move forward to better understand and mitigate the impacts of HABs which threaten all of our coasts and inland waters. This report is an effort to assess the extent of federal, state and local efforts to predict and respond to HAB events and to identify opportunities for charting a way forward.

Sincerely,

James L. Connaughton
Chairman, Council on Environmental Quality
Chair, Committee on Ocean Policy

John H. Marburger III
Director
Office of Science and Technology Policy

# Joint Subcommittee on Ocean Science and Technology (JSOST)

Julie Morris, NSF, Acting Co-Chair
Richard Spinrad, DOC/NOAA, Co-Chair
Dan Walker, OSTP, Co-Chair

**Arctic Research Commission**
John Farrell
*Garrett Brass

**Department of Agriculture**
Louie Tupas
Alternate: Meryl Broussard

**Department of Commerce**
**National Oceanic and Atmospheric Administration**
Steve Murawski
Richard Spinrad
Alternate: Marie Colton
*Ronald Baird
*Holly Bamford
*Colleen Hartman

**Department of Defense**
Charles Chesnutt
Frank Herr
Alternate: Joan Pope
Alternate: James E. Eckman
*Melbourne Briscoe
*Steve Lubard

**Department of Energy**
Jerry Elwood
Alternate: James Ahlgrimm
*Ari Patrinos

**Department of Health and Human Services**
Allen Dearry
Robert Dickey
Michael McGeehin
Alternate: Lorraine Backer
Alternate: William Jones
Alternate: G. David Williamson
*George Hoskin

**Department of Homeland Security**
Jonathan Berkson
*Daniel McClellan

**Department of the Interior**
James Kendall
P. Patrick Leahy
Alternate: John Haines
*Linda Gunderson
*Robert LaBelle

**Department of Justice**
Bradford McLane
*Kristen Gustafson
*Vahid Majidi
*Peter Oppenheimer

**Department of State**
David Balton
Alternate: Liz Tirpak

**Department of Transportation**
Todd Ripley
*Kevin Krick
*Alex Landsburg
*Carl Setterstrom

**Environmental Protection Agency**
George Gray
Alternate: Steven Hedtke
*Timothy Oppelt

**Executive Office of the President**
**Council on Environmental Quality**
Gerhard Kuska
*Kameran Onley

**Executive Office of the President**
**Domestic Policy Council**
Paul Skoczylas
*Allison Boyd
*Annie Holand

**Executive Office of the President**
**Office of Management and Budget**
Emily Woglom
Alternate: Kimberly Miller
*Lewis McCulloch
*Marcus Peacock

**Executive Office of the President**
**Office of Science and Technology Policy**
Dan Walker
*David Halpern
*Teresa Fryberger

**Joint Chiefs of Staff**
Robert Winokur
Alternate: Commander James Kraska
*John Kauffman

**National Aeronautics and Space Administration**
Jack Kaye
Alternate: Eric Lindstrom
*Lucia Tsaoussi

**National Science Foundation**
Julie Morris
Alternate: H. Larry Clark
*Margaret Leinen

**Marine Mammal Commission**
Tim Ragen
David Laist

**Smithsonian Institution**
Leonard Hirsch

*Past JSOST members

# JSOST Interagency Working Group on Harmful Algal Blooms, Hypoxia and Human Health (IWG-4H)

**Lorraine C. Backer** (Co-Chair)
*Centers for Disease Control and Prevention*

**Paul A. Sandifer** (Co-Chair)
*National Oceanic and Atmospheric Administration*

**Paula Bontempi**
*National Aeronautics and Space Administration*

**Herbert T. Buxton**
*United States Geological Survey*

**Stacey M. Etheridge**
*Food and Drug Administration*

**David Garrison**
*National Science Foundation*

**Sherwood Hall**
*Food and Drug Administration*

**Rob Magnien**
**Alternate: Quay Dortch**
*National Oceanic and Atmospheric Administration*

**Tim Ragen**
**Alternate: Mike Simpkins**
*Marine Mammal Commission*

**Teri Rowles**
*National Oceanic and Atmospheric Administration*

**Juli Trtanj**
*National Oceanic and Atmospheric Administration*

**Frederick L. Tyson**
National Institute of Environmental Health Sciences

**Usha Varanasi**
**Alternate.: Walton Dickhoff**
*National Oceanic and Atmospheric Administration*

**William Russo**
**Barbara T. Walton***
*Environmental Protection Agency*

**Mark Weltz**
**Alternate: Mike O'Neill**
*Department of Agriculture*

# JSOST IWG-4H Subcommittee on Harmful Algal Blooms and Hypoxia

**Quay Dortch** (Co-Chair)
*National Oceanic and Atmospheric Administration*

**Lorraine C. Backer** (Co-Chair)
*Centers for Disease Control and Prevention*

**Megan Agy**
*National Oceanic and Atmospheric Administration*

**Paula Bontempi**
*National Aeronautics and Space Administration*

**Herbert T. Buxton**
*United States Geological Survey*

**Stacey M. Etheridge**
*Food and Drug Administration*

**David Garrison**
*National Science Foundation*

**Rob Magnien**
*National Oceanic and Atmospheric Administration*

**Tim Ragen**
**Alternate: Mike Simpkins**
*Marine Mammal Commission*

**Teri Rowles**
*National Oceanic and Atmospheric Administration*

**Usha Varanasi**
**Alternate.: Walton Dickhoff**
*National Oceanic and Atmospheric Administration*

**William Russo**
**Barbara T. Walton***
*Environmental Protection Agency*

**Mark Weltz**
**Alternate: Mike O'Neill**
*Department of Agriculture*

# Primary Authors

**Elizabeth B. Jewett**
**Cary B. Lopez**
**Quay Dortch**
*National Oceanic and Atmospheric Administration*

**Stacey M. Etheridge**
*Food and Drug Administration*

**Lorraine C. Backer**
*Centers for Disease Control and Prevention*

# Contributors

**Mark Poli**
*United States Army Medical Research Institute of Infectious Diseases*

**Sheridan MacAuley**
*National Aeronautics and Space Administration*

**Paul Becker**
*National Institute of Standards and Technology*

*Past IWG-4H member

**Peter McGowan**
*United States Fish and Wildlife Service*

**Stephen Brandt, Steve Gittings, Kelly Goodwin, John Ramsdell, Marc Suddleson, Pat Tester, Michelle Tomlinson, Vera Trainer, Dwight Trublood**
*National Oceanic and Atmospheric Administration*

**Donald Anderson**
*Woods Hole Oceanographic Institution*

**Kevin Sellner**
*Chesapeake Research Consortium*

# Table of Contents

# List of Boxes

# List of Acronyms

**AOAC** Association of Official Analytical Chemists

**AOML** OAR Atlantic Oceanographic and Meteorological Laboratory, NOAA

**ASP** Amnesic Shellfish Poisoning

**AUV** Automated Underwater Vehicle

**CCEHBR** NCCOS Center for Coastal Environmental Health and Biomolecular Research, NOAA

**CCFHR** NCCOS Center for Coastal Fisheries and Habitat Research, NOAA

**CCMA** NCCOS Center for Coastal Monitoring and Assessment, NOAA

**CCMP** Culture Collection for Marine Phytoplankton

**CDC** Centers for Disease Control and Prevention

**CICEET** Cooperative Institute for Coastal and Estuarine Environmental Technology

**CFP** Ciguatera Fish Poisoning

**COHH** Center for Oceans and Human Health, NSF/NIEHS

**CSCOR** NCCOS Center for Sponsored Coastal Ocean Research, NOAA

**DHHS** U.S. Department of Health and Human Services

**DNA** Deoxyribonucleic Acid

**DOC** U.S. Department of Commerce

**DOD** U.S. Department of Defense

**DOI** U.S. Department of the Interior

**DSP** Diarrhetic Shellfish Poisoning

**ECOHAB** Ecology and Oceanography of Harmful Algal Blooms

**EPA** U.S. Environmental Protection Agency

**FDA** U.S. Food and Drug Administration

**FRN** Federal Register Notice

**FWRI** Florida Fish and Wildlife Research Institute

**GEOHAB** Global Ecology and Oceanography of Harmful Algal Bloom Program

**GEOSS** Global Earth Observation System of Systems

**GOOS** Global Ocean Observing System

**HAB** Harmful Algal Bloom

**HABHRCA** Harmful Algal Bloom and Hypoxia Research and Control Act

**HABISS** HAB-related Illness Surveillance System

**HABSOS** Harmful Algal Blooms Observing System

**HARR-HD** Harmful Algal Research and Response: A Human Dimensions Strategy

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

**HML** Hollings Marine Laboratory

**IAEA** International Atomic Energy Agency

**IEOS** U.S. Integrated Earth Observation System

**IOC** Intergovernmental Oceanographic Commission

**IOOS** Integrated Ocean Observing System

**ISSC** Interstate Shellfish Sanitation Conference

**IWG-4H** Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health

**JSOST** Joint Subcommittee on Ocean Science and Technology

**MERHAB** Monitoring and Event Response for Harmful Algal Blooms

**MMC** Marine Mammal Commission

**MSA** Magnuson-Stevens Fishery Conservation and Management Act

**NASA** National Aeronautics and Space Administration

**NCCOS** National Centers for Coastal Ocean Science, NOAA

**NEFSC** NMFS Northeast Fisheries Science Center, NOAA

**NEP** National Estuary Program, EPA

**NERR** National Estuarine Research Reserve, NOAA

**NHC** National HAB Committee

**NIEHS** National Institute of Environmental Health Sciences

**NIST** National Institute of Standards and Technology

**NMFS** National Marine Fisheries Service, NOAA

**NMS** National Marine Sanctuaries, NOAA

**NOAA** National Oceanic and Atmospheric Administration

**NOS** National Ocean Service, NOAA

**NSF** National Science Foundation

*(List of acronyms continued on next page)*

# List of Acronyms
## *(continued)*

**NSP** Neurotoxic Shellfish Poisoning

**NWFSC** NMFS Northwest Fisheries Science Center, NOAA

**OHH** Oceans and Human Health

**OHHI** Oceans and Human Health Initiative, NOAA

**ONR** Office of Naval Research, DOD

**ORHAB** Olympic Region Harmful Algal Bloom Monitoring Program

**PCM** Prevention, Control and Mitigation

**PCR** Polymerase Chain Reaction

**P.L.** Public Law

**PSP** Paralytic Shellfish Poisoning

**RDDTT** Research Development Demonstration and Technology Transfer

**SBIR** Small Business Innovation Research

**STAR** Science to Achieve Results Program, EPA

**START** Solutions To Avoid Red Tide Organization

**SWAT** Soil and Water Assessment Tool

**TVA** Tennessee Valley Authority

**UAV** Unmanned Aerial Vehicle

**UME** Unusual Mortality Event

**USACE** U.S. Army Corps of Engineers

**USAMRIID** U.S. Army Medical Research Institute of Infectious Diseases

**USDA** U.S. Department of Agriculture

**USFWS** U.S. Fish and Wildlife Service

**USGS** U.S. Geological Survey

**WGUMME** Working Group on Unusual Marine Mammal Mortality Events

**WHO** World Health Organization

**WHOI** Woods Hole Oceanographic Institution

# Executive Summary

## The HAB Problem

Algae are the most abundant photosynthetic organisms in marine and freshwater ecosystems and are essential, energy-producing components of aquatic food webs. Harmful algal bloom or "HAB" species are a small subset of algal species that produce toxins and/or bloom to excess, thus creating harm to humans and ecosystems. Humans, domestic animals, and wildlife, including endangered species, can be exposed to algal toxins through their food, drinking water, the water in which they swim, or aerosols.

Symptoms from toxin exposure range from neurological impairment to gastrointestinal upset to respiratory irritation, in some cases resulting in severe illness and even death. Other HAB species cause problems by generating excessive biomass which can result in water discoloration, oxygen-depleted bottom waters devoid of animal life, shading of submerged aquatic vegetation, damage to coral reefs, or other adverse ecosystem effects. It has been estimated that the economic effects of HABs in U.S. communities amount to at least $82 million per year including lost income for fisheries, lost recreational opportunities, decreased business in tourism industries, public health costs of illness, and expenses for monitoring and management[1]. The sociocultural impacts of HABs may be significant, but remain mostly undocumented.

It is widely believed that the frequency and geographic distribution of HABs have been increasing worldwide. All U.S. coastal states have experienced HABs over the last decade, and new species have emerged in some locations that were not previously known to cause problems. HAB frequency is also thought to be increasing in freshwater systems.

## Legislative Background

Efforts to address the HAB problem at the Federal level began with the 1993 report, *Marine Biotoxins and Harmful Algae: A National Plan*[2] and the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA) of 1998. In 2004, in response to the growing concerns about HABs, Congress passed the Harmful Algal Bloom and Hypoxia Amendments Act (P.L. 108-456), which reconstituted the Interagency Task Force on HABs and Hypoxia, mandated five reports, and authorized funding for research programs. Two of the required reports are closely related and have been combined in this report. Chapters 1-4 of this report were submitted to Congress in September 2007 as the *National Assessment of Efforts to Predict and Respond to Harmful Algal Blooms in U.S. Waters*[3]. The assessment specifically addresses both the state of research and methods for HAB prediction and response, especially at the Federal level, but state, local, and tribal efforts are also described. Accomplishments and areas for advancement were also identified.

The second required report, the *National Scientific Research, Development, Demonstration and Technology Transfer Plan for Reducing Impacts from Harmful Algal Blooms* (herein the RDDTT Plan), has been incorporated into this final report as Chapter 5. It establishes research priorities and a plan for peer-reviewed, competitive prevention, control, and mitigation (PCM) efforts to advance current prediction and response

A cyanobacteria bloom in a Maryland pond.
*Photo: U.S. Fish and Wildlife Service*

Public Law 108–456
108th Congress

An Act

Dec. 10, 2004
[S. 3014]

To reauthorize the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998, and for other purposes.

*Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,*

Harmful Algal Bloom and Hypoxia Amendments Act of 2004.
16 USC 1451 note.

**TITLE I—HARMFUL ALGAL BLOOM AND HYPOXIA AMENDMENTS ACT OF 2004**

**SEC. 101. SHORT TITLE.**

This title may be cited as the "Harmful Algal Bloom and Hypoxia Amendments Act of 2004".

*Harmful Algal Bloom and Hypoxia Amendments Act of 2004*
(P.L. 108-456)

capabilities. Combined, these reports constitute this final document.

## U.S. Prediction and Response Efforts: Accomplishments and Opportunities for Advancement

Since most HAB problems occur within state waters, states have the primary responsibility for responding to HAB events. At least 25 states conduct HAB response efforts, operating through a wide range of state government departments and local entities, including tribal governments. Other than responding to the rare HAB events that occur in Federal waters, Federal prediction and response programs have focused on developing new approaches, providing resources and infrastructure to improve response and research, and assisting in regional coordination. At present, 16 Federal extramural funding programs, including two spanning multiple agencies, and 20 intramural Federal research programs either specifically or generally target HAB prediction and response. Although the focus of this report is on Federal prediction and response, it also details state, tribal, and international activities and highlights cooperation with the HAB research conducted through the various oceans and human health programs.

As a result of Federal efforts, considerable progress has been made in the following areas of HAB prediction and response, but opportunities for advancement also remain, as outlined below:

1) Monitoring*: Almost all agencies are actively engaged in developing new methods for determining HAB cell abundance and toxin concentration; some of these new methods are operational. This is a critical first step since it is not possible to predict and respond to a problem that cannot be quantified or tracked. Although many methods are in development, simple, accurate, and rapid methods that can be used in the field will continue to be important. Multiple methods are often needed for each HAB species and its toxins because no method fulfills all purposes. Coordination of water quality monitoring activities which might reveal conditions conducive to or indicative of HABs, such as high nutrients or low dissolved oxygen, is also an acknowledged priority. Improvements in infrastructure—including availability of standards and probes, shared-use facilities, platforms for continuous, real-time monitoring including integrated observing systems, and training to develop the necessary expertise—could support state-of-the-art HAB monitoring and detection and lead to more accurate short- and long-term HAB predictions.

2) Prediction: Short-term HAB prediction and tracking methods that integrate satellite data and transport models with monitoring data are now operational for *Karenia brevis* off the Florida coast. Similar approaches are planned for other regions of the country. Improvements in prediction depend on developing models based on the scientific understanding of HAB causes and on the availability and integration of HAB-specific data into observing system products in regions where HABs are common occurrences.

3) Control: A number of new potential approaches to controlling some HAB species have been identified—including physical cell removal by clay flocculation, natural byproducts of aged barley straw as algicides, and the use of naturally occurring, HAB-specific pathogens, such as bacteria, viruses, and parasites. However, many scientific challenges, risk assessment and communication shortcomings, and regulatory obstacles must be overcome prior to the testing and use of these approaches in the natural environment. Additional approaches need to be explored that expand the number of targeted HAB species, and

*The term "monitoring" as used in this document is not meant to convey requirements under regulation unless specified.

The Slocum Glider AUV with “Brevebuster,” an automated sensor for detecting *Karenia brevis. Photo: Gary Kirkpatrick, Mote Marine Laboratory*


permitting processes need to be developed for testing these methods in the natural environment.

4) Event Response: Several HAB event response programs have been established with the purpose of helping managers minimize impacts of events and mobilize resources while providing data to enhance the understanding and prediction of future events. While these programs have been effective for occasional, small scale blooms, a more comprehensive approach may be justified as the number and severity of HAB events increase.

5) Coordination: There is a high level of coordination among researchers, public health and resource managers, and Federal agencies in responding to HAB events and conducting research to improve response to these events at both the local and national level. Although some of the coordination is formal, most of it consists of informal regional partnerships with common interests. The *Harmful Algal Research and Response: A National Environmental Science Strategy 2005–2015* (*HARRNESS*)[4] stresses the need for better coordination. A National HAB Committee has been formed, as recommend by *HARRNESS*[4], to improve coordination within the research and management communities and to enhance communication with Federal agencies. Improved formal coordination among Federal agencies, however, is still needed. Building on *HARRNESS*[4], the *Harmful Algal Research and Response: A Human Dimensions Strategy* (*HARR-HD*)[5] report provides detailed guidance for social science research critical to optimize the effectiveness and efficiency of coordinated approaches.

6) Incentive-Based Programs: Some incentive-based programs have been established in which recipients of Federal assistance must provide resources either as funds or in-kind support (e.g., the National Oceanic and Atmospheric Association’s Sea Grant). This approach to improve HAB prediction and response has not been fully exploited.

7) Economic and Sociocultural Impacts: In the last few years, assessments of the economic impacts of HABs in the United States have been conducted [1,6,7,8,9]. These estimates are considered conservative due, in part, to the lack of local information available during actual events in many areas, as well as the infrequent quantification of the economic effects of environmental damage. Further, the assessment of sociocultural impacts of HABs and development of plans to mitigate these impacts have lagged behind, as described in a recent report[5].

In addition to the issues outlined above, other broad areas for advancement identified through the Federal agency survey include:

- HAB efforts dedicated to addressing problems with inland HABs other than those in the Great Lakes, especially those focused on toxins in drinking and recreational waters,
- Operationalizing pilot projects dealing with HAB prediction and response, and
- Improving human and wildlife health reporting and guidelines. As many animals serve as sentinels of HAB events, mechanisms for wildlife illness surveillance and reporting and public health surveillance systems will enhance the ability to respond to HAB events.

As required by the legislation, a summary of the draft assessment was published in the Federal Register, and the public was asked to comment on the issues and priorities identified. These comments were summarized and included in the revised *National Assessment of Efforts to Predict and Respond to Harmful Algal Blooms in U.S.* Waters[3] which was submitted to Congress in September 2007.

## RDDTT Plan

The next step in the report process was the development of the RDDTT Plan (see Chapter 5).

Issues addressed in the RDDTT Plan include those identified through the Federal agency survey, the comments received during the Federal Register notice (FRN) process, and the areas of focus outlined by the *HARRNESS* report[4]. A workshop was held in June 2007 with attendees from Federal agencies, academia, and state and local resource and public health agencies with an interest in HAB prediction and response in order to propose approaches for moving forward. The combination of the original assessment[3] with the FRN comments and the workshop proceedings[10] provide the basis for the RDDTT Plan presented in Chapter 5.

The RDDTT Plan recommends the following three-pronged strategy to improve U.S. HAB prediction and response: 1) conduct extramural research focused on development, demonstration, and technology transfer of methods for PCM of HABs and HAB impacts; 2) develop a coordinated, regionally organized HAB event response, and 3) ensure availability of core infrastructure to support HAB research and response. This strategy involves a combination of improving the availability of existing resources, fostering better coordination and communications, and setting priorities for programs to facilitate technology transfer. It is recommended that social science research be incorporated into all three components to ensure socially responsible development and effective implementation of new technologies and strategies.

Cyanobacterial bloom and dead fish in a Nebraska Lake.
*Photo: Nebraska DEQ*

# Chapter 1

# *Legislative Background and Purpose of this Report*

The Harmful Algal Bloom and Hypoxia Amendments Act of 2004 (HABHRCA 2004, P.L.108-456) reauthorized the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 (HABHRCA 1998, P.L. 105-383), reconstituted the Interagency Task Force on Harmful Algal Blooms and Hypoxia (Box 1), and required five reports to assess and recommend research programs on harmful algal blooms (HABs) and hypoxia in U.S. waters, including two reports that were closely related and have been combined in this report (Box 2).

The Interagency Task Force on HABs and Hypoxia (Box 1) was incorporated into the Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health (IWG-4H) of the National Science and Technology Council's Joint Subcommittee on Ocean Science and Technology (JSOST). The IWG-4H was tasked with implementing the requirements of both HABHRCA 2004 and the Interagency Oceans and Human Health Research Program established in the Oceans and Human Health Act of 2004 (Box 3). The IWG-4H streamlined the reporting process by linking the *National Assessment of Efforts to Predict and Response to Harmful Algal Blooms* (herein the Prediction and Response Report [3]) with the *National Scientific Research, Development, Demonstration, and Technology Transfer Plan on Reducing Impacts from Harmful Algal Blooms* (herein the RDDTT Plan) (Box 4). The *Prediction and Response Report* was originally published as an interim assessment in 2007[3] and now constitutes Chapters 1-4 of this report. The RDDTT Plan was developed in response to the interim assessment and now constitutes Chapter 5 of this report.

The assessment (Chapters 1-4 of this report) reviews and evaluates HAB prediction and response techniques, identifies current prevention,

### Box 1. Interagency Working Group on Harmful Algal Blooms and Hypoxia (as specified by HABHRCA)

- Department of Commerce, Co-chair
- Department of Health and Human Services (DHHS), Co-chair
- Environmental Protection Agency (EPA)
- National Science Foundation (NSF)
- National Aeronautics and Space Administration (NASA)
- Department of the Navy
- Department of Agriculture (USDA)
- Department of the Interior
- Food and Drug Administration (FDA), DHHS
- Office of Science and Technology Policy
- Council on Environmental Quality

### Box 2. HABHRCA 2004 calls for the following reports or assessments

- **Harmful Algal Bloom Management and Response: Assessment and Plan**
  - National Assessment of Efforts to Predict and Respond to Harmful Algal Blooms in U.S. Waters **(Prediction and Response Report)**
  - Report on National Scientific Research, Development, Demonstration, and Technology Transfer Plan for reducing HAB Impacts **(RDDTT Plan)**
- Scientific Assessment of Freshwater Harmful Algal Blooms
- Scientific Assessment of Marine Harmful Algal Blooms
- Scientific Assessment of Hypoxia

## Box 3. Oceans and Human Health Act 2004 (P.L. 108-447)

The Oceans and Human Health (OHH) Act requires the National Science and Technology Council to establish an Interagency Oceans and Human Health Research Program to improve understanding of the role of the oceans in human health and establishes the NOAA Oceans and Human Health Initiative as part of this interagency program. The JSOST IWG-4H, in addition to serving as the "Interagency Taskforce on Harmful Algal Blooms and Hypoxia" as called for in HABHRCA, was charged with the responsibility for coordinating the interagency OHH program and producing both the HAB-related and OHH- related reports to Congress. HABs are included as part of the OHH program scope, but the OHH Act specifically states that "nothing in this subsection is intended to duplicate or supersede the activities of the Inter-Agency Task Force on Harmful Algal Blooms and Hypoxia." The IWG-4H has prepared a draft 10-year Interagency OHH Implementation Plan, which was called for by the OHH Act. Coordination with HABHRCA activities is provided through the IWG-4H since it has responsibilities for both OHH as well as HABs and hypoxia.

control, and mitigation (PCM) programs for freshwater, estuarine, and marine HABs, and highlights options for improving prediction and response efforts and associated infrastructure. Prediction and response are narrowly defined for the purpose of this report (Box 5) in order to avoid overlap with two other reports in this series (Box 2), the *Scientific Assessment of Marine Harmful Algal Blooms* (Box 6) and the *Scientific Assessment of Freshwater Harmful Algal Blooms* (Box 7). The focus of Chapters 1- 4 is on Federal prediction and response, but it also includes information on state, tribal, and international activities and highlights cooperation with the HAB research conducted through the various interagency oceans and human health (OHH) programs. In an effort to identify current activities, information was synthesized from several sources. Federal agencies involved in prediction and response provided information about current programs and identified opportunities for advancement. Recent reports[2,4,11,12,13] analyzing national and local efforts to respond to HABs were also consulted, most notably the *Harmful Algal Research and Response: A National Environmental Science Strategy 2005–2015* (*HARRNESS*)[4] report. In addition to drawing from general information on state programs detailed in *HARRNESS*[4], research into state prediction and response initiatives was conducted to ensure the state information is as comprehensive as possible. Information on tribal prediction and response initiatives was derived from other recent reports.

HABHRCA 2004 required that a summary of the Prediction and Response Report (Chapters 1-4 of this report) be published in the Federal Register (FR) to give the general public an opportunity to provide comments. Comments received through the FR process were summarized and included in the revised assessment[3] submitted to Congress in September 2007 (Box 4) and in this final report in Chapter 4. The Federal Register notice (FRN, Appendix V) specifically asked for comments to provide feedback on the current state of prediction and response efforts and to suggest how those efforts might be enhanced.

The IWG-4H used the opportunities for advancement identified in Chapter 4 to shape

## Box 4. Timeline for two linked reports

- Interim *Prediction and Response Report* (including public comments in response to FRN) submitted to JSOST (12/31/06)
- RDDTT Workshop recommended in *Prediction and Response Report* organized and conducted (01/07 - 06/07)
- *Prediction and Response Report* cleared and submitted to Congress (09/07)
- Workshop Proceedings published and synthesized into RDDTT Plan (06/07 - 12/07)
- Final *Prediction and Response Report* and RDDTT Plan submitted to JSOST as one report, *Harmful Algal Bloom Management and Response: Assessment and Plan* (12/31/07)

## Box 5. Definitions

***Prediction***, for this report, is defined as short-term forecasting methods used to predict the transport of HABs in U.S. waters once a bloom has formed. Modeling efforts to predict the development of HABs, based on an understanding of the causes of HABs, will be described in the *Scientific Assessment of Marine Harmful Algal Blooms* (Box 6).

***Response*** includes 1) prevention, control and mitigation (PCM) of freshwater, estuarine, and marine HABs; 2) assessment of public health, ecological, social, and economic impacts of HABs; and 3) the infrastructure used to conduct these prediction and response activities.

a HAB research and management community workshop as part of the process to develop the RDDTT Plan. The RDDTT workshop report[10], along with other HAB reports, provided the basis for the IWG-4H to develop the coordinated, national agenda presented in Chapter 5 to improve prediction and response efforts as requested by HABHRCA 2004. The Prediction and Response Report, together with the RDDTT Plan, constitute this final report, *Harmful Algal Bloom Management and Response: Assessment and Plan*, and represent a comprehensive evaluation and strategy developed with input from multiple stakeholders to improve the national and local response to HABs in U.S. waters.

## Box 6. HABHRCA Report: *Scientific Assessment of Marine Harmful Algal Blooms*

Determining the causes of HABs and the factors that control bloom dynamics and toxin production are a focus of much HAB research. Understanding HABs is also a challenge because the causes vary with species and geographic region and depend on complex biological, chemical, and physical interactions.

Understanding these underlying processes is critical for developing effective strategies for **prevention** and **control** and for developing and improving models used for short- and long-term **predictions**, but research to improve scientific understanding of bloom dynamics is not the subject of this report. Progress related to research on HAB causes and dynamics is included in the *Scientific Assessment of Marine Harmful Algal Blooms*.

## Box 7. HABHRCA Report: *Scientific Assessment of Freshwater Harmful Algal Blooms*

The *Scientific Assessment of Freshwater Harmful Algal Blooms*[14] assesses the state of the knowledge on 1) occurrence of freshwater blooms and toxins, 2) causes, prevention, and mitigation, 3) toxins and toxin kinetics and dynamics, 4) human health and ecologic effects, 5) exposure, and 6) risk assessment for freshwater HABs.

The freshwater report also addresses regulatory considerations, such as the current lack of regulations and guidelines on freshwater HAB toxins in drinking and recreational waters, and identifies research priorities for creating a research plan to improve understanding, response, and management of HABs.

# Chapter 2

# Assessment of the HAB Problem and Definitions

## What Are Harmful Algal Blooms?

Algae, in general, are beneficial because they provide the main source of energy that sustains marine life. However, a small percentage of algal species cause harm to humans, animals, and the environment through toxin production or excessive growth, and these algae are referred to collectively as harmful algal bloom (HAB) species. The majority of HAB species are phytoplankton, which are microalgae (microscopic, single-celled algae) or cyanobacteria, that live suspended in the water. "Harmful algae" also include some microalgae that live attached to plants or other substrates as well as some species of macroalgae (seaweeds).

Even though a small percentage of the world's algal species are considered harmful, the geographic distribution of HAB phenomena is broad and the impacts are pervasive. All coastal states in the United States have experienced HAB events over the last decade, and it is generally believed[15-18] that the frequency and distribution of HABs and their impacts have increased considerably in recent years in the United States and globally. In 2005, New England and Florida each experienced a HAB event that was more severe than any since the early 1970s (Boxes 8 and 9). There are also HAB species and toxins that have emerged recently as new threats in the United States. Two significant examples of this are the saxitoxin-producing dinoflagellate, *Pyrodinium bahamense,* which was discovered in Florida's Indian River Lagoon and Banana River in 2002[19], and the diatom, *Pseudo-nitzschia*, which was found to produce domoic acid in 1987[20] and became a threat in the United States in the early 1990s when domoic acid was detected in Monterey Bay, California, and in razor clams on the Washington coast.

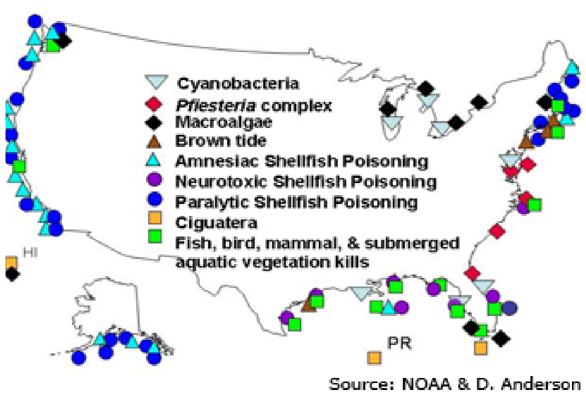



Figure 1. Major HAB events in coastal U.S. waters and the Great Lakes

## What Causes Harmful Algal Blooms?

HABs are a natural phenomenon in coastal ecosystems, but human activities are thought to contribute to the increased frequency of some HABs. For example, although not all HABs occur in high nutrient environments, increased nutrient loading has been acknowledged as a likely factor contributing to increased occurrence of high biomass HABs[21]. Other human-induced environmental changes that may foster development of certain HABs include changes in nutrient regimes, alteration of food webs by overfishing, and modifications to water flow.

The specific causes of HABs are complex, vary between species and locations, and are not well understood. In general, algal species proliferate when environmental conditions, such as nutrient and light availability, temperature, and salinity, are optimal for cell growth. Other biological (e.g., grazing) and physical (e.g., transport) processes determine if enhanced cell growth will result in biomass accumulation. The challenge for understanding the causes of HABs stems from the complexity of these biological, chemical, and physical interactions and their variable influence on growth and bloom development among different species[22]. Further, environmental control and genetic variation of toxin production, vertical migration, life cycles, and cell physiology are an additional challenge for understanding HAB dynamics. Knowledge of how all these factors control HAB initiation, maintenance, and decline is critical for advancing HAB prediction and response, but are research questions that will be covered in two other HABHRCA reports (Boxes 4 and 5).

## Impacts of HABs

HAB impacts are variable in their scope and severity and depend on the causative species. Some harmful microalgae produce potent toxins which cause illness or death in humans and other organisms, including endangered species. Humans, wildlife, and domestic animals can be exposed to algal toxins via contaminated food, water, or aerosols, depending on the toxin. Other HAB species are nontoxic to humans and wildlife but degrade ecosystems by forming such large blooms that they alter habitat quality through overgrowth, shading, or oxygen depletion (hypoxia), adversely affecting corals, seagrasses, and bottom-dwelling organisms. High biomass blooms of certain nontoxic harmful algae can also harm fish and invertebrates by damaging gills or by causing starvation or low reproduction due to poor food quality. Human health and ecosystem impacts of HABs can, in turn, have significant economic and sociocultural ramifications. Economic impacts on coastal communities have been studied, but assessments of sociocultural consequences and community vulnerabilities are important to understand the full range of HAB impacts and devise strategies to mitigate them. The general impacts of HABs on human health, ecosystems, economies, and coastal communities are reviewed below.

### Human Health

#### Exposure through ingestion

Shellfish, such as clams, mussels, and oysters, pose a threat to human consumers because these organisms filter large volumes of water as they feed and, as a result, can rapidly concentrate algal toxins in their tissues. In some cases, a single clam can accumulate enough toxin, which cannot be destroyed through cooking or traditional methods of preparation, to be deadly to a human consumer. Shellfish poisonings that are known to occur in the United States include neurotoxic shellfish poisoning (NSP), paralytic shellfish poisoning (PSP), amnesic shellfish poisoning (ASP), and diarrhetic shellfish poisoning (DSP) (Table 1). Fish can also accumulate toxin to harmful levels by feeding directly on toxic algae or feeding on grazers of toxic algae. Ciguatera fish poisoning (CFP) occurs in subtropical and tropical waters and is the most common finfish poisoning, with more than 400 fish species

### Box 8. 2005 *Alexandrium fundyense* bloom in New England

In the spring of 2005, the most severe bloom since 1972 of the toxic dinoflagellate, *Alexandrium fundyense*, spread from Maine to Massachusetts. This bloom event resulted in extensive and, in some locations, unprecedented closures of shellfish harvesting areas to prevent PSP in human consumers. State closures along the New England coast began as early as mid-May, disrupting shellfish sales during the busiest period of the tourist season. NOAA instituted a closure of approximately 15,000 square miles of Federal waters at the request of the FDA and declared a Fisheries Failure to allow emergency disaster relief for the region's commercial fishers affected by the closures. Both Maine and Massachusetts issued disaster declarations.

An estimate of the economic impact due directly to lost shellfish sales in Massachusetts and Maine as a result of imposed closures is approximately $20 million (based on historical state and NOAA National Marine Fisheries Service annual harvest data[24]). Furthermore, offshore surf clam, ocean quahog, and roe-on sea scallop fisheries that are indefinitely closed due to shellfish toxicity have likely resulted in millions of dollars of additional lost revenue.

## Table 1. Human illness table (modified from *HARRNESS*[4])

| Toxin | Vector | Short-term Health Consequences | Long-term Consequences of Toxin Exposure | Susceptible Regions |
|---|---|---|---|---|
| Ciguatoxins | Reef fish | CFP: Abdominal pain, nausea, vomiting, diarrhea; paresthesias, temperature dysthesia, pain, weakness, bradycardia, hypotension | Long duration (months to years) of symptoms, Chronic depression | Florida Keys Caribbean Hawaii, Pacific Islands |
| Okadaic Acid | Shellfish | DSP: Nausea, vomiting, diarrhea, abdominal pain accompanied by chills, headache, fever | Gastrointestinal tumor promoter in laboratory animals | Northeast U.S. |
| Yessotoxins, Pectenotoxins | Shellfish | Not documented as toxic in humans, but co-occur with DSP and are highly toxic to mice | Unknown | Unknown |
| Azaspiracids | Shellfish | Azaspiracid Shellfish Poisoning: Nausea, vomiting, severe diarrhea, stomach cramps | Unknown | Unknown |
| Brevetoxin | Shellfish | NSP: Numbness of lips, tongue, and throat, muscular aches and pains, fever, chills, abdominal cramping, nausea, diarrhea, vomiting, headache, reduced heart rate, pupil dilation | Unknown | Gulf of Mexico |
| | Inhalation | Acute eye irritation, respiratory distress, asthma exacerbation | Unknown | Gulf of Mexico beaches |
| Saxitoxins | Shellfish | PSP: Tingling, burning, numbness, drowsiness, incoherent speech, respiratory paralysis leading to death | Unknown | Northwest U.S., Northeast U.S., Florida |
| | Puffer Fish | Saxitoxin Puffer Fish Poisoning: Tingling, burning, numbness, drowsiness, incoherent speech, respiratory paralysis leading to death | Unknown | Florida |
| Domoic Acid | Shellfish | ASP: Vomiting, diarrhea, abdominal pain, confusion, disorientation, memory loss | Anterograde memory deficit, seizures leading to coma and death | U.S. West Coast, Northeast U.S., Gulf of Mexico |
| Microcystins | Drinking and recreational water, Dietary supplements | Abdominal pain, vomiting and diarrhea, liver inflammation and hemorrhage, acute pneumonia, acute dermatitis | Hepatocellular carcinoma, liver failure leading to death | Great Lakes and Continental U.S. ponds, lakes, and rivers |
| Cylindrospermopsins | Drinking and recreational water | Abdominal pain, vomiting and diarrhea, liver inflammation and hemorrhage, acute pneumonia, acute dermatitis | Malaise, anorexia, liver failure leading to death | Great Lakes and Continental U.S. ponds, lakes, and rivers |
| Anatoxin-a | Drinking and recreational water | Tingling, burning, numbness, drowsiness, incoherent speech, respiratory paralysis leading to death | Cardiac arrhythmia leading to death | Great Lakes and Continental U.S. ponds, lakes, and rivers |
| Cyanobacterial lipopolysaccharide/s | Drinking and recreational water | Abdominal pain, vomiting and diarrhea, acute dermatitis | Unknown | Great Lakes and Continental U.S. ponds, lakes, and rivers |

implicated as potential vectors[4]. Cyanobacterial toxins can also accumulate in the tissues of fish and shellfish, especially in the viscera, so the World Health Organization (WHO) cautions against fish and shellfish consumption where large toxic cyanobacterial blooms occur[23]. These and other human illnesses or adverse symptoms due to consumption of contaminated seafood or exposure to contaminated water are given in Table 1.

Cyanobacteria are the major harmful algal group in freshwater environments; their toxins ("cyanotoxins") are a potential threat for drinking water supplies. The extent of this threat is not completely clear, but untreated source water samples taken during cyanobacteria blooms in Lake Erie, for example, have at times exceeded the WHO's advisory limit for drinking water[4]. Drinking water contaminated with low levels of cyanobacteria can have taste and odor problems

## Box 9. Impacts of 2005 *Karenia brevis* bloom in West Florida are the worst since 1970s

An unusually large and persistent bloom in 2005 of the Florida HAB dinoflagellate species, *Karenia brevis*, resulted in massive fish kills and reports of human respiratory irritation in residents and beach-goers. Manatee mortalities peaked in March and bloom impacts worsened further in the early summer when a unique set of oceanographic conditions caused the bloom to expand offshore of Sarasota and become trapped near the bottom. Initial mortalities of some fish and bottom-dwelling organisms likely resulted from exposure to *K. brevis* toxins and low oxygen. Bacterial decomposition of dead animals and *K. brevis* cells caused further depletion of bottom water oxygen, which spiraled into mass mortalities of fish, soft corals, and other bottom-dwelling organisms in over 2000 square-miles of sea-bottom west of central Florida. The last time bottom water anoxia occurred in the same area was 1971. Unusually high numbers of manatee, dolphin, and turtle deaths resulted in the first ever declaration of a multiple species Unusual Mortality Event.

The economic impacts of this event have not yet been documented, but, for reference, revenue losses during the 1971 event (which was of shorter duration) was estimated to be approximately $20 million ($96 million in 2005 dollars), with the majority of that cost due to tourism-related losses[25]. In 1999, Steidinger et al.[26] estimated economic losses of at least $15-25 million ($18-29 million in 2005 dollars) per year in Florida due to *K. brevis*.

A lifeguard is tested for respiratory function after exposure to natural red tide in Florida.
*Photo: Mote Marine Laboratory*

due to nontoxic compounds, but toxic cyanobacteria can occur without associated taste and odor problems. The presence of high levels of cyanotoxins in drinking water has caused gastrointestinal complications and liver damage in consumers. The U.S. EPA listed selected cyanobacteria and their toxins in 1998 on the first Drinking Water Contaminants Candidates List and in 2005 on the second list (http://www.epa.gov/fedrgstr/EPA-WATER/2005/February/Day-24/w3527.htm). This action made them priority organisms and compounds for possible regulatory determination pending further review and, as necessary, collection of further information on occurrence, persistence, health risks, and remediation techniques. Legislative mandates in the Safe Drinking Water Act and the Clean Water Act require attention be paid to the presence of contaminants in drinking and recreational waters. However, no specific U.S. guidelines or regulations for cyanotoxins currently exist.

The effects of chronic low-level HAB toxin exposure in food or drinking water are also of concern. Cultural traditions, like harvesting marine mammals for subsistence or consuming more seafood, may place certain populations at increased risk for recurring exposure to toxins at low levels. Furthermore, the extent to which the public may be exposed to low levels of toxins in drinking water is unknown, and the potential public health impacts of these exposures are unknown as well.

### Exposure through contact or inhalation

In addition to the human health effects from eating contaminated seafood or drinking contaminated water, acute human health impacts may occur following ambient exposures. For example, contact with toxic cyanobacterial blooms causes rashes, allergies, and gastrointestinal problems in recreational users (Box 10). In Florida, beachgoers and people working or living near the water can be exposed via sea spray aerosols to neurotoxins produced by the HAB species *Karenia brevis,* resulting in respiratory irritation in healthy people and potentially debilitating acute events in people with underlying respiratory illnesses such as asthma. The long-term consequences of recurrent exposure to these toxic aerosols are unknown.

### Minimizing human impacts

Fortunately, the risk of human illness from waterborne and food borne algal toxin exposure can be dramatically reduced or prevented through harvesting closures and beach warnings, which are issued based on data provided through rigorous monitoring programs. Illnesses are likely under reported, however, especially in cases where symptoms are non-specific and potentially attributed to other causes. In addition, long-term effects and the impacts on public health of chronic, low-level toxin exposure are not well known.

## Ecosystem Impacts

Massive fish kills are perhaps the most commonly observed impact of HABs on wildlife, but HABs can detrimentally affect many aspects of freshwater and marine ecosystems. Algal toxins have caused deaths of whales, sea lions, dolphins, manatees, sea turtles, birds, and wild and cultured fish and invertebrates[27]. Recently, algal toxins have been found in fecal samples from endangered North Atlantic right whales, suggesting that algal toxin exposure via zooplankton vectors may be a contributing factor to the population's failure to recover[28]. Fish and seagrass can also act as toxin vectors, posing threats to marine animals and potentially resulting in delayed or remote toxin exposure[29]. Toxic cyanobacterial blooms in freshwater have also killed terrestrial animals, including livestock and pets that use the contaminated water as a drinking source or lick themselves after bodily exposure (Box 10). Moreover, algal toxins can exacerbate the impacts of other stressors and indirectly lead to wildlife mortalities. Sick or dying animals are often the first indicators of a toxic bloom and may serve as sentinel species.

HABs can also harm or kill fish and invertebrates by releasing compounds or having defensive cell wall structures that impair normal functions. Diatoms of the genus *Chaetoceros*, for example, have caused mortalities of net-pen fish because their barbed spines lodge in fish gills, causing the fish to produce excess mucous and eventually suffocate[30]. *Heterosigma akashiwo* is a raphidophyte that forms blooms and has killed large numbers of cultured salmon in Washington, presumably due to the production of compounds that are toxic to fish[31,32]. Similarly, the "golden algae" *Prymnesium parvum* has caused fish kills in Texas inland waters since the 1980s[33] and is a problem in other states as well.

Degraded habitat quality is another ecosystem impact of toxic and nontoxic HAB species. High biomass blooms that cause hypoxic or anoxic events (low or no dissolved oxygen) that suffocate fish and bottom-dwelling organisms and can sometimes lead to hydrogen sulfide poisoning are a common type of HAB event. High biomass blooms can also directly inhibit the growth of beneficial vegetation by blocking sunlight penetration into the water column. For example, a bloom of the Texas brown tide organism, *Aureoumbra lagunensis,* in Laguna Madre, Texas, caused the loss of over 2,000 acres of shoalgrass due to long-term light limitation[34]. Macroalgal blooms also reduce sunlight penetration and can overgrow or displace seagrasses and corals[35]. HAB-inflicted mortalities can degrade habitat quality indirectly through altered food webs or hypoxic events caused by the decay of dead animals (Box 9).

## Economic Impacts

Hoagland and Scatasta[1] estimated that the annual economic impact due to HAB events in the United States averages $82 million per year. This estimate, an update to those given by Hoagland et al.[9] in 2002, covers a broader time period (1987-2000) and employs the same analytical methods

### Box 10. Animal deaths heighten awareness of cyanobacteria problem in Nebraska

Nebraskans were alerted to the public health threat of cyanobacterial blooms when five dog mortalities were tied to the cyanobacterial toxin, microcystin, in two Nebraskan lakes during the summer of 2004. Over 50 people reported rashes, skin lesions, headaches, and gastrointestinal illness after recreational exposure in Pawnee Lake west of Lincoln, Nebraska, where only a few days prior, health alerts banning swimming and other full-body contact activities had been issued. Livestock and wildlife deaths and human illnesses were associated with other lakes as well. Health alerts were issued for 26 lakes around the state and health advisories (meaning toxins were present but below the threshold level to prohibit full-body contact) were issued for 69 lakes due to presence of cyanotoxins (only microcystin toxins were assessed). Some alerts lasted longer than 12 weeks. Toxin levels at Pawnee Lake persisted throughout the entire recreational season, a time when the majority of the 500,000 yearly visits to Pawnee Lake usually occur.

Reports of dog deaths associated with cyanobacterial blooms have also occurred in other states over the past several years, including Northern California (9 reported in 2001) and Minnesota (several in 2004) as well as Lake Champlain (1-2 reported annually).

as the earlier study. Given that documentation is sparse on overall impacts from individual events, these estimates are likely conservative. Surplus losses (i.e., changes in economic value) and factors with uncertain monetary values (e.g., wild fish kills) were not considered. Impacts due to freshwater cyanobacterial blooms, which affect the recreational, public health, and aquaculture sectors, also were not included. A brief overview of the updated estimates is given in Box 11. Estimates of lost revenue from individual events[7, 25, 36] (Boxes 8, 9, and 12) highlight that this annual average for the Nation may be too conservative.

## Box 11. The economic effects of HABs on the U.S. economy [1, 6]

### TOTAL ($82 million per year)*

- Based on subset of outbreaks in 1987-2000
- Does not include freshwater outbreaks

#### Public Health Costs of Illness ($37 million per year)

- Medical treatment, lost productivity, transportation, causal investigations
- Ciguatera poisoning responsible for majority of costs

#### Commercial Fisheries Impacts ($38 million per year)

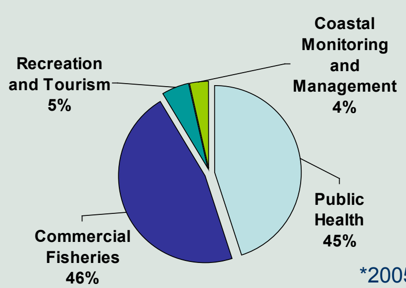
- Includes lost revenue due to closed fisheries, mortalities of shellfish and fish, some untapped fisheries (surf clams in Alaska and on Georges Bank)
- Does NOT include cost of delayed harvesting or changes in economic value (i.e., surplus losses)

#### Local Recreation and Tourism Impacts ($4 million per year)

- Data is lacking for good estimates
- Based on 1987 bloom in North Carolina and estimates of reduced spending on razor clam harvesting in Washington

#### Coastal Monitoring and Management ($3 million per year)

- Based on data obtained from state governments
- Helps reduce costs in other sectors




*2005 Dollars

## Sociocultural Impacts

As defined by the Interorganizational Committee on Guidelines and Principles for Social Impact Assessment, social impacts encompass changes to "the ways in which people live, work, play, relate to one another, organize to meet their needs, and generally cope as members of a society"[37]. The public health, ecosystem, and economic impacts discussed above can all have sociocultural consequences. The sociocultural impacts of HABs remain undocumented, although not unobserved. For instance, the razor clam fishery in Washington is not only a significant source of revenue for tourism-dependent businesses such as restaurants and motels, but also an important source of community identity and basis for subsistence of coastal native cultures. Periodic and sometimes prolonged closures of the recreational fishery have diminished the collective identity of surrounding communities and decreased opportunities for family and community recreation, including razor clam digging. Communities can also be adversely affected when local residents begin to mistrust seafood and water safety and change their lifestyles accordingly. Furthermore, *HARRNESS*[4] recognized that there are many groups whose lifestyles can be affected indirectly, such as veterinarians, environmental advocates, and community volunteers.

The breadth of HAB impacts on communities underscores the need to assess more than economic and human health impacts and to engage many sectors in HAB prediction and response efforts[5]. In general, studies to determine the extent to which HABs and management responses directly or indirectly result in family disruption, community conflict, disruption to or shifts in livelihoods, threats to subsistence, increased reliance on social services, degradation of cultural practices and values, loss of recreational opportunities, aesthetic degradation, and other sociocultural impacts would be beneficial. Even though it may not be possible to place a dollar value on all of these impacts, it is important to document them so that mitigation strategies can be focused and improved.

# What is Meant by Prevention, Control, Mitigation, and Infrastructure for HABs?

## Prevention

Prevention is defined as proactive measures to avoid occurrence or reduce the extent of HABs[3]. Developing strategies for prevention is challenging because it requires understanding causes and how they vary among systems and species. Given the complexity of these processes, there is a growing reliance on the development of predictive models to provide the quantification necessary to take proactive measures. The development of these models and quantifying the processes controlling bloom dynamics are complex. Ongoing research to improve understanding of HAB physiology, ecology, and oceanography will be covered in the HABHRCA 2004-mandated *Scientific Assessment of Marine Harmful Algal Blooms* (Box 6) and the *Scientific Assessment of Freshwater Harmful Algal Blooms* (Box 7). **Only proactive measures of prevention that apply current knowledge are considered in this report**.

Regulating the factors that *are known* to contribute, in part, to bloom occurrence is often difficult and not always feasible. Watershed land-use changes, increased nutrient loadings, altered hydrology, new species introductions, and increased aquaculture in HAB-prone areas or areas with restricted water exchange are some factors that may contribute to HAB occurrence that can be controlled or regulated to some extent. Prevention strategies will likely evolve as our knowledge grows, but the primary strategies for HAB prevention currently include[11, 13, 38]:

Minimizing nutrients flowing into coastal and inland waters: The Global Ecology and Oceanography of Harmful Algal Blooms Program (GEOHAB)[21,39] recognized increased nutrient pollution as one reason for the expansion of HABs in the United States and globally, but also emphasized the complexity of the relationship and the need for more research. In those areas where HABs have been linked to nutrient pollution, possible preventive strategies could include controlling point and nonpoint source nutrient inputs and modifying land-use practices (Box 13).

Avoiding hydrologic modifications that foster HABs: Some HABs can develop when water circulation and exchange are low. A preventive strategy in such locations would be for decisionmakers to consider the potential adverse effects of altered hydrology (such as freshwater flow reductions or diversions) on HAB occurrence when managing water resources.

Reducing new introductions: Activities that might allow the introduction of HAB species to new areas include release of ballast water, sediment dredging, and transfer of shellfish or finfish during aquaculture stocking procedures[11]. It is known that HAB cysts or cells can remain viable during shellfish transport and can be transferred in associated sediment or seaweed. Methods to prevent these introductions during these activities include:

### Box 12. Algal toxins plague fisheries of Washington

The oyster, Dungeness crab, and razor clam fisheries in Washington are cumulatively valued at $72 million/year for the local economies. These fisheries are important for commerce, recreation, and the culture of local coastal tribes. Domoic acid, the toxin that causes ASP in humans, is one of two algal toxins that present the greatest threat to these valuable fisheries (the other is saxitoxin, which causes PSP). Razor clam harvesting, cleaning, cooking, eating, and canning have been an important focus of family relationships and local culture in Washington coastal communities for many generations.

In 2002-03, high levels of domoic acid along the Pacific Coast resulted in a season-long closure of the razor clam fishery in Washington, affecting commercial and subsistence fisheries of coastal tribes as well the recreational fishery for tens of thousands of state residents. In addition, high toxin levels caused the first commercial Dungeness crab fishery closure due to algal toxins since 1991. The 2002-03 event resulted in at least $10-12 million in lost revenue[36].


Photo: Washington DFW

- assessing the potential for introduction by ballast water and applying techniques to eliminate HAB cells or cysts before ballast water release,
- assessing HAB cyst distributions prior to dredging and dredge spoil disposal, and
- assessing the risk of transfer and prohibiting or developing a treatment procedure for shellfish and finfish transfers from bloom-prone areas.

Locating aquaculture and mariculture facilities to avoid HAB-prone areas: High concentrations of fish or shellfish are especially vulnerable to naturally occurring HABs. Further, aquaculture and mariculture facilities can exacerbate blooms due to nutrient release, especially if facilities are located in areas with low water flushing.

### Box 13. Watershed nutrient reduction

In 2003, USDA's Natural Resources Conservation Service and Agricultural Research Service (ARS) began using the Soil and Water Assessment Tool (SWAT) to quantify the water quality and environmental benefits of conservation practices at the national and watershed scale for the Conservation Effects Assessment Project, an effort by the USDA to quantify environmental effects of conservation practices. Over the past four years, EPA and USDA ARS have made SWAT available to Federal and state agencies, universities, and consultants throughout the nation and the world. Recently, Texas legislators, water districts, and river authorities were impressed enough by SWAT results to pay part of the costs for farmers in these areas to apply SWAT conservation measures, such as terracing and other erosion-control measures to hold soil in place and slow its journey into reservoirs, removal of juniper and mesquite brush to increase flow in drought-stricken areas in the Southwest, and better nutrient management on agricultural land (e.g., controlled drainage management) and on confined animal feeding operations to prevent algal blooms that impact freshwater and coastal aquatic life.

Deep chiseling improves water infiltration into the soil
*Photo: USDA*

## Control

Control is the direct reduction or containment of an existing bloom. Control should not be confused with eradication, which is generally not considered feasible or ecologically desirable. Control strategies are challenging because of the potential costs, effectiveness, environmental impacts, and public perceptions. In the *Harmful Algae Management and Mitigation*[40] report, Anderson[38] acknowledged that lessons for HAB control can be learned from research that has been done to control terrestrial nuisance species. Anderson[38] grouped types of control into the following categories:

Mechanical: Mechanical control involves the removal of the algal bloom by physical means. Examples include the application of clay as a flocculent to remove cells and their toxins from the water column or the physical removal of macroalgae.

Biological: Biological control involves the introduction of organisms that will cause HAB mortality, such as bacteria, viruses, parasites, or predators. This potentially promising approach is challenging because of the need to maximize the specificity of the biological control agent and to assess and avoid risks associated with introducing non-indigenous species.

Chemical: Chemical control involves the release of a chemical into the environment to kill the algae. Examples that have been used include copper sulfate (commonly used in aquaculture ponds[41]), oxidants (such as potassium permanganate[42], hypochlorite[43], or ozone[44]), and barley straw[45]. A drawback of most chemical control is that it is not specific to HAB species and can kill other organisms. Toxicity can also be intensified when HAB cells lyse if the chemical does not cause toxin degradation. After a large-scale experiment to control a *Karenia brevis* outbreak in Florida in 1957, application of copper sulfate as a large-scale control was deemed inadvisable due to the potential for harm to other marine organisms, high cost, and short duration of control[46]. A naturally produced byproduct of aged barley straw has shown promise, however, for control of some cyanobacteria and brackish water HABs. In the future, studies of biological control may lead to naturally produced algicidal compounds that

### Box 14. Detecting toxins in shellfish quickly and easily

There was a critical need on the U.S. west coast for rapid, cost-effective monitoring tools that can be used by tribes, local environmental groups, and state agencies to monitor domoic acid concentrations. NOAA CCFHR developed a one-step assay for domoic acid that was tested in the laboratories of NOAA NWFSC and the Quileute Tribe at LaPush, Washington. This assay is quantitative and sensitive enough to measure concentrations of domoic acid in clams below action levels. It was also field tested by resource managers and public health officials from Washington, Oregon, and California.

can be used for control of specific HABs, at least on a small scale.

Genetic: Anderson[38] describes genetic control as "the genetic engineering of species that are purposely introduced to alter the environmental tolerances, reproduction, or other processes in the undesirable species." Examples might include engineering pathogenic bacteria to target HAB species or altering mating types of a targeted HAB species.

Environmental manipulation: Control by environmental manipulation would include strategies for altering the habitat so that growth of HAB species is not favored. Examples include aeration to disrupt stratification or opening or widening of channels to decrease water residence time.

## Mitigation

Mitigation is defined as minimizing *impacts*. Mitigation strategies are more feasible and, hence, currently more operational than prevention and control strategies. Mitigation strategies are broad and fall into the following categories:

Monitoring: Monitoring for cells and toxins prevents or reduces impacts on humans and animals. For example, routine monitoring for cells and toxins prevents contaminated shellfish from reaching consumers, allows warnings to be delivered to recreational users, and feeds into short-term forecasting. However, monitoring for cells and toxins can be challenging due to difficulties of sampling at adequate temporal and spatial scales and the expense and time required for sampling, analysis, and testing. Tools for more efficient monitoring include easier, cheaper, faster, and more accurate methods for detection of cells and toxins (e.g., Boxes 14 and 15), citizen monitoring networks (Box 16), and diagnostic tools for monitoring illness in humans and higher trophic level sentinel species.

Short-term predictions: Early detection of an event and short-term predictions of bloom movement can focus toxin testing where needed, can notify beachgoers in advance, and can allow fish pens to be moved and aquaculture stocks to be harvested. Accurate short-term predictions require integration of focused monitoring with data from other sources, such as satellite imagery, transport models, and ocean observing systems. Mathematical modeling that couples ocean currents and biological processes is a rapidly developing field that will lead to more accurate predictions in the future (Box 6). Coordinated observing systems can provide datasets that will help optimize predictions (Box 17).

Event Response: Event response programs provide funding or technical support to assist managers in their immediate response to HAB events in order to protect human and environmental health. Data collected during responses to events also enhance understanding and prediction of future events.

### Box 15. Simpler, more sensitive test for brevetoxin

The U.S. Army Medical Research Institute of Infectiouis Disease (USAMRIID) has recently developed an electrochemiluminescence-based immunoassay for brevetoxins which is simpler, faster, and more sensitive than the radioimmunoassay and receptor binding assay previously used. The assay is expected to be useful not only for regulatory assessment of oyster catch but also for clinical evaluation of NSP. USAMRIID is currently working with an industry partner to format this assay into test kits. An Association of Official Analytical Chemists (AOAC) multi-laboratory collaborative study to validate the assay as an official method is planned.

Risk communication, public education and outreach: Risk communication research helps scientists, coastal resource managers, water utility managers, public health authorities, and other partners communicate forecasts and other information so that the public understands the probability of a HAB event, trusts the message, and responds in ways that reduce vulnerabilities and promote recovery from impacts. Public education can reduce economic and sociocultural impacts by making consumers aware that commercially available products are safe. Informed recreational users will also pay closer attention to health alerts, which can reduce public health impacts. Doctors and veterinarians who are aware of symptoms of biotoxin exposure and are alerted to HAB events can also reduce public health impacts, and data collected by doctors during events can improve impact assessments.

## Infrastructure

Infrastructure has been cited for the past decade as an important component of HAB research and response, most recently in the *HARRNESS*[4] report. Toxin standards, radioactively-labeled (radiolabeled) toxins, tissue specimen collections, molecular probes, culture collections, databases, instrumentation, observing systems, HAB-specific and ocean color sensors (deployed *in situ* or on airborne or satellite platforms), training, educational outreach and other widely-used tools, services, or information are examples of infrastructure elements that support HAB prediction and response.

### Box 16. Citizen-based monitoring networks help agencies manage resources

Dr. Rita Horner (University of Washington) teaches phytoplankton sample collection and identification methods.
*Photo NOAA NWFSC*

Monitoring for marine biotoxins is made more challenging by the patchy and ephemeral distribution of the free-floating microalgae that produce them. The cost and time required for sampling at adequate temporal and spatial scales, coupled with the intrinsic limits of toxicity testing (both in cost and time delay), place a significant burden on coastal managers and agencies responsible for seafood safety. Employing networks of field observers, primarily volunteers equipped with portable microscopes, to give advance warning of HAB events and to help focus toxicity testing efforts can significantly improve the effectiveness and reduce the cost of monitoring and managing our coastal resources.

The California Department of Health and Safety began the first volunteer HAB monitoring network in the United States in the early 1990's. Since that time a number of states have established plankton monitoring programs. These programs not only enhance sampling capabilities and reduce costs to agencies, but they also educate the public and increase community awareness of HAB issues. FDA and NOAA support establishment of these programs in various states and training for volunteers.

#### *Example monitoring networks:*

*Delaware*
*Inland Bays citizen water monitoring program*
University of Delaware – Sea Grant
http://www.ocean.udel.edu/mas/DIBCMP/waterqual.html

*Massachusetts*
*Division of Marine Fisheries*
http://www.state.ma.us/dfwele/dmf/

*New Hampshire*
*Coastal Program*
http://www.state.nh.us/coastal/WaterQuality/phytoplankton.htm

*Maine*
*Department of Marine Resources*
http://www.ume.maine.edu/ssteward/Planktonnet.htm

*California*
*California Department of Health Services*
http://www.dhs.cahwnet.gov/ps/ddwem/environmental/Shellfish/Shellfish.htm

*South Carolina, North Carolina, Georgia*
*Southeast Phytoplankton Monitoring Network, NOAA*
http://www.chbr.noaa.gov/pmn/

*Florida*
*Florida Wildlife Research Institute*
http://research.myfwc.com/features/view_article.asp?id=24851

*Texas*
*Red Tide Rangers*

*Washington*
*Olympic Region HAB (ORHAB) Monitoring Program*
http://www.orhab.org

## Toxin-related infrastructure

Toxin-related infrastructure includes certified toxin standards, radiolabeled toxins, and information on protocols and methods for toxin analysis. Certified toxin standards and reference materials are used to develop methods, generate reliable quantitative data on toxins, and determine toxicological properties of specific toxins. New detection techniques are rapidly being developed and should be evaluated and incorporated into response efforts along with necessary protocols.

## Reference material infrastructure

Molecular probes, genetic material, live cultures, and tissue samples of intoxicated and uncontaminated control samples represent examples of reference material infrastructure. Molecular probes and genetic material are used to develop and refine methods for detection of HAB species. Contaminated and control tissue samples will allow development of new techniques for toxin analysis and retrospective investigations of past HAB events.

## Observing systems

Observing systems integrate *in situ* and remote observations made from data buoys, automated underwater vehicles (AUVs), satellites, and/or aircraft (including unmanned aerial vehicles, or UAVs). Remote sensing data that can be used in HAB research and prediction include measurements of ocean color, sea surface temperature, and ocean surface topography. Integration of HAB-specific sensors into observing systems in areas where HABs are common occurrences and coordination of observing systems data will enhance HAB prediction and response efforts (Box 17).

## Regional centers/shared facilities

Regional centers have been proposed[4] as a central base for HAB prediction and technology, analytical facilities, data management and repositories, and observing systems. It remains to be seen, however, if this concept can be implemented in a cost-effective manner given the diversity of HABs in the United States and the many different types of regional centers proposed. Shared facilities should reduce constraints caused by the expense of some instrumentation and increase the availability of expertise, technology, and reference materials. Individual shared facilities may have specific expertise related to certain HAB taxa or services (e.g., taxonomy or toxin analysis), so coordination among facilities is desirable.

## Education and training

Education and training include developing expertise within the HAB management and research communities for HAB species and toxin identification. It is important to continue to cultivate taxonomic and toxin expertise as the frequency and extent of known HABs increase and new species and toxins are identified (especially since fewer people are choosing to become experts in HAB identification). Such training would be beneficial at a wide range of levels, from that of citizen monitoring groups, local resource managers in impacted regions, to researchers who want to specialize in HAB taxonomy or toxin analysis.

### Box 17. Observing systems and HAB prediction

The U.S. Integrated Ocean Observing System (IOOS) (http://www.ocean.us/) is a coordinated national and international network of observations and data transmission, data management, and communications intended to routinely and continuously acquire and disseminate quality controlled data and information on current and future states of the oceans and Great Lakes from the global scale of ocean basins to local scales of coastal ecosystems. The IOOS is part of the U.S. Integrated Earth Observation System, the U.S. contribution to the Global Ocean Observing System (http://www.ioc-goos.org/), and a contribution to the Global Earth Observation System of Systems.

These broad, coordinated observing systems have the potential to greatly enhance HAB forecasting capabilities, but their utility in this respect will depend upon the integration of HAB-specific sensors and data in regions where HABs are common occurrences. For example, Regional Coastal Ocean Observing Systems, components of IOOS, are meant to provide the local-scale data and information to address issues that are important to the stakeholders in a particular region, which in some cases includes HABs. The Gulf of Maine Ocean Observing System, which has provided oceanographic data for use in conjunction with other data in monitoring and predictomg *Alexandrium* bloom movement in the Gulf of Maine, offers a preliminary example of their application for enhancing HAB prediction.

## Outreach

Outreach promotes community awareness of HAB issues. *HARRNESS*[4] and *HARR-HD*[5] emphasize the importance of education and outreach to subsistence and recreational harvesters and other populations most susceptible to HAB impacts. Outreach can lessen HAB impacts by promoting awareness of potential threats, imparting accurate perceptions of seafood, drinking water, and recreational safety within the community, and fostering community participation in HAB prediction and response efforts. For example, citizen monitoring networks are an example of an outreach/training activity that benefits local communities as well as the broader management community.

# Chapter 3
# Prediction and Response Programs in the United States

Given the frequency and severity of HAB events in U.S. waters, it has been important to develop prediction and response programs to prevent, control, or mitigate the impact of the blooms. The 1993 report, *Marine Biotoxins and Harmful Algae: A National Plan* (herein the HAB National Plan[2]), and HABHRCA 1998 provided the initial impetus for a national effort to address the issues posed by HABs. Efforts to predict and respond to HABs happen at all levels of government, but this report focuses primarily on *Federal* extramural and intramural efforts, which are detailed in Appendix I. Other national organizations, state and local governments, nongovernmental organizations, and tribal entities are involved in HAB monitoring and mitigation, and some states also have research programs. Other national organizations are detailed in Appendix II and state efforts are detailed in Appendix III. States play a significant monitoring role because they are responsible for the management of aquatic and marine resources in state waters, and their monitoring and response programs operate through a wide range of state government departments and nonprofit organizations. Some Tribes are collaborating with academic, Federal, and state governments to monitor the presence of HABs. Given the global scope of HABs, U.S. programs also work closely with international programs and, in some cases, contribute funding. International programs are detailed in Appendix IV.

Improved, well coordinated HAB PCM research programs and more sophisticated monitoring tools will enhance the ability to respond to HABs. This is important given the possibility that the HAB problem is worsening, with intensifying impacts on human health, coastal economies and communities, and ecosystems (especially endangered species). Significant progress has been made, but ultimately effective prediction and response programs must be based on a thorough understanding of the causes, biology, and ecology of HABs as well as sociocultural aspects integral to improving HAB responses[5]. Ongoing research programs to advance scientific knowledge will be the focus of two other reports written in response to HABHRCA 2004 legislation: the *Scientific Assessment of Marine Harmful Algal Blooms* (Box 6) and the *Scientific Assessment of Freshwater Harmful Algal Blooms* (Box 7). Incorporating a more holistic, social sciences approach into HAB response is considered in the RDDTT Plan (Chapter 5).

## Accomplishments of Federal Programs

As of 2006, there are 16 Federal extramural funding programs which either specifically or generally target HAB prediction and response, and 20 intramural Federal research programs which are generating exciting new technologies for HAB PCM (Appendix I). There are two major Federal multi-agency funding programs which represent important cross-agency collaborative efforts. Through extramural programs, Federal agencies (either as a cooperative, interagency effort or within one agency) grant funding to academic or other institutions and state agencies, often through a competitive, peer-reviewed process. This funding may support prediction and response research, outreach to mitigate impacts, event response, database development, or assessments of HAB impacts. In intramural programs, Federal agencies conduct research (mostly at Federal laboratories), coordinate and carry out HAB event response, monitor and certify seafood safety or suspend shellfish harvesting in Federal waters, collect and distribute data and satellite imagery, coordinate community stakeholders, maintain specimen collections, perform outreach and education, and perform research to guide decisions related to standards for drinking water and recreational water bodies. Federal agency efforts and advancements toward better HAB PCM and improved infrastructure and coordination are described below, and the responsible agencies are noted. Specific efforts by each agency are described in detail in Appendix I.

## Prevention

HAB prevention requires a thorough understanding of HAB physiology, ecology, and oceanography. Although the underlying causes of most HABs are not well understood (Box 6), it is generally accepted that some HAB events are intensified by high nutrients[21, 39]. USDA and EPA have funded research to develop tools for more effectively managing nutrient inputs. For example, some newer efforts to reduce the flow of nitrate into HAB prone waters, such as deep chiseling (which improves water infiltration into deep soil to reduce surface runoff and erosion) or the use of wood chips in drainage ponds, may reduce HABs in freshwater and coastal ecosystems. USDA's Soil and Water Assessment Tool (SWAT) conservation measures, which include efforts to reduce erosion, increase water flow in drought-stricken areas in the Southwestern United States, and improve nutrient management agricultural practices, have been adopted in some regions (Box 13). The Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) Program is funding research to determine the risk of transferring HAB cells/cysts during transport of live bivalves and to establish mechanisms to minimize the risk of new introductions using best management practices.

## Control

Bloom control is an active area of research. Several biological agents have been identified—such as HAB-specific viruses, pathogenic bacteria, grazers, and parasites (National Oceanic and Atmospheric Administration or NOAA's Center for Coastal Environmental Health and Biomolecular Research or CCEHBR; ECOHAB)—and their mode of action and specificity have been investigated, but many questions remain about the environmental safety of their use. Aged barley straw has been used successfully for controlling cyanobacterial HABs. The use of a clay slurry, a form of mechanical control, to remove toxic HAB cells from the water column has been tested for efficacy and safety in everything from small flasks to a field pilot project (Box 18, ECOHAB). Investigators are cautiously optimistic about its utility for removing cells of some HAB species without significant collateral damage.

There are two major obstacles to the further development of control methods: 1) difficulties in demonstrating that methods are reasonably specific for the target species and will have no or minimal damage to other organisms and the environment and 2) development of regulatory processes that allow testing and use of control methods in the field.

### Box 18. Clay investigated as control agent for some HABs

Clay flocculation was first used in Korea to effectively and cheaply remove HAB cells that threatened finfish mariculture. Through the ECOHAB Program, NOAA (CSCOR and Sea Grant) and EPA have supported a series of projects to test the feasibility of clay flocculation for controlling common HABs in U.S. waters. Studies began in small flasks, moved up to laboratory mesocosms, and finally led to pilot studies during natural blooms.

Phosphatic clays were effective against the fish-killing *Heterosigma akashiwo* and toxic *Karenia brevis* (the Florida red tide). In the case of *K. brevis*, toxin bound to clay flocs was taken up by organisms living on the bottom, so the toxin could be transferred to other parts of the food web. Toxin transfer also happens during untreated *K. brevis* blooms but the timing and pattern of toxin delivery may differ. It is unclear whether impacts to the benthos from clay treatment are significantly different from those occurring during untreated blooms. Overall, studies demonstrated the effectiveness of clay in controlling blooms under certain conditions. Impact studies have shown both positive and negative effects, so further evaluation in the context of risk management and cost benefit analysis should be considered.

## Mitigation

### Prediction

Remote sensing tools and models have helped coastal managers predict and track HABs along the Florida coast. The NOAA HAB Bulletin, which integrates satellite imagery and transport models with field data, was operationalized for *Karenia brevis* in the Gulf of Mexico in October 2004 and represents an important collaborative effort among Federal and state agencies (Box 19). Similar approaches to short-term prediction and tracking of blooms are being tested or planned for the coast of Texas, the Great Lakes, off the coasts of Washington and Oregon, and the Gulf of Maine (ECOHAB; NOAA Center for Sponsored Coastal Ocean Research or CSCOR, Center for Coastal Monitoring and Assessment or CCMA, and Great Lakes Environmental Research Laboratory or GLERL; NASA). In the Pacific Northwest, satellite remote sensing has been used to assess the location of eddies where *Pseudo-nitzschia* blooms originate (NASA) and drifter buoys have been used to track and predict bloom movement (ECOHAB; NOAA Northwest Fisheries Science Center or NWFSC). Recently, numerical models (ECOHAB; NOAA CSCOR; National Institute of Environmental Health Science or NIEHS and NSF) and drifter buoys (ECOHAB; NOAA Northeast Fisheries Science Center or NEFSC) have been used to track and provide early warning for *Alexandrium* blooms in New England.

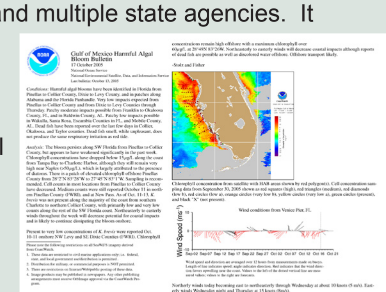
### Monitoring

Monitoring is essential for mitigation of HAB impacts, and by far the greatest effort and financial resources have been devoted to developing HAB monitoring tools and programs. Monitoring programs provide early warning of bloom events and are aimed primarily at protecting human health, especially with regard to shellfish consumption. Monitoring data are also essential for developing predictive models and forecasts.

Responsibility for most coastal monitoring resides at the state level (except in Federal waters, where the FDA has jurisdiction), and these state-run, coastal monitoring programs (Appendix III) have been largely effective at preventing human poisonings from HABs. Federal programs have assisted states by supporting development and transfer to operations (at the state level) of regional HAB monitoring systems (NOAA CSCOR). Federal programs also contribute to state monitoring efforts by providing direct assistance to state managers (FDA; NOAA CCEHBR, CSCOR, and National Marine Fisheries Service or NMFS; see "Rapid Response to HAB Events" section below), by funding efforts to improve communication between state managers and academic institutions (NOAA CSCOR), and by supporting research into improved tools and methods to enhance monitoring (NOAA; EPA; NIEHS; NIEHS/NSF). For example, molecular probes used in routine monitoring for *Pfiesteria* by Maryland Department of Natural Resources were developed with Federal ECOHAB funding and

### Box 19. HAB forecast prepares coastal managers in Florida

The Gulf of Mexico Harmful Algal Bloom Operational Forecast System (or HAB Bulletin) is the first example of forecasting being operationalized for a biological event. The HAB Bulletin is produced once to twice weekly depending on the season, provides information concerning the possible presence or confirmed identification of new blooms, and monitors existing blooms with forecasts of spatial extent, movement, and intensification conditions. The HAB Bulletin is a product of several NOAA offices, NASA, and multiple state agencies. It incorporates satellite imagery data, past and forecasted winds, a wind transport model and *in situ* sampling data of *Karenia* cell concentrations. NASA's Research, Education, and Applications Solution Network (REASoN) Project is developing products and techniques to integrate measurements from NASA and NOAA satellites, available coastal observations, and coastal ocean model outputs into the Bulletin. The Bulletin is distributed via email to coastal resource managers, state and Federal officials, and academic and research institutions. As a result of the Bulletin's forecasts, advance cautionary notice can be issued to protect beachgoers from respiratory illness. Necessary mitigation actions, such as closing shellfish beds, can also be initiated before a bloom becomes a coastal hazard.



## Box 20. Predicting cyanobacterial taste and odor problems in drinking water sources

Between 2000-2005, the U.S.Geological Survey (USGS) Kansas Water Science Center, in cooperation with the City of Wichita, Kansas, conducted a study using state of the art, real-time, continuous, water quality monitoring technology to develop reliable tools to estimate the onset of cyanobacterial-related taste-and-odor episodes in Cheney Reservoir, one of Wichita's primary drinking water supplies. The current model for geosmin (a cyanobacteria-produced compound blamed for earthy tastes and odors) estimates concentrations in real-time and includes the percent chance that concentrations will exceed the human detection limit of 0.01 mg/L. The study in Cheney Reservoir is ongoing and similar models are being developed for cyanobacterial toxins. The City of Wichita plans to use these models to guide drinking water treatment decisions.
http://ks.water.usgs.gov/Kansas/rtqw/sites/07144790/htmls/31d/p62719_7d_all_uv.shtml

through a cooperative agreement with the Centers for Disease Control and Prevention (CDC). A recent innovative monitoring approach has been the organization of citizen monitoring groups in a number of states in order to give advance warning of HABs (FDA; NOAA CCEHBR and CSCOR; (Box 16)) or to monitor marine animal mortalities (NOAA National Marine Sanctuaries or NMS) which help focus state monitoring efforts. With minimal resources, these networks of volunteers greatly improve the geographic and temporal coverage of HAB monitoring and educate citizens about issues related to HABs.

A critical component of any monitoring activity is the ability to detect HAB cells and toxins. Earlier marine HAB research plans [11,13] gave a high priority to the development of portable, fast, cheap, high throughput, and accurate detection methods for HAB cells and toxins that could be used easily in the field, *in situ* (e.g., on buoys or autonomous vehicles), and remotely. Toxins can be present in a variety of matrices, including dissolved in water, sequestered inside HAB cells or animal tissue, or dispersed in the air (as an aerosol). They often occur as mixtures with differing toxicity. Because no single method can meet all of the requirements, be suitable for all matrices, and function well on all platforms, multiple methods are needed for HAB species and toxins.

In the last few years, many methods have been developed to detect numerous HAB species and toxins (e.g., Boxes 14, 15, 20-24). These methods often rely on state-of-the-art technology, including new molecular, optical, and analytical chemical detection techniques (ECOHAB; NIEHS/NSF; NOAA Atlantic Oceanographic and Meteorological Laboratory or AOML, NWFSC, CCEHBR, Center for Coastal Fisheries and Habitat Research or CCFHR, CSCOR, CCMA, GLERL, Cooperative Institute for Coastal and Estuarine Environmental Technology or CICEET; EPA; NIEHS). Also, for cases where the toxin is metabolized quickly in the body, methods have been developed to test blood or urine for toxin exposure (Box 21) (NOAA CCEHBR, United States Army Medical Research Institute for Infectious Diseases or USAMRIID). Some of these newly developed methods are now operational and others are still in developmental stages; a few are commercially available and programs like Small Business Innovation Research (SBIR) Programs are trying to make more methods generally available (Box 22). In addition, a refined saxitoxin assay (Box 23, NOAA CCEHBR; FDA) and a newly developed brevetoxin assay (Box 15, USAMRIID) are slated for AOAC collaborative trials to validate their use as official methods for regulatory purposes. Methods and tools for monitoring drinking water for freshwater HAB toxins as well as taste and odor problems are also being explored (EPA; USGS). Further research is

## Box 21. First-time measurement of ciguatoxin in blood provides method to monitor human exposure

CFP in humans has the highest public health impact of all HAB poisoning, exceeding cost estimates for all the shellfish poisonings combined by more than twenty-fold. There is presently no means to confirm exposure in humans as the toxin had previously never been measured in body fluids of humans or experimental animals. Scientists in the NOAA CCEHBR's Marine Biotoxins Program developed a method that successfully measured toxin in the blood of mice exposed to ciguatoxins. The method utilizes blood collection cards and is designed for clinical application. Preliminary testing has indicated that the method is applicable to humans and collaborations with the CDC and FDA have been formed.

### Box 22. Research toward fast, simple, and sensitive detection of freshwater cyanotoxin

High performance liquid chromatography-based methods for detecting algal toxins generally are complex, expensive, and time-consuming because the analyses cannot be done in the field. Although simpler screening methods, such as enzyme-linked immunosorbent assay, are sometimes quite sensitive, they tend to lack specificity. The goal of an EPA-funded SBIR Phase I research project is to systematically develop a surface plasmon resonance fiber optic probe coated with a molecularly imprinted polymer that will provide fast, simple, and sensitive detection of the cyanotoxin, microcystin-LR, in the field.

also being planned (Box 7). Evaluating emerging and potential toxin vectors, such as puffer fish as a vector for saxitoxin in Florida, is another important area of research that will help mitigate HAB impacts (FDA; ECOHAB; NOAA CCEHBR).

Automated sampling devices that can be deployed either on fixed platforms or on AUVs are an important developing monitoring technology for providing early warning and prediction of HAB events. Automated, real time technology is currently being used for *in situ* detection of *Karenia brevis* off the coast of Florida (the Brevebuster, see photo on p.3) (ECOHAB; NOAA CSCOR and CCFHR) and cyanobacterial-related taste and odor problems in Kansas (USGS, Box 20). Another study combining molecular probe and fiber optic technologies for rapid HAB detection may prove useful for automated detection and early warning applications (NOAA Sea Grant). HABs can also be detected, researched, and monitored using satellite optical sensors. Chlorophyll anomalies, which can be calculated using data from space-based ocean color sensors, are means to identify new blooms and track bloom transport along coasts (NOAA CCMA). Moreover, satellite detection of HABs can be validated with the in-water detection methods described above.

Water quality monitoring for constituents that are conducive to or indicative of HABs (e.g., nutrients, low dissolved oxygen) provides important information for understanding causal mechanisms and developing models to predict HAB occurrence. Water quality monitoring is conducted by a number of Federal (USGS; EPA; NOAA NMS) and state programs for a wide range of objectives. Coordination of monitoring activities for water quality indicators of potential HABs has improved and is an acknowledged priority.

## Rapid Response to HAB Events

HAB events often occur rapidly and unexpectedly and sometimes involve species and toxins that are new to a geographic area. Immediate assistance under such circumstances enhances the ability of state resource and public health managers to protect human and environmental health. Within the past 10 years, some Federal agencies have developed programs to provide immediate funding and scientific expertise for responding to HAB events as they occur. CDC has provided funding for six east coast states to develop emergency response plans for HABs. FDA assists states with sample collection and analysis when marine biotoxins are suspected in state waters and is the primary responder to blooms in Federal waters. Other examples include 1) the NOAA Marine Mammal Health and Stranding Response Program and the Working Group on Unusual Marine Mammal Mortality Events (NOAA NMFS; U.S. Fish and Wildlife Survey or USFWS; Marine Mammal Commission or MMC; EPA) for investigating unusual mortality events (UMEs), 2) the NOAA CSCOR HAB Event Response Program

### Box 23. Method for saxitoxin detection slated for international trial

NOAA CCEHBR's Marine Biotoxins Program has developed a high throughput receptor binding assay for PSP toxins designed to provide an alternative to the mouse bioassay as a regulatory method. Training workshops have been provided to several interested state regulatory labs. CCEHBR has also partnered with the International Atomic Energy Agency (IAEA) to transfer the technology to developing Asian and African countries with HAB problems. When radiolabeled saxitoxin, which is needed for the receptor binding assay, became unavailable due to amendment of the Chemical Weapons Convention, CCEHBR partnered with FDA and IAEA to produce and distribute radiolabeled saxitoxin to state, Federal, and academic users, as well as international regulatory testing labs for monitoring algal toxins in seafood. The receptor binding assay is slated for an international AOAC collaborative trial, which is prerequisite to its acceptance as an international regulatory testing method.

## Box 24. Automated biomonitoring of fish for HAB presence

EPA's Environmental Monitoring for Public Access and Community Tracking Program sponsored a project to evaluate the ability of an automated biological monitoring system that measures fish ventilatory responses to detect developing toxic conditions in water. In the field, the automated biomonitoring system operated continuously for three months on the Chicamacomico River, a tributary to the Chesapeake Bay that has had a history of intermittent toxic algal blooms. Data gathered through this effort complemented chemical monitoring data collected by the Maryland Department of Natural Resources as part of their Pfiesteria monitoring program. Activities are ongoing to improve the biomonitoring system, including developing a system to distinguish fish responses to toxic events from responses to other environmental stressors.
www.aquaticpath.umd.edu/empact

for assisting state managers and researchers investigating HAB events, and 3) the NOAA CCEHBR Analytical Response Team for providing toxin analyses during HAB events to investigate wildlife mortalities, food web impacts, and human poisonings. The USGS National Wildlife Health Center also provides sample handling and project coordination for investigating wildlife disease or mortality events. Collaboration among these programs has led to successful response efforts (Box 25).

### Impact Assessments

It is important, for cost-benefit purposes, to have a good understanding and estimate of the economic and social cost of HAB events as well as what populations will be most affected by these impacts. Several economic impact studies have been conducted (funded by ECOHAB, NSF, and NOAA Sea Grant), including the recent study by Hoagland and Scatasta[1]. Chapter 2 and Boxes 8, 9, 11, and 12 present various cost estimates for both the Nation on average and for specific HAB events. Non-economic social impacts of HABs are much more difficult to quantify, although efforts are underway to consider these more thoroughly[5]. Ongoing studies to identify animal (Box 26) and human populations at higher risk for adverse toxicity effects (NOAA CCEHBR and NMFS; NIEHS; NSF/NIEHS) will potentially result in more effective management by targeting guidelines to more susceptible populations.

### Public Health Measures

Increased understanding of the link between ocean processes, ecosystem health, and human health is critical to reducing HAB-related public health risks. Since 1998, CDC has supported cooperative agreements with at least five east coast states to assess and control the public health effects from *Pfiesteria piscicida* and other HAB-producing organisms. In the past five years, both NOAA and NIEHS/NSF have developed programs to fund research exploring the interrelationship between oceans and human health. Human health impacts of HABs represent an important component of

## Box 25. Cooperative response to New England red tide

The extensive bloom in 2005 of the toxic dinoflagellate *Alexandrium fundyense* off the New England coast created an unprecedented PSP event that severely impacted the shellfish industry. NOAA CSCOR Event Response provided funding for tracking the bloom progress to guide toxin sampling by state resource managers. One of the factors making this event unique was the extent to which the bloom spread offshore into Federally-controlled waters, which are not monitored routinely by state monitoring programs. FDA worked closely with state laboratories and NOAA NMFS to determine necessary measures for protecting public health, while at the same time minimizing the impact on the shellfish industry. At the request of FDA, NOAA NMFS closed approximately 15,000 square miles of Federal waters in the northwestern Atlantic Ocean on 14 June 2005. Offshore shellfish toxicity was monitored by FDA with assistance from industry and NOAA from the beginning of the closure using the multi-well format receptor binding assay for saxitoxin (see Box 20) as the primary detection method with the AOAC-approved mouse bioassay providing confirmation for regulatory decisions. Analytical data supported reopening a portion of the closure on 9 September 2005 (except for whole and roe-on scallops). Due to timely and effective state responses and the assistance given by FDA and NOAA, there were no human PSP illnesses despite remarkably high toxicity in the unmarketed product.

The industry vessel *Misty Dawn* collecting ocean quahogs for toxicity testing by the FDA during 2005 PSP harvesting closure.
Photo: FDA

### Box 26. Domoic acid shown to bioaccumulate in marine mammals

NOAA NMFS has developed response and research teams which have investigated the impact of domoic acid on marine mammals from an ecosystem perspective in collaboration with NOAA's Oceans and Human Health Initiatitive (OHHI), Monitoring and Event Response for Harfmul Algal Blooms (MERHAB), and Analytical Response Team Programs. This work demonstrated that domoic acid bioaccumulates selectively in the amniotic fluid of pregnant female marine mammals, it causes permanent and often unilateral brain damage, it is responsible for extreme aggression in animals that survive, and it may cause cardiac, neurological, and reproductive damage. Low-dose chronic exposure studies, which are now underway, indicate that domoic acid could have population level effects on endangered species.

these programs. Both funding programs have established a total of seven OHH research centers which address a suite of topics including HABs. The Centers are conducting basic collaborative research to, for example, improve remote sensing capacity, build predictive models, generate strategies for prevention of HAB poisoning, create new detection tools and molecular probes, and establish methods for detecting toxin exposure in human blood and tissues.

In 2004, Congress passed the Oceans and Human Health Act (Box 3), which mandates the generation of an Interagency OHH program and research implementation plan. The purpose of the plan is to create a vision for Federal OHH work across agencies including responses to HABs. The IWG-4H is responsible for writing the implementation plan[48] as well as an annual report to update Congress on all Federal OHH activities.

## Infrastructure

Infrastructure, which ranges from analytical facilities and monitoring tools to public outreach efforts and centralized databases, enhances both the capacity to conduct research and to predict and respond to HAB events. Existing infrastructure (Table 2) that is currently supported by Federal programs includes elements that span all categories of infrastructure as described in Chapter 2.

Informational and data resources, which include databases, web sites, written materials, satellite data, list servers, and broadcast emails can ensure adequate availability of HAB information for researchers, coastal managers, government agencies, public health workers, media, and private citizens. The internet is a powerful tool being used for dissemination of general information, new methods, and HAB data. CDC has recently operationalized a web-based system for efficiently collecting and tracking information on human and animal HAB-related illnesses (Box 27). Education and training on HAB issues is provided informally to stakeholders through brochures and web sites and more formally through the development of citizen monitoring networks, teacher training, and other programs. Workshops conducted through the Intergovernmental Oceanographic Commission (IOC) (NOAA CSCOR) also provide critical training for new HAB experts. The U.S. National HAB office (NOAA CSCOR) maintains web sites and list servers that provide information to the HAB community, and the IOC maintains a global HAB event database with NOAA CSCOR funding. All of these resources represent important tools for increasing awareness of and information about HABs for public health workers, researchers, teachers, and the public, thus reducing harmful impacts[5].

Federal facilities for toxin analysis (CDC; FDA; NSF/NIEHS; NOAA CCEHBR, CCFHR, NWFSC; USGS; USAMRIID) and algal taxonomy (NOAA CCEHBR) provide access to expertise and instrumentation. These facilities are an important resource to HAB responders and researchers, but have limited capacity.

Maintenance, storage, and provision of reference materials are necessary for confirming identification, developing new probes and assays,

### Box 27. Surveillance system for HAB illness

CDC has developed the HAB-related Illness Surveillance System (HABISS, part of the Rapid Data Collection System), a web-based system with the potential for future data entry directly from the field using hand-held instruments. The system is modular, extremely flexible, and unique in that it will combine human and animal health data and environmental data in a single database. States will be able to create additional modules for diseases of other environmental etiologies. This surveillance system will ideally allow states to plan for future HAB events and take appropriate measures to protect public health.

## Table 2. Infrastructure provided or supported by Federal agencies.

| | CDC | EPA | FDA | NASA | NIEHS and NSF | NIST | NOAA/ OAR | NOAA/ NOS | NOAA/ NMFS | NOAA/ NESDIS | NSF | USGS | USAMRIID |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Information resources | Web-based HAB related illness surveillance system<br><br>HAB website | | | Satellite data (ocean color, SST, and ocean surface topography) | Remote sensing data (University of Miami) | | Web vido for assay demonstration (AOML)<br><br>HAB event response website, list-server (GLERL) | National Office for Marine Biotoxins and HABs, Harmful Algae Page website (CSCOR)<br><br>Harmful Algal Event Database (HAE-DAT) (CSCOR)<br><br>HAB Bulletin (CCMA, COOPS)<br><br>Database for HAB event response samples and analysis (CCEHBR) | Environmental Services Data and Information Management (ESDIM), Pacific HAB data, ORHAB database, website (NWFSC)<br><br>Marine Mammal National Database (Office of Protected Resources) | HAB Bulletin | | Documentation of wildlife mortality investigations (USGS National Wildlife Health Center) | |
| Shared Facilities/ Regional Centers | Saxitoxin Analysis | | Toxin analysis facility | | Toxic Algal Culture Facility and Genomics (FIU)<br><br>Culture facility (*Gamberidiscus toxicus* focus) and toxin analysis (PRCMB) | | | Algal taxonomy facility (CCEHBR)<br><br>Toxin analysis facility (CCEHBR)<br><br>Shared mass spectrometry facilities (CCFHR) | Scanning Electron Microscopy (SEM) facility (NWFSC)<br><br>Toxin analysis facility (NWFSC) | | | Toxin analysis facility | Toxin analysis facility |
| Outreach/ Education/ Training | | | Citizen-based monitoring networks | | | | Education/ outreach/ training for undergraduates, graduates, teachers, and K-12 (Sea Grant) | Taxonomic training (CCEHBR, CSCOR)<br><br>Citizen-based monitoring networks (CCEHBR, CSCOR)<br><br>National Office for Marine Biotoxins and HABs (CSCOR) | Educating Teachers at Sea (NWFSC)<br><br>Red Tides Newsletter (NWFSC)<br><br>Training for HAB sampling (NWFSC) | | | | |
| Reference Materials | | Delaware Inland Bays Phytoplankton Culture Collection | | | | National Marine Mammal Tissue Bank | | Center for Culture of Marine Phytoplankton (CCMP) at Bigelow Laboratory (CSCOR)<br><br>Algal reference materials and culture collection (CCEHBR) | Milford Culture Collection (NEFSC)<br><br>Culture Collection (NWFSC) | | UTEX Culture Collection of Algae at the University of Texas at Austin<br><br>Center for Culture of Marine Phytoplankton (CCMP) at Bigelow Laboratory | | |
| Toxins | | | Provide saxitoxin reference standard | | Brevetoxin Standards | | | Toxin reference materials (CCEHBR)<br><br>Ciguatoxin sampling kits to public health and wildlife managers (CCEHBR) | | | | | |
| Satellite and Airborne Sensors | | | | SeaWiFS, MODIS-Aqua (Satellite-based)<br><br>AVIRIS, MAS, MASTER, LIDAR (Aircraft-based)<br><br>AMS (UAV-based) | | | Ocean Color Sensor (UAV- based, Environmental Technology Laboratory) | | | | | | |

AMS: Autonomous Modular Sensor
AOML: Atlantic Oceanographic and Meteorological Laboratory
AVIRIS: Airborne Visible/Infrared Imaging Spectrometer
COOPS: Center for Operational Oceanographic Products and Services
FIU: Florida International University
LIDAR: Light Detection and Ranging
MAS: MODIS Airborne Simulator
MASTER: MODIS/ASTER Airborne Simulator
MODIS: Moderate Resolution Imaging Spectroradiometer
PRCMB: Pacific Research Center for Marine Biomedicine
SeaWiFS: Sea-viewing Wide Field-of-view Sensor

and training new HAB experts. The Center for Culture of Marine Phytoplankton (CCMP) and the "UTEX Culture Collection of Algae" at the University of Texas–Austin are two large algal culture collections in the United States that maintain some HAB species and depend in part on Federal funding (NSF; NOAA CSCOR). Smaller culture collections of HAB species are also located at Federal laboratories (e.g., NOAA CCEHBR, NEFSC, NWFSC), state laboratories, and in some academic laboratories. The National Institute of Standards and Technology (NIST) has established the National Marine Mammal Tissue Bank for long-term storage of marine mammal tissues, which facilitates HAB toxin exposure research. Some toxin standards and radiolabeled toxins are currently made available (NOAA CCEHBR; FDA), but the supply is limited.

Observing systems, which may include data buoys, AUVs, satellites, aircraft, and UAVs, are integral to the research, monitoring, and prediction of HABs. As coordinated networks of observing systems, the Integrated Ocean Observing System (IOOS) and the U.S. Integrated Earth Observation System (IEOS) have the potential to optimize predictive capabilities (Box 17). NASA and NOAA satellites provide ocean biology and physical data, which support NOAA's HAB forecasting. NOAA's buoy-based systems provide meteorological data and can be used as platforms for HAB-specific sensors. NASA has confirmed the launch of the Aquarius satellite in 2010, which will measure sea surface salinity from space with unprecedented precision, providing HAB forecasters with additional data on salinity anomalies, such as freshwater input into coastal systems and its impact on blooms.

## Cooperation/Coordination

Growing cooperation among Federal agencies and among Federal, state, local, and tribal agencies has enhanced HAB monitoring capability. Through multi-agency extramural programs (ECOHAB; NIEHS/NSF), Federal agencies have developed lines of communication for discussing HAB issues. Some Federal programs fund research conducted by other Federal agencies, further improving the flow of critical information among agencies. In addition, coordination among Federal agencies and state and local entities has improved and expanded monitoring capacity, which in turn has reduced potential harmful impacts and saved money for local economies (Box 28). Recently, the IWG-4H, as the body fulfilling the role of the Interagency Task Force on HABs and Hypoxia, has begun providing Federal coordination for HAB research and response.

For many years, the U.S. HAB community (academic researchers, state managers, and Federal agencies) has been well organized as evidenced by the well-attended U.S. HAB symposia (supported by NOAA CSCOR, Sea Grant) which are held every other year. The HAB community has now formed a National HAB Committee (NHC) to provide formal organizational, informational, and technical support to the greater HAB community and facilitate communication with Federal agencies[4]. Although this is an effort outside Federal control, it represents another important opportunity for improving coordination among HAB responders. Other examples of formal coordination include: 1) partnerships among the Interstate Shellfish Sanitation Conference (ISSC), FDA, and state resource managers to insure that commercially available shellfish are not contaminated with HAB toxins and 2) the National Water Quality Monitoring Council—which comprises multiple Federal agencies and state, academic, tribal, and local entities and provides a national forum for coordination of water quality

### Box 28. Innovative collaboration mitigates HAB impacts in Washington


Photo: Vera Trainer, NWFSC

In 1999, the ORHAB partnership (funded by NOAA's MERHAB Program) was organized to develop collaboration and cooperation among Federal, state, and local management agencies; coastal Indian tribes (the Quinault and Makah tribes plus others); marine resource-based businesses; public interest groups; and academic institutions. ORHAB has successfully improved local self-sufficiency in mitigating impacts of HABs by providing better tools for protecting public health, building consumer confidence in fishery products, and enhancing revenues for coastal communities in the Olympic region[47]. It has been estimated that at least $3 million has been saved each year for the Washington coastal fisheries via selective beach openings during bloom events in 2001 and 2003-2005 as a result of the ORHAB partnership.

monitoring, assessment, and reporting.  Programs, such as NOAA's MERHAB, are intended to enhance and formalize partnerships.

Several Federal prediction and response programs have used incentive-based partnerships to enhance delivery of services or development of new technologies.  SBIR programs in EPA and NOAA have motivated private industry to develop new technologies for HAB monitoring.  The NOAA MERHAB program is based on the concept that mitigation of HABs involves a broad spectrum of stakeholders, from citizen volunteers to Federal agencies.  The incentive to participate is a higher level of response capacity than possible for a state acting alone.  Finally, several Federal programs require cost-sharing with other Federal or state governments, foundations, or nonprofit institutions in the funding of HAB prevention and response research, increasing cost-effectiveness of Federal funds.

# Chapter 4

# Opportunities for Advancement

In order to advance HAB prediction and response, it is first necessary to identify areas for improvement in current services and programs. The following approaches have been used to accomplish this: 1) Federal agencies were given the opportunity to highlight issues of concern during the process of collecting information for this report, 2) the *HARRNESS*[4] report included detailed recommendations, many of which directly affect prediction and response, and 3) the HABHRCA 2004 legislation mandated that a summary of this report be published in the Federal Register to solicit comments from the public on how HAB prediction and response might be improved. The public comments were summarized and included in Section 3 below. All of this information and the recommendations from *HARR-HD*[5], which provides a detailed implementation plan for social science research critical to achieve the goals of *HARRNESS*[4], were used by the IWG-4H to shape the RDDTT Plan (Chapter 5) through a carefully conceived workshop process. The RDDTT Plan establishes research priorities and puts forth a coordinated strategy for improving current efforts in HAB prediction and response.

## (1) Approaches for Improving Prediction and Response Identified by Federal Agencies

As part of the process for developing this report, Federal agencies were asked to identify areas where prediction and response could be improved. The following issues were identified and organized into broad categories that were addressed in the workshop and led to the RDDTT Plan described in Chapter 5:

### A. HAB infrastructure development

The following types of infrastructure were specifically identified as priorities for enhancing prediction and response capacity (in no particular order of priority):

i. **Increase availability of certified toxin standards**, labeled toxins, and information on protocols and methods for toxin analysis. Some toxin standards are available in the United States, such as radiolabeled saxitoxin, and a few others are available from Canada, but many other toxin standards, especially certified compounds, are not available.

ii. **Make reference materials more generally available**. Reference materials include molecular probes for cell identification, clonal cell isolates and genetic material for research and refinement of assays, and contaminated and control animal and human tissue samples for developing new protocols and examining past events.

iii. **Improve researcher training in HAB identification and toxin analysis** to ensure a timely response to events, sustain long-term monitoring, and facilitate research to improve prediction and response.

iv. **Locate observing systems with HAB-specific and environmental sensors in areas where HABs occur frequently**. Integration and coordination of observing system data will allow easier data access for scientists and managers. Concomitant model development will use the data from these systems for early warning and prediction.

v. **Make satellite coverage of ocean and coastal zones more comprehensive, add more calibration moorings for satellite data, and integrate existing satellite data**

**into observing systems**. New remote sensing technologies will provide better spatial and temporal coverage of ocean biological and physical data, which will improve HAB prediction, forecasting, and monitoring.

**vi. Augment data repositories and develop protocols for the biological, environmental, public health, economic, and sociocultural data** associated with HAB events and HAB-focused observing systems to make data more generally accessible and data products more readily understood and adopted by non-scientific communities. At present, database management is done on an individual project-by-project basis.

**vii. Improve water quality monitoring on a national scale.** Water quality monitoring activities may alert to conditions conducive to or indicative of HABs, such as high nutrients or low dissolved oxygen. River monitoring would allow calculation of seasonal and annual fluxes of freshwater and loads of constituents from the uplands to coastal marine waters and the Great Lakes. Recently the Advisory Committee on Water Information developed a plan for a possible monitoring network**,** *A National Water Quality Monitoring Network for U.S. Coastal Waters and their Tributaries* (http://acwi.gov/monitoring/network/). The network design includes monitoring of runoff and groundwater inflows where direct discharge into coastal waters is important. As described in the plan, this network would monitor HAB-related parameters and freshwater fluxes. The network also would include monitoring of coastal beaches, estuaries, nearshore marine waters and the Great Lakes, and the ocean to the seaward edge of the Exclusive Economic Zone.

**viii. Promote better coordination and more rapid communication** among Federal agencies (intramural and extramural programs) and between Federal and state entities to strengthen HAB monitoring, reporting, and response. Given that HAB monitoring has traditionally been the responsibility of state agencies (because most HAB events occur in state waters), the role of the Federal government in prediction and response monitoring has been limited. Better coordination of existing resources and response at the national level would improve efficiency (*HARRNESS*[4]), especially as the frequency and geographic extent of the blooms increase and cross-state and international boundaries and the economic impacts broaden. Strategies to promote efficiency and effectiveness of governance should be considered. The social scientific field of "institutional analysis" can contribute to this goal[5].

**ix. Plan to transfer promising new monitoring and prediction technology and approaches from research to operational use**. As monitoring programs expand and new sensors and technologies greatly increase, transferring these capabilities to agencies routinely responsible for local management becomes paramount. Agencies should seek expanded Federal/state/academic partnerships to provide hardware and software, which will permit broader use of new sensors and data, and to enhance training capacities to facilitate routine use.

**x. Develop more HAB-specific sensors**. Quick, accurate tests for HAB cells and toxins for use in the field by managers and harvesters will make monitoring to protect human health faster, cheaper, and allow precise closures. HAB-specific sensors for *in situ* monitoring and satellite remote sensing will facilitate early warning and prediction.

## B. Research on Prevention, Control and Mitigation Strategies that would enhance current prediction and response efforts

**i. Develop permitting processes so that pilot studies can be undertaken and promising technology can be demonstrated in the natural environment for potential adoption as an operational program**. Permitting practices are local decisions, so Federal-state discussions need to be streamlined to foster rigorous assessment of demonstration projects of peer-reviewed control strategies in the field that might have potential for routine use as HAB control. It is only through informed decisions at the local, permitting level that potential HAB controls might be evaluated for potential adoption in coastal systems.

ii. **Research new HAB suppression or control methods**.

**iii. Address prediction and response for inland HABs other than those in the Great Lakes, especially efforts focused on toxins in drinking and recreational waters**. This problem is also discussed in the *Scientific Assessment of Freshwater Harmful Algal Blooms* (Box 7).

### C. Impact assessments, social science approaches, and public and wildlife health surveillance in HAB response that would enhance current prediction and response efforts

**i. Assess environmental, public health, sociocultural, and economic impacts**. Susceptible human and animal populations and community vulnerabilities should be identified to focus mitigation strategies[5].

**ii. Provide a more rigorous social sciences approach to mitigating HAB impacts as recommended by *HARR-HD*[5]**. These studies would determine the extent to which HABs and management responses directly or indirectly impact communities and evaluate the socioeconomic benefits of mitigation strategies, such as HAB forecasts. Assessing public perceptions, identifying and assessing vulnerability of potentially affected communities, and developing strategies for risk communication will improve response efforts[5].

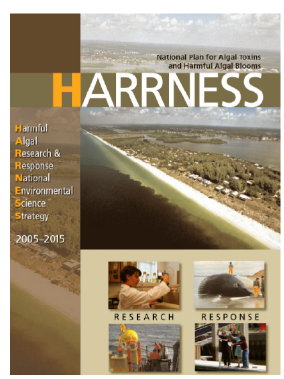
**iii. Improve human HAB-related disease surveillance and reporting** by incorporating a central repository for information and involving non-coastal state health departments since shellfish consumption is not restricted to coastal areas. Development and circulation of guidelines for human exposure to cyanotoxins (in both drinking water and recreational waters) and non food-related exposures to other algal toxins are also discussed in both the *Oceans and Human Health Implementation Plan*[48] (Box 3) and the *Scientific Assessment of Freshwater Harmful Algal Blooms*[14] (Box 7).

**iv. Improve wildlife HAB-related disease surveillance and reporting**. Since a variety of animals serve as sentinels of HAB events, a mechanism for wildlife illness surveillance and reporting will enhance the ability to respond to HAB events. This problem is also discussed in the *Oceans and Human Health Implementation Plan*[48] (Box 3), the *Scientific Assessment of Freshwater Harmful Algal Blooms*[14] (Box 7), and the *Scientific Assessment of Marine Harmful Algal Blooms* (Box 6).

### D. Make Event Response Programs more effective, particularly as numbers and severity of events increase

## (2) Priorities to Improve Prediction and Response Efforts Identified in *HARRNESS*[4]

*HARRNESS*[4] made detailed recommendations for future HAB research and management. Several categories of recommendations are particularly relevant for HAB prediction and response work. Additional recommendations were made, but are not as relevant to this report and will be included in the *Scientific Assessment of Marine Harmful Algal Blooms* report (Box 6).



### Prediction and Response-Specific Recommendations from *HARRNESS*[4]:

#### Reference materials and data management:

- Establish facilities for toxin standards, culture, and genomic resources
- Establish facilities for archiving case and clinical samples
- Establish information databases

#### 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

#### Controls, Monitoring, Prediction, and Mitigation:

- Develop effective, environmentally sound techniques to control/reduce HABs and their impacts
- Develop methods for rapid field-based detection of HABs and toxins
- 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

## (3) Focus Areas Identified in Response to the Federal Register Notice

HABHRCA 2004 required that a summary of this report be published in the FR and be available for public comment for a period of not less than 60 days. While comments were welcome on all aspects of this report, the FRN (Appendix V) specifically requested input on the following: 1) the current state of efforts (including infrastructure) in prediction and response to prevent, control, or mitigate HABs, and 2) suggestions for specific improvements in those efforts.

The majority of public comments were received were from the NHC, a committee recently established as recommended in *HARRNESS* to provide coordination for the HAB research and management community. Comments were also received from four individuals. The major comments are summarized below and revisions have been made, when appropriate, in the final version of this report. Comments were primarily used to inform the workshop and to develop the RDDTT Plan. Minor editorial comments were incorporated, but are not included in the public comment summary.

### Public Comment Summary

#### HAB Detection in the Field Needs More Focus

Existing monitoring technologies cannot fill the need for early detection of dangerous events. Most current field monitoring programs, for example, do not capture offshore HABs, which adversely impact wildlife and can be transported inshore and threaten human health. Moreover, not all blooms can be detected optically (i.e., by in-water optical or satellite remote sensors) because HAB species can share similar optical characteristics with non-HAB species and some HABs may occur when cell concentrations are below detection limits of satellites. The need for more rapid development of new field-based detection systems was not given enough weight in the report. New assays for HAB detection, however, are much more evolved than the impression given by reading the report, as there are a number of U.S. labs running molecular-based assays for HAB species routinely. While these assays do need further development and testing, it is critically important that these assays be integrated into routine monitoring practices and field-based detection systems. Therefore, technology needs include not only species and toxin probes but also the engineering of new devices that will physically house them for monitoring. These devices need to be readily deployable and, ideally, be able to identify cells and/or toxins *in situ* and telemeter their data to shore or satellite. Considerably more engineering funding is needed for the success of such new approaches for HAB detection in the field.

### Wildlife Monitoring and Illness Surveillance Needs More Attention

Marine birds and mammals can be excellent indicators of the presence of toxic blooms as these animals may traverse or feed in waters contaminated by HABs and then return to land. In California, for example, sea lions exhibiting diagnostic symptoms are the very best indicators of toxic blooms. The report mentioned this connection, but the HAB community needs to take greater advantage of the naturally occurring wildlife “sentinels” as indicators of the presence of HABs. To enable use of these natural monitors, new directions of research, cross-discipline collaborations, and innovative thinking will be necessary. Recognition of HAB-exposure symptoms in seals and sea lions, for example, could be a research area receiving more attention. Outfitting seals and sea lions with some type of HAB detector could also be an avenue for research.

### Role of Overfishing Not Recognized Sufficiently

The draft document, as well as much of the HAB community, has rarely mentioned that the increasing presence of HABs around the world’s coastlines is not simply a consequence of what ecologists call “bottom-up” controls on algal growth (e.g. nutrients, pollutants), but also a possible, and likely synergistic, result of “top-down” controls. Some researchers have suggested that the increasing catch of fishery species has ecological effects that cascade down the food chain. To remedy declines in fish catch, fisheries scientists increasingly argue for “marine protected areas”, where ecosystems and high-level predators can begin to repopulate the regions and re-establish healthy ecosystems. Investigations of the link between HAB events (and their potential decline) and higher-level predator recovery in such systems is much needed. Attention has been too narrowly focused on factors that may only partially explain the increasing presence of HABs.

### Role of Nutrients and Nutrient Form Needs More Attention

The report should emphasize the known relationships between nutrients and HABs, as recognized in the GEOHAB report on HABs and eutrophication. Specific HAB events from more oligotrophic areas are highlighted in various boxes in the report, so the increasing occurrence of HABs in eutrophic environments should be highlighted for balance. Secondly, *watershed nutrient reduction* (Box 13) needs to include important efforts by other agencies, such as USGS and EPA, in water quality monitoring and nutrient reduction.

When discussing HAB *prevention* in terms of minimizing nutrient loading, the report needs to specifically recognize that the form of nutrient can be equally important as the quantity. Many HABs favor forms of nitrogen other than nitrate and many, in fact, thrive on organic nutrients. This has important implications for prevention, in that most monitoring efforts focus solely on <u>total</u> nutrient loads or <u>inorganic</u> nutrient loads. Models need to be developed that incorporate the complexity of nutrient form, the processes that alter biogeochemistry of nutrients from land to sea, and new and evolving knowledge of the physiological responses of the HAB organisms. Water quality monitoring plans must also recognize the importance of monitoring nutrient form as well as nutrient loads.

Despite the number of programs working on HAB issues, insufficient steps have been taken in this Nation to reduce nutrient loadings from agribusiness operations through improved practices and regulation.

### Information on Economic Estimates of Prediction and Response Lacking

There is some information provided about the economic effects of HABs, and some of this information comprises estimates of true economic costs. It would be useful to compare information on the economic costs of HABs with estimates of the costs of prediction and response. There appears to be little or no information on the latter in the report. If estimates of prediction and response costs do not exist, this kind of comparison should be an explicit recommendation in Chapter 4.

### Suggestions to Improve Coordination

Strategies to promote efficiency and effectiveness of governance should be adopted and formalized, with mandated quarterly meetings to discuss HAB-related activities that are occurring in each agency and how to effectively encourage collaboration across these efforts. This should be done with the NHC as an advisory board for solicitation of non-Federal comments. Specific advancements in research, education, and training can also be made by improving coordination, interaction, and funding with the international community. Programs such as those identified in Appendix IV should be fostered.

### Suggestions to Advance Event Response Programs

Adoption of event response programs will require routine distribution of information from the programs to appropriate managers and leaders responsible for protecting citizens and living resources in each state. A designated agency representative (for all participating agencies) should use as many avenues as possible, including state Coastal Zone Management staff, National Estuarine Research Reserves staff, NMS staff, and agency extension agents, to reach these state and local hazards administrators.

### More Emphasis on Human Dimensions Needed in Report

In the executive summary, other broad areas for advancement should include the following social scientific needs: 1) assessing the socioeconomic benefits of HAB forecasts at different temporal and regional scales, 2) identifying groups at increased risk of sociocultural, public health, and economic impacts so that mitigation strategies can be focused where needed most, 3) studying and developing practices to promote the effectiveness and efficiency of coordinated governance, institutional, and sociopolitical processes in reducing and responding to the impacts of HABs, 4) assessing public perceptions and management needs to help reduce recreational and drinking water impacts, and 5) improving the communication of forecasts and other information to promote public perceptions and behaviors that reduce vulnerability to HAB impacts.

### Importance of Integrating Social Sciences into the RDDTT Plan

Integrating social science needs into the workshop and subsequent RDDTT Plan is critical, so this process should involve social scientists who are actively engaged with the HAB community. The *HARR-HD* report has been welcomed by the HAB community as expanding on *HARRNESS* recommendations to integrate the human dimensions of HABs into HAB research and response. For this reason, and as the only human dimensions research planning tool available, *HARR-HD* should be explicitly mentioned and used as a key resource in shaping the RDDTT Plan.

### Fisheries Regulations in Federal Waters Need Assessment

An assessment of the regulatory environment for Federal waters is missing from the report. Mitigation of the HABs often comes down to avoidance (e.g., beach closures and shellfish harvesting prohibitions) that are implemented through some type of regulatory action. A general concern, and one that impacts the fishing industry, is that it is very easy to close an area due to a HAB but difficult to re-assess and, if prudent, re-open Federally-controlled waters, which are not under rigorous water quality monitoring programs due to their size and distance from shore. A public document with a set of guidelines or a protocol that could be used in reevaluating a closure in Federal waters would be very beneficial. For this to occur, there would have to be funding for data collection and analysis programs for Federal waters.

Moreover, if the Magnuson-Stevens Fishery Conservation and Management Act (MSA) is going to continue to be used as the regulatory authority to prohibit the possession of a marine resource for reasons of public health, then the MSA should be strengthened and made more explicit in this regard. The MSA, and thereby NMFS, may not be the best mechanism to close waters due to a public health event. As it stands NMFS can only close an area based on the concurrence of the Secretary of Health and Human Services. It could be argued that the Department of Health and Human Services should be given the authority to open and close Federal waters, as it may be a better fit than with NMFS.

End Public Comment Summary

# Chapter 5

# RDDTT Plan

## 5.A. Overview

HABHRCA 2004 mandates the creation of a National Scientific Research, Development, Demonstration, and Technology Transfer (RDDTT) Plan on Reducing HAB Impacts from Harmful Algal Blooms, "a coordinated national research agenda" to improve prediction and response efforts for marine and freshwater HABs. This chapter, the RDDTT Plan, is the final step in the process and presents a strategy (Box 29) for advancing HAB prediction and response in the four focus areas identified in Chapter 4: 1) prevention, control, and mitigation of marine and freshwater HABs, 2) marine and freshwater event response, 3) infrastructure for HAB research and response, and 4) incorporation of social sciences in HAB response programs. This strategy requires interagency coordination among all of the agencies that have a major role in both extramural and intramural HAB research and response: NOAA, EPA, NSF, National Institutes of Health (NIH), NASA, Office of Naval Research (ONR), FDA, CDC, USFWS, USGS, and USDA. Because HABHRCA 2004 requires wide community involvement in the development of reports and plans, a workshop was held with representatives from all sectors of the marine and freshwater HAB communities (Box 30), including Federal and state managers, researchers, and private industry. The workshop findings[10] (http://www.whoi.edu/redtide/page.do?pid=15052) were used by the IWG-4H in formulating this plan.

## 5.B. Process for Developing the RDDTT Plan

The RDDTT Workshop was organized by a Steering Committee (Appendix VI) selected by the IWG-4H. The Steering Committee consisted of representatives of Federal agencies on the IWG-4H with expertise on HABs, as well as representatives of the HAB research and management community nominated by the NHC (http://www.whoi.edu/page.do?pid=13935).

The process of selecting participants for the workshop was designed to ensure breadth of expertise in the subject areas and wide geographic and community sector (management and research; Federal, state, local, tribal, and private industry) coverage. The Steering Committee first developed a list of sub-topics in each of the subject areas that the RDDTT Plan would address. They then listed multiple experts in each of those sub-topics and chose participants based on established criteria. The Steering Committee assigned each participant to a workgroup and chose a workgroup lead. Prior to the workshop, workgroups developed topical status reports and detailed agendas to guide their discussions.

The RDDTT Workshop was held June 22-25, 2007, in Woods Hole, Massachusetts, and consisted of a half-day of plenary talks and two and a half days of alternating workgroup and plenary discussions. Plenary talks described the workshop process, summarized pertinent previous reports, and outlined the current status of HAB infrastructure, PCM, and event response. Workgroups then met to propose approaches for moving forward to improve HAB management and response. Because of the wide array of expertise in the workgroups, ideas developed in individual workgroups were presented in daily plenary sessions to all of the participants to solicit a broad range of feedback as the potential approaches were developed. Detailed notes taken during the workshop discussions were developed into the workgroup report by rapporteurs, workgroup leaders, and the Steering Committee co-chairs.

## Box 29. Outline of RDDTT components

**1. Prevention, Control, and Mitigation: Development, Demonstration, and Technology Transfer**

a. Move promising technologies and strategies, arising from other HAB research programs, to end users
b. Three phases: development (Phase 1), demonstration (Phase 2), technology transfer to end users (Phase 3)
c. Competitive, peer-reviewed research initiative*

**2. Event Response**

a. Provide immediate assistance during events and improve response capacity**
b. National and regional coordinators and regional network of resources***
c. Contingency Fund— similar to current Event Response (http://www.cop.noaa.gov/stressors/extremeevents/hab/current/fact-ev_resp.html)

**3. Core Infrastructure**

a. Increase availability of analytical facilities and reference and research materials, improve integration of HAB activities with existing monitoring and emerging observational programs, enhance communication and coordination
b. National and regional coordinators and regional network of resources***
c. Competitive peer-reviewed research initiative* to develop and support infrastructure

**Structure of competitive peer-review may vary to suit the purpose of the program*
***Requests for assistance would most likely come from state, local or tribal governments.*
****Coordinators for event response and infrastructure can be the same people. In phased implementation, the national coordinators would be put in place first and regional coordinators would be added in next phase.*

The resulting RDDTT Workshop report[10] summarizes the current status of the field, recommends strategies to improve HAB prediction and response, and suggests an implementation process. The RDDTT Plan presented in this chapter, which was written by the IWG-4H, drew from the RDDTT Workshop recommendations as well as recommendations from other relevant reports. These reports included the *HARR-HD* report[5], which identified human dimensions research critical to prevent and respond to impacts of HABs, *HARRNESS*[4], a community consensus report which identified the important components to be included in a national HAB response plan, and the *Scientific Assessment of Freshwater Harmful Algal Blooms*[14], one of the other HAB reports required by HABHRCA 2004.

## 5.C. Three Strategies for Improving HAB Prediction and Response

The workshop process identified three interdependent strategies for advancing HAB prediction and response:

1) conduct research focused on development, demonstration, and technology transfer of methods for PCM of marine and freshwater HABs and HAB impacts,

2) develop regionally organized marine and freshwater HAB event response, and

3) improve availability and support core infrastructure to facilitate HAB research and response.

Descriptions of these strategies are provided in Sections 5.C.1, 5.C.2, and 5.C.3 and are summarized in Box 29. More detailed suggestions are provided in the RDDTT Workshop report [10].

### 5.C.1. PCM Development, Demonstration, and Technology Transfer Strategies

The development of PCM strategies for HABs has been identified as a priority since release of *Harmful Algal Blooms in Coastal Waters: Options for Prevention, Control and Mitigation*[11] and *Prevention, Control, and Mitigation of HABs: A Research Plan*[13]. The *National Assessment of Harmful Algal Blooms in U.S. Waters*[12] observed "there are currently no national research initiatives

## Box 30. Institutions represented at the RDDTT Workshop

### Academic and Private

- Alliance for Coastal Technologies
- Chesapeake Research Consortium
- Cornell University
- Florida Institute of Oceanography
- Marine Mammal Center (California)
- Monterey Bay Aquarium Research Institute
- Mote Marine Laboratory (Florida)
- North Carolina State University
- Oregon State University
- Smithsonian Environmental Research Center
- Spinney Creek Shellfish, Inc. (Maine)
- State University of New York
- University of California
- University of Florida
- University of Maryland Center for Environmental Science
- University of Maryland School of Medicine
- University of Tennessee
- University of Vermont
- Woods Hole Oceanographic Institution
- Wright State University

### State and Tribal

- California Department of Public Health
- Florida Fish and Wildlife Conservation Commission
- Maine Department of Marine Resources Biotoxin Monitoring
- Maryland Department of Natural Resources
- Northwest Indian Fisheries Commission
- Washington Department of Fish and Wildlife Region Six Office
- Washington Department of Health Office of Shellfish and Water Protection

### Federal

- CDC National Center for Environmental Health, Health Studies Branch
- EPA National Center for Environmental Research
- FDA Center for Food Safety and Applied Nutrition
- NASA Laboratory for Hydrospheric Processes and Goddard Space Flight Center
- NIEHS National Toxicology Program
- NOAA
  - CCEHBR Marine Biotoxins Program
  - CCMA
  - CSCOR
  - NCCOS Human Dimensions Research
  - National Sea Grant College Program
  - Northwest Fisheries Science Center
  - Office of Protected Resources
- USAMRIID
- USGS

to promote efforts in prevention, control, and mitigation of HABs and their impacts." A call for applied research to develop PCM tools was also made in HABHRCA 1998 and the 2004 reauthorization, the *HARRNESS* report[4], the International Symposium on Cyanobacterial Harmful Algal Blooms proceedings[49], and in Chapter 4 of this report.

Effective management of HABs and their impacts requires a comprehensive, multi-pronged approach that must include strategies for PCM. Real progress has been made in some aspects of PCM (Chapter 3), particularly in the area of mitigating bloom impacts by improved monitoring and early warning (Boxes 19, 25, 28). Promising options for HAB control or suppression have been developed, such as removal by clay flocculation (Box 18) and use of HAB-specific biological controls, but many obstacles must still be overcome before control methods can be used during blooms. HAB prevention is the ultimate goal, but the complexity of the HAB organisms and the ecosystems in which they live make this the most significant challenge of all. As the problems associated with HABs continue to expand, the need to find practical, cost-effective, and long-term solutions will undoubtedly increase as well.

The proposed PCM approach would focus available resources on conducting peer-reviewed competitive research to move promising technologies and strategies from development through demonstration to technology transfer. These steps would depend on concepts, technologies, and strategies generated by other HAB research programs, such as ECOHAB, MERHAB, Sea Grant, and the various OHH programs. There is strong support in management communities for the development of new PCM tools. Thus, end-users, including local, state, and Federal resource and public health managers, nonprofit organizations, and a variety of businesses must be involved throughout the process. Social science research would be included in all phases to ensure socially responsible development and effective implementation of PCM technologies and strategies.

Competitive, peer-reviewed research on PCM should be conducted in three phases with rigorous review at each stage to insure cost effective implementation:

**Development (Phase I):** This phase is proposed to support development and evaluation of promising PCM technologies and strategies, including human dimensions research advancing PCM. Phase I research will establish the suitability of a technology, approach, or product for achieving PCM goals and objectives. All Phase I proposals must demonstrate active discussion of their research plans with relevant end-users and involve these individuals or agencies in the evolution of the PCM concept from research and development through operational use. The goal of these interactions is not necessarily to establish "support," but rather to learn about the challenges facing these managers and confirm the relevance of the proposed research in addressing these challenges.

**Demonstration (Phase II):** This phase is proposed for field testing, validation, and evaluation of PCM strategies across a range of temporal and spatial scales. In addition to scientific and engineering studies related to HAB PCM, assessments of socioeconomic costs and benefits, as well as educational/outreach activities, needed to support evaluation and implementation of these strategies will be addressed. In order to be considered for Phase II, projects must establish the feasibility and potential effectiveness of the proposed PCM technology or strategy either through the successful completion of a Phase I PCM project or the equivalent if funded outside of the formal PCM program. Phase II and III projects will be guided by an advisory committee, which will include the PCM research program manager and members of the research, intended user, and human dimensions communities. Involvement of PCM researchers and user groups throughout the PCM development, demonstration, and implementation processes will ensure that projects with the most societal relevance are supported and brought into operational use.

**Technology Transfer (Phase III):** This program element will support the formation of partnerships and the ultimate transitioning of validated PCM technologies and strategies to end-users. Crucial aspects of this element will include education, training, and capacity-building. Phase III projects will have either successfully completed a Phase II demonstration project or undergone a comparable process.

Although some research has been transitioned to operational use (e.g., Boxes 19 and 28), many more promising HAB response technologies are available for transition. Examples of prevention include modifications of hydrodynamic conditions and methods to avoid introducing HAB cells and cysts as invasive species. Although nutrient reduction is also a very promising strategy, many nutrient management programs already exist and are motivated by issues other than HABs. Methods of control or bloom suppression through the removal of HAB cells or toxins by biological, chemical, or mechanical means are ready for further investigation. For example, mechanical removal by clay flocculation (Box 18) is one approach that has already been tested in pilot field studies, so is ready for further Phase II evaluation. A number of biological control methods are ready for Phase 1 development for use in the field with concomitant research in risk communication to construct messages that foster public understanding, trust, and participation in decision-making about appropriate control strategies. Many opportunities exist to improve mitigation to reduce the impacts of HABs. A few examples include developing new methods of monitoring and forecasting HAB cells and toxins; maintaining safe seafood, water, and beaches to limit exposure to HABs and their toxins; preventing and treating human and animal disease syndromes; assessing the socioeconomic impacts of HABs and the effectiveness of PCM strategies; and advancing education and outreach.

Transitioning PCM tools from concept to operational use is a demanding process, analogous in scale to developing a promising drug, carrying out clinical trials, and marketing it. The research, engineering, and testing needed to transition from research to operational use is associated with both high risks and high costs. Traversing this transition requires both the motivation ("push") on the part of researchers to take on this risk and the desire ("pull") from end-users needing the operational tool. A strategy focused on transitioning PCM from research to technology transfer that includes both researchers and end-users will increase both the "push" and the "pull".

### 5.C.2. Improvement Strategies for Event Response

Further development of the capacity for anticipating HAB events and responding rapidly would facilitate mitigation of HAB impacts. The range of stakeholders involved in event response depends upon the nature of the HAB, the geographic area affected, and the implications for health and local economies. States, counties, tribes, and academic researchers are generally the first responders. In some instances, the aquaculture industry has also acted as a front line responder by providing helpful data to state managers. When HAB events occur on small, localized scales, the capacity and financial resources of individual states usually are sufficient to respond quickly and effectively if there is a local history of the occurrence of HABs. A good example of this kind of response capacity is Maine's shellfish monitoring and closure program. Under normal conditions, the state is able to mitigate adverse public health outcomes through the imposition of a system of carefully timed and positioned shellfish closures. Additional examples of well-organized states include Florida, California, Washington, and Maryland. Oregon and Texas are currently improving their capacities.

However, as HABs increasingly occur at larger scales and/or with greater frequency, have a broader scope of impact, or involve species that are new to state or regional waters, the capacity for responding rapidly may be inadequate or nonexistent. In addition, freshwater HAB events are occurring in states that have never before needed a capacity for response. These frequently toxic freshwater blooms can threaten public water supplies and lead to widespread recreational impacts. In marine systems, large-scale HAB events can lead to extensive closures of shellfisheries in states that may not have the equipment, personnel, or financial resources to monitor, evaluate, and mitigate impacts adequately. The difficulty responding at the state level to new or large-scale HAB events is, in part, a product of inexperience, lack of resources, and the unpredictable nature of such events. It is costly and time-consuming to develop a response capacity for events that are sporadic or rare, or for those that have increased in frequency and scale, and for which damages are very uncertain. These characteristics argue strongly for a regional approach to event response, so that experience and capacity within a region or even across regions can be brought to bear quickly and effectively to lessen or prevent impacts from new, large-scale, or repeated HAB events. In effect, such an approach helps a region and the Nation protect more effectively against the likelihood of significant public health effects, ecological impacts, and economic damages that could arise from unusual, unpredictable, and devastating HAB events. Regional alliances such as the Gulf of Mexico Alliance and the West Coast Governors' Agreement on Ocean Health may represent possible coordination mechanisms.

Both Federal legislation and numerous recent reports have stressed the importance of improved event response. HABHRCA 1998 requires the implementation of a coordinated response system to support state and local efforts during HAB events, and HABHRCA 2004 requires a plan for programs to reduce the frequency and intensity of HAB events and their impacts. Further, *HARRNESS*[4] calls for: 1) the development of early warning systems, response plans, and methods to reduce exposure and 2) improved coordination of responses across local and regional scales. Thus, Chapter 4 of this report recommended that improving and coordinating event response should be part of the RDDTT Plan.

Management response to HAB events to protect human and animal health and coastal economies usually occurs at the state and local levels. However, HAB events can occur suddenly and overwhelm existing event response capabilities, especially in the case of a newly emerging HAB problem or a large-scale or persistent event. Although such events pose major management challenges, they also provide an unequalled opportunity to improve understanding of the causes and consequences of HABs in order to advance future HAB response efforts. Current Federal HAB event response programs are effective for assisting managers and adding to the knowledge base, but were nearly overwhelmed in 2005 when multiple major events occurred within several months (Box 8 and 9). The current programs may have difficulty addressing any increases in HAB frequency or intensity.

There are currently only two HAB event situations which require a Federal response. Under authority of the MSA, if a bloom that threatens public health occurs in Federal waters, then FDA can request that NOAA NMFS take appropriate action, such as temporarily closing a commercial fishery. The other exception is if federally protected species are involved, in which case the appropriate Federal agency (NOAA, USFWS, or USGS) responds. However, in both cases states are often involved as well. In all other cases the role of the Federal government is to provide assistance at the request of state and local governments.

The workshop report[10] (http://www.whoi.edu/redtide/page.do?pid=15052) proposes establishing regionally based, national marine and freshwater HAB event response programs. These regionally based programs would have two components:

1) Regional marine and freshwater coordinators who would maintain web sites cataloging regionally available resources, assist in developing regional response plans, organize training and information-sharing workshops, and provide coordination during events, if requested by Federal, regional, state, or local authorities. The regional coordinators would also request resources from other regions and, if needed, request funding from emergency funding sources, and

2) National marine and freshwater coordinators who would assist regional coordinators during unprecedented HAB events.

NOAA has already instituted a pilot event response program for marine HABs and freshwater HABs in the Great Lakes and upper reaches of estuaries (http://www.cop.noaa.gov/stressors/extremeevents/hab/current/fact-ev_resp.html) coordinated nationally by the MERHAB and ECOHAB program managers.

### 5.C.3. Improvement Strategies for Infrastructure

Advances both in basic knowledge and in methods and tools have led to significant new opportunities for responding to HABs to reduce or prevent their impacts. However, as HAB research and response has matured, the infrastructure requirements of the community have also increased (see Table 2 for an interagency list of existing infrastructure). Areas to improve infrastructure were identified in the first National HAB Plan in 1993[2] and reiterated in the revised national plan for 2005-2015[4]. Ways to improve event response, research, and implementation of new PCM strategies include: 1) increased availability of adequate analytical facilities, reference and research materials (e.g., toxin standards, culture collections, tissue banks), technical training, and access to data; 2) improved integration of HAB activities with existing monitoring and emerging observational programs; and 3) enhanced communication and regional and national coordination.

The workshop[10] (http://www.whoi.edu/redtide/page.do?pid=15052) proposed to accomplish this goal by developing a regional network with national and regional coordinators to leverage existing resources, encourage coordination and foster active communications with users and stakeholders within and between regions. Because of the similarity in structure and function between the national and regional networks for infrastructure and event response, the functions of the national and regional coordinators could initially be combined for the two efforts, and as efforts expand, the functions could be separated. As described in the event response section, regional alliances which represent partnerships among states and with Federal agencies could provide a structure for these regional HAB networks. It will be the responsibility of the national and regional coordinators to determine the mechanisms for moving forward on the specific recommendations described below. The approach may differ by region.

Detailed descriptions are given below (see Sections 5.C.3.a.–5.C.3.e). They would improve access to existing resources through better information sharing, communication, and coordination.

### 5.C.3.a. Priorities for Improved Infrastructure

**Analytical, Reference, and Research Materials**

Shared-use analytical facilities provide access to expensive, state-of-the-art equipment in situations where their purchase by a single user may not be justified, yielding an overall savings in community research funds. These shared facilities will allow frontiers of knowledge to expand, while encouraging the development of standardized methods and supporting training of new scientists and technicians. The existence of analytical facilities accessible to the entire HAB community will promote the development of new analytical methods and sensor technologies. These facilities might be located in academic, state, or Federal laboratories.

Toxin reference materials are highly purified toxins whose properties (i.e., mass, purity, stability) are sufficiently characterized to be used in calibrating instruments, assessing methods, or assigning concentrations to materials. Certification of a reference material establishes its accuracy within a stated level of confidence and is essential in the modern regulatory environment.

Other research materials include items such as HAB cultures, isolated cell cultures, purified but not certified toxins, molecular probes, genetic material, and animal and human tissue samples. Shared research materials such as these are critical to develop and verify new techniques, assure uniformity of analyses, and allow retrospective analysis of HAB events as technology improves.

**Training**

Training also plays an important role in basic infrastructure as a highly qualified workforce is essential to respond to HAB events. Training includes advanced courses, workshops, and mentoring opportunities. This training can be integrated with analytical facilities and repositories to provide specialized techniques involving instrumental methods and effective utilization of research material. Sponsored mentoring and career development awards are effective for more in-depth training, to rebuild expertise in disappearing skills such as taxonomy, as well as enabling established

Science teachers learn how to identify Lake Erie plankton as part of a science-teacher collaborative workshop. *Photo: Anne Danielski*

Table 3. Federal agencies involved in HAB research and response

| Agency | Program or Office | Extra-mural | Intra-mural | Marine, Great Lakes | Fresh-water |
|---|---|---|---|---|---|
| NOAA, EPA, NSF, NASA, ONR | ECOHAB Program | ■ | | ■ | |
| NSF, NIH (NIEHS) | Centers for Oceans and Human Health | ■ | | ■ | |
| CDC | National Center for Environmental Health | ■ | ■ | ■ | |
| DOD | Army Corps of Engineers | | ■ | | ■ |
| EPA | Office of Research and Development | ■ | ■ | ■ | ■ |
| | Gulf of Mexico Program | ■ | | ■ | ■ |
| FDA | Center for Food Safety and Applied Nutrition | | ■ | ■ | ■ |
| NASA | Applied Sciences Program | ■ | | ■ | |
| NIH | National Institutes of General Medical Sciences | ■ | | ■ | ■ |
| | National Institute of Environmental Health Sciences | ■ | | ■ | |
| NOAA | MERHAB Program | ■ | | ■ | |
| | Oceans and Human Health Initiative | ■ | ■ | ■ | |
| | Sea Grant College Program | ■ | | ■ | |
| | CICEET | ■ | | ■ | |
| | Northwest and Northeast Fisheries Science Centers | | ■ | ■ | |
| | NCCOS | | ■ | ■ | |
| | GLERL | | ■ | ■ | |
| | National Marine Sanctuaries | | ■ | ■ | |
| | Marine Mammal Health and Stranding Response Program | ■ | ■ | ■ | |
| NSF | Biological Oceanography Program | ■ | | | |
| USDA | Agricultural Research Service | ■ | | | ■ |
| USGS | Various centers | | ■ | ■ | ■ |
| USFWS | Various offices | | ■ | | ■ |

researchers to take on emerging technologies. Continual training assures maintenance and expansion of workforce skill sets and promotes technical advancements necessary to continue to meet the expanding research and management needs for HAB prediction and response.

**Monitoring and Emerging Observational Programs**

Field monitoring is increasingly being conducted from buoys, aircraft, satellites, ships, and ferries. Much of this network will be part of the newly emerging observing systems such as the IOOS, which is the U.S. contribution to the GOOS, both of which list HABs as a priority area of concern. These are also part of the incipient GEOSS. In addition, the Ocean Observatories Initiative, while not part of a monitoring network, may provide data useful for research on HABs and thus contribute to improved management and response strategies. This suite of observations can provide information on the environmental conditions favoring, accompanying, or inhibiting harmful algal species and their toxin expression. Monitoring for harmful algae and their adverse effects on humans and wildlife provides the foundation for operational modeling and forecasting and, when appropriately condensed and interpreted, can then be used to improve predictions of HAB events, promote mitigation efforts, and reduce public health risks. It will be important to maintain dialogue with these ocean observing initiatives as they unfold, given their potential role in HAB monitoring and prediction. To be useful to HAB management, observing systems must be located in areas where HABs frequently occur and must have sensors capable of detecting HAB cells and toxins and monitoring the environmental conditions that foster blooms. They must also deliver integrated data sets that can be used in operational mode for forecasting HAB events.

**Communication and Networking**

A primary goal of communication and networking is to maintain and disseminate information about HABs that is accurate, timely, and targeted to the appropriate audience so that individuals, groups, and communities understand the message, trust its source, and respond appropriately. Information should be developed in forms that are easily accessible and understandable to a variety of age and interest groups. Many impacted communities also have special cultural or other needs that should be recognized so that information is conveyed in formats that are meaningful and useful. Specialists in risk communication should be involved in developing effective communication messages and delivery strategies. Risk communication specialists would use social science methods (e.g., focus groups, message pretest studies, and field surveys) to develop effective messages and delivery mechanisms integral to education and outreach efforts.

Sentinel mussel bags placed on a monitoring buoy in Casco Bay, Maine. *Photo: Maine DMR*

### 5.C.3.b. Coordinated Regional Infrastructure Network

National marine and freshwater infrastructure coordinators in appropriate agencies, who work with regional resources and communication capacities to provide inventories, updates, and contact information to users in the region, could provide regional coordination for marine and freshwater HAB infrastructure. These coordinators would maintain an active link to, and coordination with, other regional programs, such as Sea Grant extension and outreach. Regional coordinators and regional advisory teams of scientists, managers, and industry representatives would regularly interact with the national coordinator to further guarantee focused regional resource recognition. At the national level, the national and regional coordinators would interface with Federal agencies and the NHC to continue to identify new partnerships that enable leveraging of all resources.

## 5.D. The Role of Existing HAB Programs for RDDTT

It must be emphasized that achieving the goals identified in this report depends on the extramural and intramural HAB programs that already conduct HAB research and response (Table 3). The extramural, interagency (NOAA, EPA, NSF, NASA, ONR) ECOHAB Program, the NOAA and NIEHS/NSF OHH programs, and the NOAA Sea Grant programs fund basic and applied (or mission-oriented) research on ecological, physical, chemical, and human health issues related to HABs. Intramural research conducted within Federal agencies is a major component of the U.S. HAB research effort and some agencies already carry out operational HAB prediction and response activities. The NOAA MERHAB Program should continue to focus on long-term HAB response capacity and establish science-management partnerships, leading to more effective monitoring programs and the movement of new HAB detection tools into routine use by monitoring and response programs. Strong partnerships between the HAB programs and wildlife programs leverage available information on impacts of HABs on ecosystems and populations. The relatively new OHH programs have the potential to provide the linkages between the scientific and biomedical communities through the support of interdisciplinary research in areas where improved understanding of marine processes and systems has the potential to reduce public health risks.

## 5.E. Benefits of Implementing the RDDTT Plan

Implementation of the strategies outlined in this Plan will yield many benefits both for the public health and management communities and for residents, resource users, businesses, and other stakeholders in at-risk and affected coastal communities. It will also address many of the frustrations that people living in HAB-impacted communities experience and provide them with new approaches to address the problems. These benefits could include:

- Healthier fisheries industries selling seafood that is safer with respect to biotoxins,
- Reductions in the frequency and impacts of highly toxic or large, unsightly and noxious accumulations of algae,
- Ecosystems that are less threatened by invasions of non-indigenous HAB species,
- Mitigation of bloom impacts using a suite of practical, previous tested strategies,
- Sophisticated, yet less expensive, easy-to-operate instruments for HAB detection,
- Teams of scientists, managers, and community leaders prepared to respond to events,
- Improved prediction and early warning of blooms and HAB impacts due to better predictive models, networks of moored automated observing systems, and satellite surveillance capability for detection and tracking over large distances,
- Improved human, animal, and ecosystem health and risk assessment,
- Effective means of educating and warning the public,
- Prevention of human health impacts, and
- Prevention of economic impacts and community disruption.

# References


1. Hoagland, P., Scatasta, S. 2006. The economic effects of harmful algal blooms. In E. Graneli and J. Turner, eds., *Ecology of Harmful Algae*. Ecology Studies Series. Dordrecht, The Netherlands: Springer-Verlag, Chap. 29.
2. Anderson, D.M., Galloway, S.B., Joseph, J.D. 1993. *Marine Biotoxins and Harmful Algae: A National Plan*. WHOI Technical Report-93-02, Woods Hole Oceanographic Institution, Woods Hole, MA. 44pp
3. Jewett, E.B., Lopez, C.B., Dortch, Q., Etheridge, S.M. 2007. *National Assessment of Efforts to Predict and Respond to Harmful Algal Blooms in U.S. Waters*. Interim Report. Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology. Washington, DC.
4. HARRNESS. 2005. *Harmful Algal Research and Response: a National Environmental Science Strategy 2005-2015*. Ramsdell, J.S., Anderson, D.M., and Glibert, P.M. (eds.) Ecological Society of America, Washington, D.C., 96pp. http://www.whoi.edu/redtide/nationplan/HARRNESS.pdf
5. Bauer, M. (ed). 2006. H*armful Algal Research and Response: A Human Dimensions Strategy*. National Office for Marine Biotoxins and Harmful Algal Blooms, Woods Hole Oceanographic Institution, Woods Hole, MA., 58 pp http://coastalscience.noaa.gov/stressors/extremeevents/hab/HDstrategy.pdf
6. Anderson, D.M., Hoagland, P., Kaoru, Y., White, A.W. 2000. *Estimated Annual Economic Impacts from Harmful Algal 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.
7. 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.
8. NOAA Economic Statistics Report. 2006. http://www.economics.noaa.gov/library/documents/economic_statistics_and_methodology/NOAAEconomicStatistics-May2006.pdf
9. Hoagland, P., Anderson, D.M., Kaoru, Y., White, A.W. 2002. The economic effects of harmful algal blooms in the United States: estimates, assessment issues, and information needs. Estuaries 25(4b): 677-695.
10. Dortch, Q., Anderson, D., Ayres, D., Glibert, G. (eds.). 2008. *Harmful Algal Bloom Research, Development, Demonstration and Technology Transfer Workshop Report*. http://www.whoi.edu/redtide/page.do?pid=15075.
11. Boesch, D.F., Anderson, D.M., Horner, R.A., Shumway, S.E., Tester, P.A., Whitledge, T.E. 1997. *Harmful Algal Blooms in Coastal Waters: Options for Prevention, Control, and Mitigation.* NOAA COP Decision Analysis Series No.10, NOAA Coastal Ocean Office, Silver Spring, MD 46 pp. + appendix
12. CENR. 2000. *National Assessment of Harmful Algal Blooms in U.S. Waters*. National Science and Technology Council Committee on Environment and Natural Resources, Washington, D.C., 38pp.
13. Sea Grant. 2001. *Prevention, Control, and Mitigation of Harmful Algal Blooms: A Research Plan.* NOAA National Sea Grant College Program. 28pp.
14. Lopez, C.B., Jewett, E.B., Dortch, Q., Walton, B.T., Hudnell, H.K. 2008. *Scientific Assessment of Freshwater Harmful Algal Blooms.* Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology. Washington, DC.
15. Anderson, D.M. 1989. Toxic algal blooms and red tides: A global perspective, pp. 11-16. In: T. Okaichi, D.M. Anderson, and T. Nemoto (ed.) *Red Tides: Biology, Environmental Science and Toxicology.* Elsevier, New York.
16. Hallegraeff, G.M. 1993. A review of harmful algal blooms and their apparent global increase. *Phycologia* 32: 79-99.
17. Hallegraeff, G.M. 2003. Harmful algal blooms: a global overview. In: Hallegraeff, G.M., Anderson, D.M., Cembella, A.D. (eds.) *Manual on Harmful Marine Microalgae*. UNESCO, Paris, 793 pp.
18. Smayda, T.J. 1990. Novel and nuisance phytoplankton blooms in the sea: evidence for a global epidemic, pp. 29-40. In: Graneli, E., Sundstrom, B., Edler, L., Anderson, D.M. (eds.) *Toxic Marine Phytoplankton*. Elsevier.
19. Landsberg, J.H., Hall, S., Johannessen, J., White, K., Conrad, S., Flewelling, L.J. 2002. Pufferfish poisoning: widespread implications of saxitoxin in Florida. In: Abstracts of the International Harmful Algal Bloom Conference, St. Petersburg, FL, October 21–26.
20. Bates, S.S., Bird, C.J., de Freitas, A.S.W., Foxall, R., Gilgan, M., Hanic, L.A., Johnson,G.R., McCulloch, A.W., Odense, P., Pocklington, R., Quilliam, M.A., Sim, P.G., Smith, J.C., Subba Rao, D.V., Todd, E.C.D., Walter, J.A., Wright, J.L.C. (1989). Pennate diatom *Nizschia 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.
21. GEOHAB. 2006. *Global Ecology and Oceanography of Harmful Algal Blooms, Harmful Algal Blooms in Eutrophic Systems*. Glibert, P. (ed.). IOC and SCOR, Paris and Baltimore, 72 pp.
22. Glibert, P.M., Anderson, D.M., Gentien, P., Graneli, E., Sellner, K.G. 2005. The global complex phenomena of harmful algal blooms. *Oceanography* 18(2): 136-147.
23. Chorus, I., Bartram J. (eds) 1999. *Toxic Cyanobacteria in Water: a Guide to Their Public Health Consequences, Monitoring and Management*. E & FN Spon: published on behalf of the World Health Organization, London, 416 pp.
24. Jin, D., Thunberg, E., Hoagland, P. 2008. Economic impact of the 2005 red tide event on commercial shellfish fisheries in New England. *Ocean and Coastal Management*. 51(5): 420-429.
25. Habas, E. J. and Gilbert, C. K. 1975. A preliminary investigation of the economic effects of the HAB of 1973-1974 on the west coast of Florida. In: LoCicero V.R., (ed.) *Proceedings of the First International Conference on Toxic Dinoflagellate Blooms*, The Massachusetts Science and Technology Foundation.

26. Steidinger, K.A., Landsberg, J.H., Tomas, C.R., Burns, J.W. 1999. Harmful algal blooms in Florida, Unpublished technical report submitted to the Florida Harmful Algal Bloom Task Force, Florida Marine Research Institute, 63pp.
27. Landsberg, J. H. 2002. The effects of harmful algal blooms on aquatic organisms. *Reviews in Fisheries Science* 10: 113-390.
28. Doucette, G.J., Cembella, A.D., Martin, J.L., Michaud, J., Cole, T.V.N., Rolland, R.M. 2006. Paralytic shellfish poisoning (PSP) toxins in North Atlantic right whales *Eubalaena glacialis* and their zooplankton prey in the Bay of Fundy, Canada. *Marine Ecology Progress Series* 306: 303-313.
29. Flewelling, L.J., Naar, J.P, Abbott, J., Baden, D, Barros, N., Bossart, G.D., Bottein, M.D., Hammond, D.G, Haubold, E.M., Heil,C.A., Henry, M.S., Jacocks, H.M., Leighfield, T.A., Pierce, R.H., Pitchford, T.D., Rommel, S.A., Scott, P.S., Steidinger, K.A., Truby, E.W., Van Dolah, F.M., Landsberg, J.H.2005. Unexpected vectors of brevetoxins during marine mammal mortalities. *Nature* 435:755-756.
30. Rensel J E 1993. Severe blood hypoxia of Atlantic Salmon (Salmo salar) exposed to the marine diatom Chaetoceros concavicornis p. 625-630. In *Toxic Phytoplankton Blooms in the Sea* Proc. 5th Int. Conf on Toxic Marine Phytoplankton. Elsevier.
31. Yang, C.Z., Albright, L.J., Yousif, A.N.. 1995. Oxygen radical mediated effects of the toxic phytoplankter Heterosigma carterae on juvenile rainbow trout Oncorhynchus mykiss. Diseases Aq. Organisms 23: 101-108.
32. Horner, R.A., Garrison, D.L., Plumley, F.G. 1997. Harmful algal blooms and red tide problems on the U.S. west coast. *Limnol. Oceanogr*. 42: 1076-1088.
33. Watson, S. 2001. Literature Review of the Microalga Prymnesium parvum and its Associated Toxicity. http://www.tpwd.state.tx.us/publications/pwdpubs/media/pwd_rp_t3200_1158.pdf
34. Onuf, C.P. 1996. Seagrass response to long term light reduction by brown tide in upper Laguna Madre, Texas: Distribution and biomass patterns. *Marine Ecology Progress Series* 138:219-231.
35. Valiela, I., McClelland, J., Hauxwell, J., Behr, P.J., Hersh, D., Foreman, K. 1997. Macroalgal blooms in shallow estuaries: Controls and ecophysiological and ecosystem consequences. *Limnology and Oceanography* 42:1105-1118.
36. Ayers, D., Reed, H. 2004. Managing important recreational and commercial shellfish fisheries around harmful algal blooms. In Droscher. T.W., Fraser, D.A. (eds.) *Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference*. Session 4F. http://www.psat.wa.gov/Publications/03_proceedings/start.htm
37. Interorganizational Committee on Guidelines and Principles for Social Impact Assessment. 2003. Principles and guidelines for social impact assessment in the USA. *Impact Assessment and Project Appraisal* 21(3): 231-250.
38. Anderson, D.M. 2004. Prevention, control, and mitigation of harmful algal blooms: multiple approaches to HAB management. In: Hall, S., Etheridge, S., Anderson, D., Kleindinst, J., Zhu, M., Zou, Y. (eds.) *Harmful Algae Management and Mitigation*. Asia-Pacific Economic Cooperation (Singapore):APEC Publication #204-MR-04.2, pp. 123-130.
39. GEOHAB 2001. *Global Ecology and Oceanography of Harmful Algal Blooms, Science Plan.* In: Glibert, P., Pitcher, G. (eds.) SCOR and IOC, Baltimore and Paris, 86 pp.
40. *Harmful Algae Management and Mitigation. 2004.* Hall, S., Etheridge, S., Anderson, D., Kleindinst, J., Zhu, M., Zou, Y. (eds.) Asia-Pacific Economic Cooperation (Singapore):APEC Publication #204-MR-04.2
41. Masser, M.P. 2000. Aquatic vegetation control. In Stickney, R.R. (ed.) *Encyclopedia of Aquaculture*. John Wiley and Sons Inc., New York, pp. 51-61
42. Deeds, J.R., Mazzaccaro, A.P., Terlizzi, D.E., Place, A.R. 2004. Treatment options for the control of the ichthyotoxic dinoflagellate *Karlodinium micrum* in an estuarine aquaculture facility: A case study. In: Hall, S., Etheridge, S., Anderson, D., Kleindinst, J., Zhu, M., and Zou, Y. (eds.) *Harmful Algae Management and Mitigation*. Asia-Pacific Economic Cooperation (Singapore):APEC Publication #204-MR-04.2, pp. 177-181.
43. Jeong, H.J., Kim, H.R., Kim, K.I., Kim, K.-Y., Park, K.-H., Kim, S.T., Yoo, Y.D., Song, J.Y., Kim, J.S., Seong, K.A., Yih, W.H., Pae, S.J. 2002. NaOCl produced by electrolysis of natural seawater as a potential method to control marine red-tide dinoflagellates *Phycologia* 41: 643-656.
44. http://www.start1.com/redtide/research.aspx
45. Barrett, P.R.F., Littlejohn, J.W., Curnow, J. 1999. Long-term algal control in a reservoir using barley straw. *Hydrobiologia*. 415: 309-313.
46. Rounsefell, G.A., Evans, J.E.. 1958. Large-scale experimental test of copper sulfate as a control for the Florida red tide. U.S. Fish Wildlife Service, Spec. Sci. Rep. Fish. 270, 57 p.
47. Red Tides Newsletter. 2002. Northwest Fisheries Science Center and Washington Sea Grant Program. Autumn 2002.
48. Sandifer, P., Sotka, C., Garrison, D., Fay, V. 2007. *Interagency Oceans and Human Health Research Implementation Plan: A Prescription for the Future*. Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology. Washington, DC.
49. Hudnell, H.K. (ed.) 2008. *Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs. Advances in Experimental Medicine & Biology*. Vol. 619. Springer. 500 pp.
50. Crago, T. 2006. Scientists Join Forces in Search for Faster Detection of Harmful Algal Blooms. Two if by Sea. MIT and WHOI Sea Grant Newsletter. 9 (1).
51. U.S. Food and Drug Administration. 2001. Fish and fisheries products, hazards, and controls guidance. Third Edition.

# *Appendices*

# Appendix I. Federal Prediction and Response Programs

## A. Multi-agency Efforts

### 1. Centers for Oceans and Human Health

The **National Institute of Environmental Health Sciences** (NIEHS) and NSF support four Centers for Oceans and Human Health (COHH): the University of Miami Oceans and Human Health Center, the Pacific Research Center for Marine Biomedicine, the University of Washington's Pacific Northwest Center for Human Health and Ocean Studies, and the Woods Hole Center for Oceans and Human Health. The centers foster interdisciplinary collaborations using oceanography, chemistry, genomics, proteomics, risk prevention and public health approaches to address OHH research, including HABs (http://www.niehs.nih.gov/dert/cohh/).

At the **University of Miami's Oceans and Human Health Center,** two research projects specifically focus on HABs, 1) Toxic HABs (Toxic Algae: a General Phenomenon in Subtropical and Tropical Coastal Waters and Open Ocean Environments), and 2) HAB Functional Genomics (Functional Genomics of a Subtropical Harmful Algal Bloom Species: *Karenia brevis*). In addition, genomics, remote sensing and toxic algal culture facilities have or are being developed to support these HABs research projects.

The **University of Washington's Pacific Northwest Center for Human Health and Ocean Studies** is developing DNA-based high throughput quantitative assays for four species of *Pseudo-nitzschia*. The Center also collaborates with ECOHAB Pacific Northwest and the Monterrey Bay Aquarium Research Institute to interface surface plasmon resonance sensors with buoy mounted sensing systems set up for telemetric data reporting. Researchers are also working with Native American communities to investigate diet and behavioral factors which may define potential exposure and health impacts from domoic acid. The center has also funded work in the area of institutional analysis to examine social and economic consequences and policy approaches for mitigation of *Pseudo-nitzschia* blooms with a goal of improving coordination among institutions.

The **Pacific Research Center for Marine Biomedicine's** Ciguatera Project is examining how to develop effective prevention and detection strategies for ciguatera, resulting in the improved health and well being of humans living in tropical ecosystems. At the **Woods Hole Center for Oceans and Human Health**, studies of *Alexandrium fundyense* are ongoing, including modeling and event response efforts. A numerical model developed during previous **ECOHAB** and **MERHAB** projects is being used to provide predictions of bloom location and cell abundance to state and Federal managers. The Woods Hole Center is also developing rapid detection and enumeration methods for *Alexandrium* cells.

### 2. Ecology and Oceanography of Harmful Algal Blooms Program

The Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) Program is a multi-agency program that includes **NOAA CSCOR (lead)**, **NOAA Sea Grant**, **NSF**, **EPA's Science to Achieve Results (STAR) Program**, **NASA**, and **ONR** (Box 31). Through competitive peer-reviewed research by partnerships of academic, state, Federal, and nonprofit institutions, ECOHAB seeks to produce new, state-of-the-art detection methodologies for HABs and their toxins, to understand the causes and dynamics of HABs, to develop forecasts of HAB growth, transport, and toxicity, and to predict and ameliorate impacts on higher trophic levels and humans. Research results are used to guide management of coastal resources to prevent or reduce HAB impacts. ECOHAB has focused primarily on long-term studies that will lead to improved monitoring, prediction, and prevention. These topics will be covered in two future reports: the *Scientific Assessment of Marine Harmful Algal Blooms* and the *Scientific Assessment of Freshwater Harmful Algal Blooms*. Although not the focus of ECOHAB, some of the agencies have conducted PCM research, particularly in the areas of new detection methodologies, control methods (see Box 18), and economic analyses.

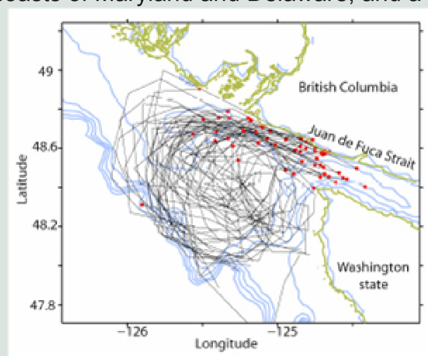
### Box 31. Interagency ECOHAB Program prediction and response efforts

- **NOAA Center for Sponsored Coastal Ocean Research** – Projects have included studies to explore the use of clay and naturally occurring HAB-specific pathogens, such as bacteria, viruses, and parasites, to control HABs after they bloom. Although potential candidates have been discovered, there are many biological and regulatory obstacles to their testing and use in the natural environment. Many new detection methods have been developed, such as the Brevebuster (see photo), a real time polymerase chain reaction (PCR) assay for *Kryptoperidium*, and a Nucleic Acid Sequence-based Amplification assay for rapid, genetic detection of *Karenia brevis*. CSCOR has also funded economic assessments and studies of newly emerging toxins, such as saxitoxin in puffer fish.

- **EPA Science to Achieve Results (STAR) Program** – Projects have included studies to explore the use of clay to control HABs after they bloom, an economic impact study of *K. brevis* blooms along the coast of Florida, the development of PCR assays for rapid detection of HAB species off the coasts of Maryland and Delaware, and a study to assess the risk of introducing HAB species to new regions via shellfish transport.

- **NASA Ocean Biology and Biogeochemistry Research Program** – Projects have included studies to identify the optical properties of *K. brevis* in the Gulf of Mexico, to explore the use of mycosporine-type amino acids as markers for harmful dinoflagellates, and in the Pacific Northwest, to characterize the Juan de Fuca eddy and the transport of eddy-origin water (and potential Pseudo-nitzschia blooms) onshore using data from NASA and NOAA satellites (see inset figure).

- **NOAA Sea Grant** – Projects have included studies to explore the use of clay (Phase I) to control HABs after they bloom and two HABs economic impact studies: 1) economic impacts of Pfiesteria and 2) the development of a framework for conducting economic impact studies. Another study is combining molecular probe and fiber optic technologies for the rapid detection and enumeration of HAB species, which could prove to be a useful technology for automated detection of HABs.




Composite of eddy outlines from 95 cloud-free turbidity maps over 7 years of satellite data; eddy generally follows isobaths (blue) and has a diameter of approximately 50 km. Figure courtesy of K.Edwards, Univ. of Washington. Turbidity derived from NASA SeaWiFS data by R.Stumpf, NOAA.

## 3. Small Business Innovation Research Program

The Small Business Innovation Research (SBIR) Program supports creative advanced research in scientific and engineering areas that encourages the conversion of government-funded research into a commercial application. SBIR awards lead to new technology, major breakthroughs, innovative new products, and next-generation products or processes. Funds are awarded competitively in phases through incentive based partnerships. The first phase demonstrates technical feasibility. Later phases allow research and development of a prototype, and, with additional funding from private industry, commercialization.

Many agencies have separate, although similar, SBIR programs. **EPA** and **NOAA** have used SBIR to develop and commercialize new technologies for detecting HAB cells and toxins. EPA has funded a Phase I project to develop a surface plasmon resonance fiber optic probe coated with a molecular imprinted polymer to provide fast, simple, and sensitive detection of the cyanotoxin, microcystin-LR (See Box 22). NOAA has requested proposals for portable HAB monitoring systems for small aircraft of opportunity, in-field sensors for detection of HAB toxins and/or toxigenic species and AUVs capable of carrying sensors and taking water samples. Four NOAA-funded phase I projects have been completed.

# B. Federal Agency Efforts

## 1. U.S. Department of Agriculture

### *USDA Intramural*

The Agricultural Research Service (ARS) National Program #201 (Water Resource Management), whose mission is “A Safe, More Water-Efficient Society”, directly addresses prevention of HABs caused by excess nutrients. This program has two primary goals: to develop innovative concepts for determining the movement of water and its associated constituents in agricultural landscapes and watersheds, and to develop new and improved practices, technologies, and strategies to manage the Nation’s agricultural water resources (See Box 13). Agricultural watershed management, irrigation and drainage, and water quality protection and management represent the main components of this research. Field practices have been developed that reduce impacts of nutrients, pesticides and other synthetic chemicals, pathogens and other bacterial contaminants, sediments, salts, trace elements, and water temperature in surface waters and groundwater. Monitoring, research, and assessment efforts have been increased to develop tools for implementing total maximum daily load guidelines for nonpoint source water quality improvements to protect fresh and coastal water ecosystems.

### *USDA Extramural*

ARS has funded research related to monitoring and remote sensing of cyanobacteria blooms in freshwater aquaculture facilities. Cyanobacteria may be causing off taste in catfish so blooms might have a negative economic impact on the fishery when present.

Cooperative State Research, Education, and Extension Service’s National Integrated Water Quality Program funds research, education, and extension projects aimed at protecting and improving the water resources of the Nation. The cornerstone of this program is a set of 10 Regional Water Quality Coordination Projects of which eight have extension programs focused on coastal water quality. Sample regional activities (http://www.usawaterquality.org/regional/default.html) include animal waste management, drinking water and human health, environmental restoration, watershed management, nutrient and pesticide management, community involvement in watershed managements, river and stream restoration, sustainable landscaping, volunteer water quality monitoring, and watershed/rangeland management.

## 2. U.S. Department of Commerce

### 2.1. National Oceanic and Atmospheric Administration (NOAA)

#### *2.1.1. NOAA Extramural*

**2.1.1.1. Cooperative Institute for Coastal and Estuarine Environmental Technology**

The Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) was established in 1997 as a partnership between NOAA and the University of New Hampshire. CICEET uses the capabilities of the University, the private sector, and academic and public research institutions throughout the United States, as well as the 26 reserves in the National Estuarine Research Reserve (NERR) System, to develop and apply new environmental technologies and techniques. CICEET has funded projects to develop quick, portable, and accurate detection methods for HAB cells or toxins. Other projects were geared toward adapting technologies for field use and to assure that existing techniques for detecting HAB species meet user needs. The projects funded through CICEET are cooperative efforts that involve researchers in NOAA labs, managers of NERRs sites, academia, and industry.

### 2.1.1.2. National Marine Fisheries Service (NMFS)

#### Marine Mammal Health and Stranding Response Program

**The John H. Prescott Marine Mammal Rescue Assistance Grant Program** was established as an amendment to the Marine Mammal Protection Act in 2000. It provides grants to eligible marine mammal stranding network members up to $100K per award with a required 25% non-Federal match. There are two sub-programs: annual competitive and emergency needs. The grants are awarded for response, research and infrastructure. Some applicants have received funds for biotoxin research and response with regards to HABs.

**The Marine Mammal Unusual Mortality and Morbidity Event Program** provides emergency response and investigative funds for marine mammal unusual mortality events. These include assessment of the impacts on populations from acute high dose exposure. This fund was established by the Marine Mammal Protection Act of 1972 (as amended in 2001) Title IV, Section 404. Since 1998, marine mammal unusual mortality events have been increasingly associated with HAB associated biotoxins, suggesting that a close collaboration between the marine animal health programs and the HAB programs should continue to grow.

**The Research on Animal Health Assessment**s program provides funds for health assessment work on marine mammals. Research, management, response, and information dissemination are covered under this program. Some funds for HAB related monitoring, response, effects, assessments, and research have been distributed both internally and externally to NOAA since 1998. Many topics are covered under this program, but a few contracts have been given for HAB related monitoring in marine mammals, biotoxin effects, or other HAB-related research relevant to impacts or detection.

#### NMFS Regional Offices

NOAA NMFS regulates commercial fisheries for shellfish in Federal waters under the authority of the Magnuson-Stevens Fishery Conservation and Management Act. When the FDA advises that the consumption of shellfish could be harmful to human health, the NMFS Regional Office closest to the problem works to close the appropriate fishery(ies) through rule-making and alerts the public. Affected parties (e.g. states, fishing organizations, individuals) can request that the Secretary of Commerce declare a fisheries failure. If funds are then appropriated by Congress, NMFS provides financial assistance to fishers and other persons and businesses affected by such closures or other regulations imposed to protect human health.

### 2.1.1.3. National Ocean Service

#### 2.1.1.3.1. Oceans and Human Health Initiative.

In 2004, NOAA established the OHHI to bring together oceans and human health expertise across NOAA, in partnership with academic and private sector communities, and in collaboration with other Federal and state agencies. One of the many areas of concentration for this initiative is the intersection between HABs and human health. OHHI has funded two research projects related to HAB prediction and response since 2004: 1) development of lateral flow tests to detect toxins in shellfish and 2) establishment of sentinel species as early warning indicators of HAB problems that might affect humans. In addition to extramural funding, the OHHI established three OHH Centers of Excellence at NOAA Laboratories, two of which are conducting research related to HAB prediction and response—GLERL in Ann Arbor, Michigan and NWFSC in Seattle, Washington (see NOAA intramural section for information on research programs at these Centers).

### 2.1.1.3.2. National Centers for Coastal Ocean Science. Center for Sponsored Coastal Ocean Research (CSCOR)

**The MERHAB Program** assists coastal resource and public health managers respond to the growing threats from HABs. The prime focus of MERHAB is to build capacity for regular and intensive monitoring for HAB cells and toxins-- making local, state, and tribal shellfish, water quality, and public health monitoring programs more efficient while providing better coverage in time and space. MERHAB encourages collaborative efforts between the scientific and management communities designed to evaluate the application of new HAB detection methodologies, transfer new knowledge about the causes and dynamics of HABs, and demonstrate operational capabilities for HAB growth, transport, and toxicity predictions and forecasts (see Box 28). Project topics range from low cost HAB detection methods to large-scale, multi-disciplinary regional efforts to develop and sustain enhanced HAB monitoring programs.

MERHAB projects in the Lower Great Lakes and Eastern Gulf of Mexico identify and transfer into operational capability HAB regional monitoring systems to mitigate impacts from cyanobacteria and *Karenia brevis* respectively. Regional projects in California and Washington enhance existing state HAB and water quality monitoring programs and advance, in collaboration with ECOHAB, the science required for a west coast HAB forecasting capability. Targeted studies are demonstrating operational uses for new HAB detection technologies including an ultra sensitive detection method to track low levels of domoic acid, quantitative PCR probes for detecting multiple toxic HABs species, and automated nutrient monitoring in Chesapeake Bay. Project summaries may be viewed at: http://www.cop.noaa.gov/stressors/extremeevents/hab/current/abs_MERHAB_cover.html

**HAB Event Response.** State and Federal managers responding to blooms often lack timely access to cutting-edge science useful in minimizing HAB impacts on coastal communities. The HAB Event Response program addresses the need to make science available to management by supporting coastal managers faced with responding to unusual or unexpected HABs. Upon notification of an event, CSCOR and its partner, the National Office for Marine Biotoxins and Harmful Algal Blooms at the Woods Hole Oceanographic Institution, work to provide access to the best technology and expertise available, provide supplemental financial support for investigating a unique event, and ensure proper scientific documentation to add to the HAB knowledge base. Three important projects in 2005 included 1) support for the State of Oregon to expand a monitoring program to respond to domoic acid-related shellfish closure, 2) support for the State of Florida and researchers from Florida Fish and Wildlife Research Institute (FWRI) and the University of South Florida to investigate the underlying cause of reported benthic mortalities related to an extensive *Karenia brevis* bloom in the Gulf of Mexico, and 3) support for monitoring the spatial extent and movement of the largest *Alexandrium fundyense* bloom in New England in 30 years (Box 25). In the latter, this data helped to provide managers with early warnings of shellfish toxicity to protect public health in the region, and also allowed them to focus toxin sampling on areas where shellfish openings were most likely possible.

**CSCOR** also supports the National Office for Marine Biotoxins and HABs and WHOI (see Section on Nongovernmental National Programs) and provides partial support with NSF for the Culture Collection for Marine Phytoplankton (CCMP) at Bigelow Laboratory for Ocean Sciences (Table 2). The CCMP maintains cultures of more than 2000 algae and makes them available to the public for a nominal fee. CSCOR also provides funds for the IOC to support taxonomic training workshops and the development of databases compiling HAB events globally.

### 2.1.1.4. Office of Ocean and Atmospheric Research

**The National Sea Grant College Program** is a Federal/university/state partnership that allows NOAA to engage universities to meet national, regional, and local priorities. The program is a competitive, science management, capacity building, service enterprise committed to creating new knowledge (research) and transferring science-based information to users through outreach (extension, education and communications) for mission-related objectives. There is a Sea Grant program in every coastal state.

One of the three national priority areas for Sea Grant is HABs. Through both the national and individual state programs, Sea Grant has funded research and outreach projects with a focus on HAB prediction and response. Specifically, Sea Grant researchers have investigated new detection methods such as the recent development combining molecular probe and fiber-optic technology in order to detect target HAB species (*Alexandrium fundyense, Alexandrium ostenfeldii*, and *Pseudo-nitzschia*) in the Gulf of Maine[50]. This novel technique can detect multiple species at once, and efforts are underway to test applicability for automated detection in the field. New methods for public education and outreach on HAB issues have also been created by Sea Grant programs. In 2001, Sea Grant submitted a report[7] to Congress outlining a forward-looking research, outreach and public education program that would provide the means for academic, government and industry scientists and engineers to combine their efforts with those of coastal communities and managers in order to lessen the impacts of HABs on our Nation's coasts. Sea Grant also funds projects through the multi-agency ECOHAB program (Box 31).

## *2.1.2. NOAA Intramural*

### 2.1.2.1. Oceans and Human Health Initiative Centers of Excellence

The OHHI established three OHH Centers of Excellence across different line offices: HML in Charleston, South Carolina; GLERL in Ann Arbor, Michigan; and NWFSC in Seattle, Washington.

**HML** in NOAA's NOS promotes collaborative and interdisciplinary scientific research. It is operated as a partnership among NOAA, the National Institute of Standards and Technology (NIST), the South Carolina Department of Natural Resources, the College of Charleston, and the Medical University of South Carolina. See CCEHBR (Appendix I, Section 2.1.2.4.1.2) and NIST (Appendix I, Section 2.2) for more information on HML HAB research.

**GLERL** in NOAA's Office of Oceanic and Atmospheric Research uses multidisciplinary research to develop technology for predicting the formation, location, and severity of toxic algal blooms, which will help reduce potential impacts on human health. A broad public outreach program will disseminate HAB information to the public and managers. (See Appendix I, Section 2.1.2.5.2 for more information)

**NWFSC** in NOAA's NMFS houses the West Coast Center for Oceans and Human Health, which focuses its HAB research on the relationship of climate factors and HAB events with an interest in developing predictive factors for bloom occurrence. An additional emphasis is the use of flow cytometry for the detection of domoic acid in single cells, an important tool for the study of environmental influences on toxin production. (See Appendix I, Section 2.1.2.3.1 for more information)

### 2.1.2.2. National Environmental Satellite, Data, and Information Service

#### National Oceanographic Data Center.

Within the **National Coastal Data Development Center (NCDDC),** the Harmful Algal Blooms Observing System (HABSOS) pilot project was a proof-of-conceptual 2-3 year demonstration of an integrated information and communication system for managing HAB data, events, and effects and was co-funded by the EPA Gulf of Mexico Program. The HABSOS pilot project was initially focused on *Karenia brevis* in the Gulf of Mexico but may expand to other coastal regions. For the HABSOS Case Study, the data provided by five U.S. states over three years (legacy data, not a real time study) was organized and a geospatial data model was created to store this data, and to display it uniformly in an Internet Map Service. Future activities planned involve integration of near real time cell counts provided by the states into the near real time map service, and continued work with the EPA within the Gulf of Mexico to facilitate integration of data from Veracruz Mexico.

## 2.1.2.3 National Marine Fisheries Service

### 2.1.2.3.1. NOAA Fisheries Science Centers

The NWFSC has partnered with a broad spectrum of academic and governmental organizations in its efforts to improve understanding of HABs through research, data management and outreach and education. It led the effort to create the Olympic Region HAB Monitoring (ORHAB) partnership (see Box 28) in response to domoic acid poisoning along the Olympic coast. In addition, NWFSC has worked on other aspects of HAB mitigation including short-term forecasting technology (the use of drifters at toxic hot spots to track HAB blooms) and research on toxin accumulation in shellfish to help target closures more efficiently. Infrastructure elements supported by NWFSC include the Environmental Services Data and Information Management's Pacific HAB data access project with NOAA's National Oceanographic Data Center which compiles biological, chemical, and physical data for the national HAB database, the global HAB database for the North Pacific Marine Science Organization (PICES) international program, and creation of a local database for ORHAB partners. In addition, NWFSC contributes to outreach and education through the education of Pacific Northwest Teachers at Sea and ORHAB website and outreach materials.

The NEFSC has conducted drifter studies to track movement of blooms of *Alexandrium,* a saxitoxin producing dinoflagellate, in the Gulf of Maine. NEFSC has been working with FDA to monitor closures of shellfish harvesting from Federal waters off New England (Box 25).

### 2.1.2.3.2. Marine Mammal Health and Stranding Response Program

**The Marine Mammal Response and Health Assessments** program provides internal research and response funds for marine mammals. Funding has supported a workshop on brevetoxin and dolphins to develop a research plan, sample collection, travel and personnel expenses for responses, technical support for analyses, histopathology and development of special stains, toxin analyses and cell screening. The overall program is integrated with the MERHAB, OHHI, and ECOHAB programs, NOAA's Coastal Services Center HAB forecasting program, and the Marine Biotoxins Analytical Response Team in Charleston, South Carolina. NMFS also supports stranding network personnel in each region who work to coordinate responses, research and sample and data collection. Additionally NMFS has provided funding for a post-doctoral fellow to work in NOAA's Hollings Marine Lab and with the Marine Biotoxin Program to develop a risk assessment for domoic acid in California sea lions as a model for potential risks to critically endangered pinniped populations (Box 26). The Working Group on Unusual Marine Mammal Mortality Events (WGUMME, see Appendix II) is another component of the Marine Mammal Health and Stranding Response Program (http://www.nmfs.noaa.gov/pr/health/).

## 2.1.2.4. National Ocean Service

### 2.1.2.4.1. National Centers for Coastal Ocean Science Center

#### 2.1.2.4.1.1. NCCOS Center for Coastal Monitoring and Assessment

The Remote Sensing Team in CCMA focuses on the monitoring and forecasting of estuarine and coastal environmental problems. While emphasis is on standard sensors, particularly satellites, researchers also develop and use new techniques to monitor coastal water quality, track HABs, and assess coastal habitat changes. These new techniques are integrated with field and instrument observations to generate data and reports for resource managers which allow them to respond rapidly to conditions which may be impacting coastal habitats and marine resources. For example, remote sensing is integrated with models and field and instrument observations for development of improved detection and forecasts for HABs. The techniques developed for HAB monitoring are currently being used for the HAB Bulletin, an operational forecast system for the Gulf of Mexico (Box 19), and are being developed for other U.S. coastal regions including the Great Lakes, Washington State outer coast, and the California coast.

#### 2.1.2.4.1.2. NCCOS Center for Coastal Environmental Health and Biomolecular Research/ Hollings Marine Lab

The **Marine Biotoxins Program,** located in laboratories at CCEHBR and HML, targets its research and services on HABs and HAB toxins. Ongoing research includes 1) assessing toxic impacts on high risk human and animal populations to support human epidemiological studies and risk assessment of marine animals, 2) developing methods to monitor toxin exposure in living animals which has been identified as a critical need by human and wildlife health managers (Box 21), 3) developing capabilities for automated, *in situ* detection of HAB species and their toxins, and 4) evaluating the potential application of algicidal bacteria as a control technique.

The Marine Biotoxins Program also supports an array of infrastructure elements (Table 2) including 1) an algal reference materials and algal taxonomy facility that produces new algal cultures and molecular probes, maintains a culture collection, provides taxonomic training, and houses an advanced microscopy facility for species identification, 2) a toxin reference and toxin analysis facility that produces toxin standards and validated assays and houses a state of the art shared facility for toxin analysis (Box 23), and 3) the Southeastern Phytoplankton Monitoring Network, which was established as an outreach program to unite volunteers and scientists in monitoring marine phytoplankton community and HABs, (http://www.chbr.noaa.gov/default.aspx?category=mb&pageName=biotoxin).

NOAA CCEHBR's Marine Biotoxin Program's **Analytical Response Team** (ART) provides rapid and accurate identification of algae and algal toxins suspected in association with HAB events, marine animal mortalities, and human poisonings. ART provides a formal framework through which resource or public health managers request immediate coordinated assistance during HAB-related events. ART is national in scope and maintains a database of all samples and analyses conducted since 1998. ART also has coordinated with the **NMFS** WGUMME to investigate marine mammal mortality events in U.S. coastal waters**.**

#### 2.1.2.4.1.3. NCCOS Center for Coastal Fisheries and Habitat Research

Researchers at NCCOS's Center for Coastal Fisheries and Habitat Research (CCFHR) have developed cost-effective tools for detecting HABs and HAB toxins. Specifically, in conjunction with the Marine Biotoxins Program at the NWFSC, they developed a much needed quick test for the toxin domoic acid to be used by tribes and environmental managers on the west coast of the United States (Box 14). They also developed molecular assays to monitor the distribution and abundance of the non-descript organism *Pfiesteria piscicida* on the Atlantic Coast and to distinguish *P. piscicida* from significantly more abundant nontoxic "look-a-like" species. These molecular assays have been used since 2003 and have prevented misidentification and unnecessary concern about *Pfiesteria* related fish kills and the associated economic losses to the seafood and tourism industries. CCFHR also documented the presence of the cyanotoxins called microcystins in the Great Lakes and produced and provided maps of microcystins to aid public health officials and resource managers.

### 2.1.2.4.2. National Marine Sanctuaries

The mission of NOAA's National Marine Sanctuaries (NMS) Program is to serve as the trustee for the Nation's system of marine protected areas in order to conserve, protect, and enhance their biodiversity, ecological integrity, and cultural legacy. HABs have been identified as an information need in a number of NMSs, and three have actively participated in HAB prediction and response-related activities. The Olympic Coast National Marine Sanctuary contributes to the ORHAB partnership by maintaining moorings for monitoring from April through October and collecting water samples for collaborators at NWFSC. The Monterey Bay NMS BeachCOMBERS (Coastal Ocean Mammal/ Bird Education and Research Surveys) project utilizes volunteers to monitor beaches for dead birds and mammals and may collect and send animals to the state for analysis. Monterey Bay NMS's Sanctuary Integrated Monitoring

Network integrates existing monitoring programs that are examining various aspects of the Sanctuary, including HABs, and serves to make the monitoring data available to managers, decision makers, the research community, and the general public. The Florida Keys NMS collaborates with the University of South Florida and NOAA CCMA to identify and track blooms in southwest Florida and the Florida Keys.

#### 2.1.2.5. Office of Ocean and Atmospheric Research

##### 2.1.2.5.1. Atlantic Oceanographic and Meteorological Laboratory

Researchers at the Atlantic Oceanographic and Meteorological Laboratory (AOML), with funding from CICEET, are developing improved molecular methods to detect *Karenia brevis* and are making detailed instructions of the technique available via a web video. In collaboration with the COHHs and industrial and academic partners and with funding from CICEET, AOML is also developing electrochemical methods for use in portable and *in situ* biosensors to detect the genetic signatures of problem organisms, including *K. brevis*.

##### 2.1.2.5.2. Great Lakes Environmental Research Laboratory

With OHHI funding, GLERL has begun monitoring *Microcystis* cyanobacteria and has initiated outreach efforts to educate the public about its presence and potential toxic effects. During the summers of 2004 and 2005, sampling was conducted in western Lake Erie, Saginaw Bay, and in inland lakes around southeastern Lake Michigan to identify the presence of *Microcystis* cells in surface waters. If present, the samples were analyzed for both *Microcystis* cell counts and microcystin (toxin) concentration. A PCR-based assay has been developed by GLERL researchers to determine what proportion of a bloom consists of toxic *Microcystis* strains. As part of an important outreach effort, a website (http://www.glerl.noaa.gov/res/Centers/HABS/habs.html) and a list server "Habcomm" were created to share the monitoring data with the public health community, researchers, and concerned citizens. In addition, work on the short-term prediction of toxic cyanobacterial blooms in the Great Lakes is happening through the development of MODIS and other satellite imagery.

### 2.2. National Institute of Standards and Technology

NIST has established the National Marine Mammal Tissue Bank (NMMTB) as a satellite facility of the National Biomonitoring Specimen Bank (NBSB) at HML in Charleston, SC. NMMTB is dedicated to banking marine environmental specimens. The NBSB serves as a long-term storage repository of specimens that are collected and stored under well-established and well-documented protocols. A major focus of the NMMTB is providing specimen banking support to the Marine Mammal Health and Stranding Response Program administered by the NOAA NMFS Office of Protected Resources and the Alaska Marine Mammal Tissue Archival Project conducted by the USGS and NMFS Office of Protected Resources.

## 3. U.S. Department of Defense

### 3.1. United States Army Medical Research Institute of Infectious Diseases

*USAMRIID Intramural*

The mission of USAMRIID includes development of diagnostic capabilities for agents of potential threat to deployed troops worldwide. Of special concern is testing of clinical samples such as urine and serum. Diagnostic methods have been developed, or the technology has been imported from other laboratories, for various HAB toxins including brevetoxins, ciguatoxins, saxitoxins, and microcystins. For brevetoxins, USAMRIID has recently developed an electrochemiluminescence (ECL) based immunoassay that significantly improves assay speed and sensitivity in a variety of matrices (Box 15). Development of a new ECL-based immunoassay for microcystins is in progress.

# 4. U.S. Department of Health and Human Services

## 4.1. Centers for Disease Control and Prevention

### *CDC Extramural*

Since 1998, CDC has had a cooperative agreement in place with Atlantic Coast state health agencies in Florida, Virginia, South Carolina, Maryland, and North Carolina to conduct a number of projects to mitigate human exposures to and illnesses from HABs. The HAB response plans in these states include toll-free telephone hotlines, poison information centers to collect data on HAB-related illnesses, publicly accessible websites, environmental and fish sample collection and analysis plans, and a human illness surveillance system.

The five state HAB programs funded by CDC have addressed the range of interactions among marine and freshwater HABs and people. Specific state-based projects include aerosol exposures to Florida red tide, attempts to develop a biological marker of ciguatoxin exposure, assessing the presence of cyanobacteria in drinking water sources, and investigating human exposures to cyanobacteria and cyanobacterial toxins in recreational waters.

### *CDC Intramural*

CDC has supported a number of studies to assess the public health effects from human exposures to marine and freshwater HAB-related toxins in food, water, and aerosols. CDC's information technology program has developed the HAB-related Illness Surveillance System (HABISS) internally as the first application of the Rapid Data Collection System (Box 27). In July 2006, the system became live on the World Wide Web. As with the other public health surveillance systems supported by CDC, HABISS is a secured website for data entry by trained state public health. CDC is holding workshops to train representatives from interested states to use the system. HABISS is a modular system, and data on characteristics of or exposures to any HABs (marine or freshwater) can be accommodated.

## 4.2. U.S. Food and Drug Administration

### *FDA Intramural*

**Center for Food Safety and Applied Nutrition**

FDA conducts research to support the agency's regulatory mission of protecting public health by assuring the safety, efficacy, and security of human and veterinary drugs, biological products, medical devices, our nation's food supply, cosmetics, and products that emit radiation. FDA's knowledge and understanding of seafood hazards, risk assessments and risk management are guided by scientific research provided by the agency's research division. Ongoing FDA research includes improving and implementing detection methods for marine biotoxins. This research involves enhanced sample preparation procedures, assays, and analyses to improve sensitivity, robustness, and ease of use. FDA performs research to identify emerging toxin sources and vectors that may potentially affect food safety. One example is the collaborative study (funded by NOAA CSCOR) with FWRI and NOAA CCEHBR into the recent occurrence of saxitoxin containing puffer fish in Florida. Identifying both current and emerging sources and vectors of toxicity provides information to FDA so that proactive measures can be taken to both prevent and rapidly respond to potential food borne illnesses from marine biotoxins.

FDA works closely with state programs, NMFS, and the ISSC to ensure that all marketed seafood products are safe. FDA responds to events by assisting states with sampling and toxin analysis when marine biotoxins are suspected in state waters. FDA also conducts an annual review of State Shellfish Control Programs to determine the degree of conformity with the National Shellfish Sanitation Program, a program in which state shellfish control agencies, the shellfish industry, FDA, and other Federal agencies participate to promote controls over shellfish safety. The FDA has established action levels for poisonous or deleterious substances, such as natural toxins from HABs, to control the levels of contaminants in human food including seafood[51]. Action levels represent limits at or above which FDA will take legal action to remove adulterated products, including shellfish, from the market. FDA is responsible for seafood harvested from Federal waters and conducts the necessary sampling to determine closures in these waters. FDA also supports citizen-based volunteer monitoring networks to improve marine biotoxin management programs (see Box 16).

## 4.3 National Institute of Environmental Health Sciences

### *NIEHS Extramural*

NIEHS-funded research on HAB mitigation and impact assessment is conducted through three different programs: 1) a program project at University of North Carolina – Wilmington (UNCW), 2) a collaborative research program, the Advanced Cooperation in Environmental Health Research (ARCH), between Florida International University, a minority serving institution, and the University of Miami, and 3) the four COHHs, jointly funded with NSF (see Appendix I, Section A.1).

NIEHS-funded research, based at UNCW, has been investigating, through controlled studies, the health effects of aerosolized brevetoxin. In one study, significantly more respiratory distress was reported during natural Florida red tide (*Karenia brevis*) events which has lead to health advisories and, perhaps, more accurate disease reporting. Compounds that are antagonistic to effects of brevetoxin have been identified and may represent potential chemical control agents or therapies for people with toxin exposure. Finally, a brevetoxin enzyme-linked immunosorbent assay has been developed which is now used by the State of Florida for risk assessment in shellfish monitoring.

NIEHS-supported ARCH program researchers are developing, optimizing, and assessing the effectiveness of molecular methods for detecting *Karenia brevis* and other HAB organisms. They are also involved in the evaluation of a remote sensing system (using NASA and NOAA satellite data) with substantially improved resolution downloadable for investigators within four hours.

# 5. U.S. Department of the Interior

## 5.1 U.S. Fish and Wildlife Service

### *USFWS Intramural*

The USFWS is the principal Federal agency charged with protecting and enhancing the populations and habitat of more than 800 species of birds as well as protecting terrestrial and freshwater wildlife species listed as endangered or threatened. USFWS response to wildlife impacts is conducted by personnel from the USFWS Environmental Contaminants Branch within the USFWS Division of Environmental Quality. Current USFWS HAB-response activities involve field response to bird die-offs, including collection of carcasses and water samples for toxin analysis. In addition, there is limited participation by the USFWS on technical advisory groups that address algal monitoring.

## 5.2 U.S. Geological Survey

### *USGS Intramural*

The USGS provides reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life.

The USGS monitors water quality in the Nation's streams, which provides information useful to both early warning and a general understanding of HABs.

The USGS supports HAB research related to mitigation of negative impacts from cyanobacteria and their toxins. For example, the USGS Kansas Water Science Center is improving sample collection and analytical techniques for measuring cyanotoxins in environmental samples. In collaboration with the Texas Water Science Center, they are investigating the distribution of cyanobacteria blooms, including toxin and geosmin production, in source water reservoirs in Texas. They are have developed models using environmental variables measured in real time to estimate the onset of cyanobacterial-related taste and odor episodes in drinking water reservoirs. Similar models are being developed for cyanobacterial toxins. The City of Wichita, Kansas plans to use these models to guide drinking water treatment decisions (Box 20).

The USGS Columbia Environmental Research Center has ongoing projects that measure microcystin concentrations in reservoirs and wetlands, linking the results to water quality and toxicity events affecting fish and birds. Methods have been developed for analysis of microcystin in tissue samples, algae and water and have been used in comprehensive cooperative studies with other Federal agencies (Fish and Wildlife Service and Bureau of Reclamation).

USGS is also working collaboratively with universities and Federal laboratories to document impacts of biotoxins on marine and aquatic birds, mammals, and reptiles. The USGS National Wildlife Health Center in Madison, WI receives and prepares samples for analysis from the entire United States. The center documents in a database all disease investigations where biotoxins were identified or were a suspected cause of mortality.

The Western Fisheries Research Center, in partnership with the Bureau of Reclamation, is studying the impact of algal blooms on aquatic species in Upper Klamath Lake. In response to draining surrounding marshes and agricultural practices, massive blooms of cyanobacteria have been directly related to poor water quality episodes. The information provided by the USGS is used in management decisions by the Bureau of Reclamation and U.S. Fish and Wildlife Service to protect the endangered Lost River suckers (*Deltistes luxatus*) and shortnose suckers (*Chasmistes brevirostris*).

## 6. U.S. Environmental Protection Agency

### *EPA Extramural*

EPA's extramural **Regional Grants** have been awarded to a number of state, regional, and academic entities to conduct research on surveillance, detection, mitigation, restoration, and public education regarding HABs. The reduction of algal blooms is an expected beneficial outcome of one recently funded project which is working to restore shellfish habitat for a keystone clam species in Lake Pontchartrain, Louisiana. EPA's Environmental Monitoring for Public Access and Community Tracking (**EMPACT**) program evaluated the ability of an automated biological monitoring system to detect the development of toxic events using fish ventilatory responses (Box 24). EPA also funds projects through the multi-agency **ECOHAB** program (Box 31).

**EPA National Estuary Program (NEP).** EPA's National Estuary Program (NEP) was established by Congress in 1987 to improve the quality of estuaries of national importance. There are 28 NEPs along the continental U.S. coast and in Puerto Rico. A few NEPs list HABs and many list nutrients as a priority management issue. Through NEPs, EPA has funded projects that have successfully led to more effective management of nutrient inputs, including a demonstration project in Long Island Sound that employed biological nutrient reduction to cost-effectively reduce nitrogen in treatment plants (see http://www.epa.gov/owow/estuaries/success.htm). The Delaware Inland Bays NEP supports the Delaware Inland Bays Culture Collection http://www.ocean.udel.edu/cms/dhutchins/CIBculturecollection05.htm.

### *EPA Intramural*

The **Office of Research and Development** (ORD) is the scientific research arm of the U.S. EPA. Research pertinent to prediction and response to HABs is conducted at ORD laboratories, research centers, and offices across the country. This work primarily supports the Agency's responsibility to ensure clean safe water through the regulatory mandates of the Safe Drinking Water Act and the Clean Water Act, which protect human health and freshwater ecosystems. HAB prediction and response related research has focused on mitigation strategies, including development of an early warning system for water quality in southwest Ohio.

## 7. National Aeronautics and Space Administration

### *NASA Extramural*

NASA supports a cooperative agreement between the Naval Research Laboratory and Applied Coherent Technologies, Inc. to support NOAA HAB activities through the REASoN (Research, Education and Applications Solution Network) project. The multi-agency project is developing products and techniques to integrate measurements from NASA and NOAA satellites, available coastal observations, and coastal ocean model outputs into the NOAA HAB Bulletin (Box 19) and NOAA HABSOS (an automated near-real-time database and distribution system for the Gulf of Mexico). NASA also funds projects through the multi-agency ECOHAB program.

## 8. National Science Foundation

### *NSF Extramural*

NSF supports much research related to ecology and oceanography of HABs. Only research directly relevant to HAB prediction, response, and infrastructure is included here. Other HAB research is included two other HABHRCA reports (see Boxes 5 and 6).

NSF is the major source (with NOAA-CSCOR) of Federal funding to the Culture Collection of Marine Phytoplankton (CCMP) (Table 2). The CCMP, located at Bigelow Laboratory for Ocean Sciences, is the national culture collection of marine phytoplankton for the United States with 2105 strains from around the globe. NSF also provides the principal financial support for the freshwater Culture Collection of Algae at the University of Texas at Austin (UTEX). The UTEX Culture Collection maintains approximately 3,000 different strains of living algae. The primary function of both culture collections is to provide algal cultures at modest cost to the user community.

# Appendix II. Other National Programs

## National Office for Marine Biotoxins and Harmful Algal Blooms at Woods Hole Oceanographic Institution.

The National Office provides organizational, informational, and technical support to the HAB community by maintaining an informational webpage, an e-mail distribution list, conducting outreach, compiling U.S. HAB data, administering the CSCOR HAB event response program, organizing U.S. HAB meetings, and distributing HAB reports (Table 2). The *HARRNESS*[3] report identified this independent organization as essential for organizing the many HAB stakeholders in all aspects of HAB research and response.

## National HAB Committee (NHC)

The National HAB Committee has been established as a critical component for implementation of the *HARRNESS*[3] plan. The NHC represents research and management for the HAB community at the National level and serves as an important link between Federal programs and organizations involved in HAB research and management.

## The National Water Quality Monitoring Council

The National Water Quality Monitoring Council was created in 1997. It has 35 members and is a balanced representation of Federal, tribal, interstate, state, local and municipal governments, watershed and environmental groups, the volunteer monitoring community, universities, and the private sector, including the regulated community. The Council is co-chaired by the **USGS** and the **U.S. EPA**, and its other Federal members include **NOAA**, **TVA**, **USACE**, **USDA**, and the remaining **DOI** agencies. The purpose of the Council is to provide a national forum for coordination of consistent and scientifically defensible methods and strategies to improve water quality monitoring, assessment, and reporting. The Council promotes partnerships to foster collaboration, advance the science, and improve management within all elements of the water quality monitoring community. More information on the National Water Quality Monitoring Council is available on the Internet at: http://acwi.gov/monitoring/

## The Working Group on Unusual Marine Mammal Mortality Events (WGUMME).

The WGUMME was created under the *Marine Mammal Protection Act* as an advisory board to the Secretary of Commerce and Secretary of Interior and is another component of the NOAA NMFS Marine Mammal Health and Stranding Response Program. The Working Group is made up of twelve members that rotate every three years, two international observers from Canada and Mexico, and four permanent agency representatives from **NOAA NMFS**, **USFWS**, the **MMC**, and **EPA**. The primary role if the Working Group is to determine when an unusual mortality event (UME) is occurring and then to direct responses to such events. Response to UMEs is coordinated by the NMFS Regional Offices and the regional stranding networks, as well as other Federal, state, and local agencies. Increased marine animal strandings can be the first sign of a HAB event, so UMEs can serve to identify HABs in areas not actively monitored. Investigation of such events has also led to a greater understanding of HAB impacts on marine mammal populations.

## Interstate Shellfish Sanitary Conference.

The Interstate Shellfish Sanitation Conference (ISSC) fosters and promotes shellfish sanitation through the cooperation of state and Federal control agencies, the shellfish industry, and the academic community. With respect to HAB prevention, control and mitigation efforts, the ISSC has a Biotoxin Committee and a Laboratory Methods Review Committee to address HAB and marine biotoxin concerns (e.g., monitoring and detection methods).

## U.S. Integrated Earth Observing System and U.S. Integrated Ocean Observing System.

The Integrated Earth Observing System (IEOS) is the U.S. contribution to the Global Earth Observation System of Systems (GEOSS) of which the Integrated Ocean Observing System (IOOS) is the oceans and coasts component. IOOS is the U.S. contribution to GOOS (the ocean component of GEOSS). IEOS and IOOS provide a platform to enhance HAB forecasts by providing real-time data that can be incorporated into predictive models or forecasts (Box 17). IOOS conceptually consists of three linked systems: an observing system, a data management and communications (DMAC) subsystem, and a data analysis and modeling (DAM) subsystem, and is being designed and developed for the sustained provision of quality controlled data and information on the physics, chemistry, biology and geology of the oceans, Great Lakes, and coastal marine and estuarine systems. IOOS is a collaborative effort among multiple Federal agencies (NOAA, Navy, NSF, NASA, USACE, USGS, MMS, EPA, USCG, and DOE) as well as industry and the private sector. http://www.ocean.us/

# Appendix III. State, Local, and Tribal Prediction and Response Efforts

State and local governments, non-governmental organizations, and tribal entities are involved in HAB monitoring and mitigation, and some states also have research programs. Tribal and state public health or resource management agencies are responsible for monitoring programs and shellfish harvesting or beach closures. FDA works closely with state shellfish control authorities to ensure the safety of shellfish harvested from state waters. State programs disseminate toxin advisory information to the public through websites, the media, and written materials. Several citizen HAB monitoring networks have also been established, which assist state efforts to track HABs and contribute to ground-truthing of HAB forecasts (see Box 16). Agencies or organizations conducting HAB prediction and response are outlined by region and state below.

1) North East
   i) Connecticut
      (1) Connecticut Department of Agriculture: Monitoring and shellfish closures
   ii) Maine
      (1) Maine Department of Marine Resources
         (a) Red tide and shellfish sanitation status information
         (b) Maine Red Tide Information System
         (c) Maine volunteer Phytoplankton Monitoring Program
   iii) Massachusetts
      (1) Division of Marine Fisheries: protocols for monitoring, harvesting closures, and other regulatory information
      (2) Department of Public Health: permit procedures and food safety
   iv) New Hampshire
      (1) Department of Environmental Services, Shellfish Program and NH Fish and Game Department monitor toxin levels in shellfish meats to determine viability of shellfish harvest.
   v) New Jersey
      (1) Department of Environmental Protection, Division of Marine Water Monitoring: water quality procedures and shellfish monitoring
      (2) DEP, Division of Science, Research and Technology: Brown tide status
      (3) Jacques Cousteau National Estuarine Research Reserve , Center for Remote Sensing and Spatial Analysis, and DEP Brown Tide Monitoring: Monitoring and maps of brown tide events in coastal NJ (ended in 2004 due to lack of funding)
   vi) New York
      (1) Department of Environmental Conservation: Shellfish closure information.
      (2) Brown Tide Research Initiative
      (3) Lake Champlain Basin Program: monitoring cyanobacteria (with Vermont state)
   vii) Rhode Island
      (1) Bureau of Environmental Protection: Shellfish closures, http://www.dem.ri.gov/programs/benviron/water/shellfsh/clos/index.htm

2) Great Lakes States
   i) Indiana
      (1) Department of Natural Resources – Division of Fish and Wildlife: Online fact sheets about cyanobacteria and its human health effects.

3) Mid-Atlantic
   i) Delaware
      (1) Department of Natural Resources and Environmental Control in collaboration with the University of Delaware Sea Grant College Program supports the Inland Bays Citizen Monitoring Program
   ii) Maryland
      (1) Department of Natural Resources: Reports HAB events in MD. Volunteers can report potential HAB events through hotline.
      (2) Eyes on the Bay: Interactive access to Chesapeake monitoring stations with HAB data
      (3) Department of the Environment: Notices of shellfish closures and fish advisories
      (4) Department of Health and Mental Hygiene: Cooperative agreement with CDC to conduct HAB public health response activities.
   iii) North Carolina
      (1) Department of Environment and Natural Resources, Division of Water quality: Monitoring data and fish kill maps for area rivers
      (2) DENR, Division of Marine Fisheries: Shellfish closure status
      (3) Department of Health and Human Services: Cooperative agreement with CDC to conduct HAB public health response activities.
   iv) South Carolina
      (1) Department of Health and Environmental Control: Monitoring and shellfish closure status and Cooperative agreement with CDC to conduct HAB public health response activities.
      (2) SCAEL: South Carolina Algal Ecology Lab – partnership between Department of Natural Resources and University of South Carolina
   v) Virginia
      (1) Department of Environmental Quality: Procedures and regulations for water quality monitoring
      (2) Department of Health: Cooperative agreement with CDC to conduct HAB public health response activities.

4) Gulf of Mexico
   i) Florida
      (1) Florida Fish and Wildlife Research Institute: FWRI. Current red tide status for the Florida coast, including maps. Network of volunteers monitoring for *Karenia brevis* (developed with MERHAB funding).
      (2) MOTE Marine Red Tide Update Page: Local conditions for the SW Florida coast
      (3) Florida Department of Agriculture and Consumer Services: Division of Aquaculture: Shellfish closure status
      (4) START (Solutions to Avoid Red Tides): grassroots, nonprofit, citizen organization dedicated to promoting PCM programs and public awareness. Focusing on raising state funds for PCM programs.
      (5) Department of Health: Cooperative agreement with CDC to conduct HAB public health response activities.
      (6) Florida's Harmful Algal Bloom Task Force: Advisory body to address specific HAB issues and human health risks
   ii) Mississippi
      (1) Department of Marine Resources: Shellfish closure status
   iii) Texas

(1) Parks & Wildlife Department: Texas coast red tide status reports, inland golden algae bloom status reports, http://www.tpwd.state.tx.us/landwater/water/environconcerns/hab/

(2) Department of Health: Shellfish closures due to red tide

(3) Red Tide Rangers: Volunteer HAB monitoring

5) West Coast

i) Alaska

(1) Department of Environmental Conservation, Division of Environmental Health: Monitoring procedures for PSP and status of shellfish closures

ii) California

(1) Department of Health Services, Division of Drinking Water and Environmental Management: Advisories and reports for marine biotoxin monitoring

(2) California Department of Fish and Game: Investigations of wildlife mortalities

iii) Oregon

(1) Department of Human Services, Environmental Services: Beach monitoring programs and fish advisories

iv) Washington

(1) Department of Health: Interactive map of recreational shellfish beach closure status

(2) Department of Health, Division of Environmental Health: Monitoring program information and biotoxin bulletins

(3) Department of Fish and Wildlife: Shellfish harvesting regulations, collection of shellfish tissue samples, collection and analysis of phytoplankton samples.

(4) Olympic Region Harmful Algal Bloom Program: Monitoring of phytoplankton and toxins in seawater

6) Inland States

i) Iowa

(1) Department of Natural Resources: Ambient Watershed Monitoring and Assessment Program http://wqm.igsb.uiowa.edu/publications/fact%20sheets/2005FactSheets/2005-5.pdf

ii) Nebraska

(1) Department of Environmental Quality: Sampling, analysis of results, posting results on website

(2) Department of Health and Human Services: Cooperative analysis of results with DEQ

iii) New Mexico

(1) Department of Game and Fish: Monitoring blooms of *Prymnesium parvum,* public education and outreach during fish kills, restocking to restore fisheries after fish kills

iv) Wisconsin

(1) Department of Natural Resources: Sampling for presence of cyanobacteria

(2) Department of Health and Human Services: Communicating with public about cyanobacteria blooms. http://www.dhfs.state.wi.us/eh/Water/fs/CyanobacteriaLHD.pdf

# Appendix IV. International Programs Related to HAB Prediction and Response

International organizations develop coordinated research programs to improve infrastructure, especially HAB observing systems and HAB cell and toxin identification, and facilitate information transfer between researchers and managers around the world. Various U.S. Federal agencies work closely with international partners. For example, the WGUMME (see Appendix II) has two international observers from Canada and Mexico. The U.S. contributes funding to international organizations in some cases. For example, NOAA CSCOR and NSF provide support for the activities of IOC and GEOHAB, which include providing training in HAB taxonomy, maintaining a global HAB event database, and developing research coordinated plans (for example the GEOHAB Plan on HABs in Eutrophic Coastal and Estuarine Environments[8]). FDA, NOAA, and USAMRIID, and individual scientists have also worked with both the AOAC and the IAEA to develop new toxin identification methods that are approved for regulatory use.

International programs that are relevant for HAB prediction and response and that partner with the United States are outlined below.

## AOAC (Association of Official Analytical Chemists) Marine and Freshwater Toxins Task Force

- International group of experts on marine and freshwater toxins and other stakeholders
- Prioritizes, funds, and accelerates validation studies of methods for marine and freshwater toxins since demand for new, officially validated methods has not been met
- In the first two years of Task Force establishment, submitted the first officially approved alternative to the PSP mouse bioassay in the last 50 years
- Has an initiative to assist in method implementation.

## GEOHAB (Global Ecology and Oceanography of Harmful Algal Blooms)

- International program that assists and coordinates investigators from different disciplines and countries to exchange information.
- Focus is on ecology and oceanography, which will be covered in the *Scientific Assessment of Marine Harmful Algal Blooms*, but one overarching program element related to prediction and response research is to improve HAB detection and prediction by developing observation and modeling capabilities.

## GEF (The Global Environmental Facility)

- An independent financial organization that helps developing countries fund projects that protect the global environment
- Supports the Global Ballast Water Management Programme (GloBallast) to reduce the transfer of HAB species in ship ballast water

## The Global Ocean Observing System (GOOS)

- A coordinated international network of ships, buoys, tidal gauges and satellites that collect real time data. The U.S. contribution is the Integrated Ocean Observing System (IOOS) (Box 17).
- Provides a platform to enhance HAB forecasts by providing real-time data that can be incorporated into short-term predictive models or forecasts.

## IAEA (International Atomic Energy Agency)

- Supports technical cooperation projects on HABs at the national, regional, and inter-regional scale.
- Supports infrastructure elements:
  - Transfers toxin detection methods internationally
  - Supports production of radiolabeled toxin standards (needed for receptor binding assay)

## IOC (Intergovernmental Oceanographic Commission) HAB Programme

- Focuses on HAB management and research in order to understand HAB causes, predict their occurrences, and mitigate their impacts. http://ioc.unesco.org/hab/intro.htm
- Supports infrastructure elements:
  - Conducts outreach and education through training courses, web based learning modules, *Harmful Algae News* newsletter
  - Supports data management through development of online databases http://ioc.unesco.org/hab/data.htm
  - Provides IOC HAB publications free of charge to developing countries
  - Provides a taxonomic identification service
  - Development of global HAB event database

## ISSHA (International Society for the Study of Harmful Algae)

- Founded in 1997, in response to a request from the Intergovernmental Oceanographic Commission (IOC) of UNESCO for an international programme on harmful algae, http://www.issha.org/
- Promotes and fosters research and training programs on harmful algae
- Co-sponsors meetings at the national, regional, and international level

## PICES (North Pacific Marine Science Organization) HAB Section

- Works with IOC to create a global Harmful Algal Event Database (HAE-DAT)
- Holds training workshops on toxin detection
- Shares information on monitoring and research programs in N. Pacific member countries.

## ICES (International Council for the Exploration of the Sea)

- Supports a Working Group on Harmful Algal Bloom Dynamics (WGHARBD) that compiles bloom event data for ICES countries and that meets annually to address current issues in HAB management, http://www.ices.dk/iceswork/wgdetail.asp?wg=WGHABD.

# Appendix V. Federal Register Notice

## Office of Science and Technology Policy

## Draft *National Assessment of Efforts to Predict and Respond to Harmful Algal Blooms in U.S. Waters*

**ACTION: Notice of draft report release and request for public comment**

**SUMMARY**: The Office of Science and Technology Policy (OSTP) publishes this notice to announce the availability of the Draft *National Assessment of Efforts to Predict and Respond to Harmful Algal Blooms in U.S. Waters* which was mandated by Congress in the *Harmful Algal Bloom and Hypoxia Amendments Act* of 2004 (P.L. 108-456). This report reviews and evaluates short-term harmful algal bloom (HAB) prediction techniques, and identifies current prevention, control and mitigation (PCM) programs and research for freshwater, estuarine and marine HABs operating at the national, state, local and tribal level.

**DATES:** Comments on this draft document must be submitted by 11/20/2006

**ADDRESSES:** *The Draft National Assessment of Efforts to Predict and Respond to Harmful Algal Blooms in U.S. Waters* will be available at the following location: http://ocean.ceq.gov/about/sup_jsost_iwgs.html. The public is encouraged to submit comments on the draft report electronically to Prediction.Response.Comments@noaa.gov. For those who do not have access to a computer, comments on the document may be submitted in writing to:

Quay Dortch
NOS/NCCOS/CSCOR/COP
N/SCI2
NOAA
1305 East West Highway
Building IV Rm 8220
Silver Spring, MD 20910

**FOR FURTHER INFORMATION CONTACT:** Quay Dortch by phone 301-713-3338 x157.

**SUPPLEMENTARY INFORMATION:** OSTP is publishing this draft report as mandated by the Harmful Algal Blooms and Hypoxia Amendments Act 2004 (P.L. 108-456) to request public comments. The report is organized into FIVE sections plus FIVE appendices: 1) Executive Summary, 2) Legislative Background and Purpose of the Report, 3) Assessment of the Harmful Algal Bloom (HAB) Problem in U.S. waters, 4) Prediction and Response Programs in the United States and 5) Opportunities for Advancement in Prediction and Response Efforts. Appendices include: Appendix I: Prediction and Response Programs in the United States, Appendix II: Other National Programs, Appendix III: State, local, and tribal Prediction and Response Efforts, Appendix IV: International Programs related to HAB prediction and response, and Appendix V: Federal Register Notice.

**Report Summary:**

The *Harmful Algal Bloom and Hypoxia Amendments Act of 2004* (P.L. 108-456) (*HABHRCA* 2004) reauthorized the original *Harmful Algal Bloom and Hypoxia Research and Control Act* (P.L. 105-383) of 1998 and stipulated generation of five reports to assess and recommend research programs on harmful algal blooms (HABs) and hypoxia in U.S. waters. Section 103 of *HABHRCA* 2004 requires a *Prediction and Response Report*. This report will review and evaluate HAB prediction and response techniques and identify current prevention, control and mitigation (PCM) programs for freshwater, estuarine and marine HABs. Prediction and response are narrowly defined for the purpose of this report in order to avoid overlap with a subsequent report in this series, *Scientific Assessment of Marine Harmful Algal Blooms*.

The Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health (IWG-4H) of the Joint Subcommittee on Ocean Science and Technology (JSOST), which was tasked with implementing *HABHRCA* 2004, streamlined the reporting process by linking the *Prediction and Response Report*(Section 103) with the National Scientific Research, Development, Demonstration, and Technology Transfer Plan on Reducing Impacts from Harmful Algal Blooms (Section 104 RDDTT Plan). The *Prediction and Response Report* will 1) detail Federal, state, and tribal prediction and response related research and impact assessments, 2) identify opportunities for improvement of prediction and response efforts and associated infrastructure, and 3) propose a process to evaluate current prediction and response programs in order to develop a coordinated research priorities plan (RDDTT Plan) . The final step (3) will lead to the development of the second report (RDDTT Plan) stipulated by the *HABHRCA* legislation (Section 104). The *Prediction and Response Report* and the RDDTT Plan together constitute a comprehensive evaluation and multi- stakeholder plan to improve the national and local response to HABs in U.S. waters.

It is widely believed that the frequency and geographic distribution of HABs have been increasing worldwide. All U.S. coastal states have experienced HABs over the last decade. HAB frequency is also thought to be increasing in freshwater systems including ponds and lakes. In response, Federal, state, local, and tribal governments in collaboration with academic institutions have developed a variety of programs over the past 10 years both to understand HAB ecology and to minimize, prevent, or control HABs and HAB impacts in U.S. waters.

As a result of the efforts initiated in 1993, there are now 16 Federal extramural funding programs which either specifically or generally target HAB prediction and response and 20 intramural Federal research programs which are generating exciting new technologies for HAB monitoring and control. There are 2 major Federal multi-agency funding programs which represent important cross agency collaborative efforts. At least 25 states conduct HAB response efforts, operating through a wide range of state government departments and nonprofits. Tribes in some states are collaborating with academic, Federal, and state governments to monitor the presence of HABs. Given the global scope of HABs, U.S. programs also work closely with international programs and in some cases contribute funding.

The *Prediction and Response Report* describes the remarkable progress made in some areas by Federal prediction and response programs. The greatest effort and progress has been made in mitigation, including improved monitoring and prediction capabilities, the establishment of event response programs, the conduct of economic impact assessments, and establishment of public health measures. Studies leading to prevention and control have led to new approaches. Infrastructure is being developed, cooperation and coordination has improved and incentive based programs have been used to address HAB problems.

Despite progress made, opportunities for advancing response to HABs still exist at the Federal and state level. The *Prediction and Response Report* outlines opportunities for advancement identified by Federal agencies for HAB prediction and response and by the HAB community in the report, Harmful Algal Research and Response: a National Environmental Science Strategy (*HARRNESS*) 2005-2015. (Ramsdell, J.S., Anderson, D.M., and Glibert, P.M. (eds.) Ecological Society of America, Washington, D.C., 96pp, 2005). This FRN requests public comment on the state of prediction and response programs in the United States and suggestions for how to improve that response.

**Comments Request:**

The Office of Science and Technology Policy (OSTP) welcomes all comments on the content of the Draft report. OSTP is specifically interested in feedback on

1) the current state of efforts (including infrastructure) in Prediction and Response to prevent, control, or mitigate Harmful Algal Blooms ;

2) suggestions for specific improvements in those efforts .

# Appendix V

Please adhere to the instructions detailed below for preparing and submitting your comments on the Draft *National Assessment of Efforts to Predict and Respond to Harmful Algal Blooms in U.S. Waters*. Using the format guidance described below will facilitate the processing of reviewer comments and assure that all comments are appropriately considered. Please format your comments into the following sections: (1) background information for yourself including name, title, organizational affiliation and email or phone (optional), (2) overview or general comments, (3) specific comments with reference to pages or line numbers where possible, and (4) specific comments about the current state of efforts in prevention, control and mitigation of HABs (PCM), including infrastructure. Please number and print identifying information at the top of all pages.

Public comments may be submitted from 9/27/06 to 11/20/2006.

# Appendix VI. RDDTT Workshop Steering Committee

**Don Anderson (Co-Chair, Work Group Lead)**
Director - Coastal Ocean Institute
Woods Hole Oceanographic Institution
Biology Department
Mail Stop 32, Redfield 332
Woods Hole, MA 02543-1049
(508) 289-2351
danderson@whoi.edu

**Quay Dortch (Co-Chair)**
ECOHAB Program Coordinator
Center for Sponsored Coastal Ocean
Research/NOAA
1305 East West Highway
Silver Spring, MD 20910
(301) 713-3338 x 157
Quay.Dortch@noaa.gov

**Patricia M. Glibert (Co-Chair, Work Group Lead)**
University of Maryland Center for
Environmental Science
Horn Point Laboratory
PO Box 775
Cambridge, MD 21613
(410) 221-8422
glibert@hpl.umces.edu

**Megan Agy**
National Sea Grant College Program
NOAA
1315 East-West Highway R/SG
Silver Spring, MD 20910
(301) 713 - 2431 x 150
megan.agy@noaa.gov

**Dan L. Ayres (Work Group Lead)**
Coastal Shellfish - Lead Biologist
Washington State Department of Fish and
Wildlife Region Six Office
48 Devonshire Road
Montesano, WA 98563
(360) 249-4628 x 209
ayresdla@dfw.wa.gov

**Gregory L Boyer**
Professor of Biochemistry
State University of New York
College of Environmental Science and Forestry
Syracuse, NY 13210
(315) 470-6825
glboyer@esf.edu

**Stacey M. Etheridge**
Center for Food Safety and Applied Nutrition
US Food and Drug Administration
5100 Paint Branch Parkway
College Park, MD 20740
(301) 436-1470
Stacey.Etheridge@fda.hhs.gov

**Porter Hoagland**
Marine Policy Center
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
(508) 289-2867
phoagland@whoi.edu

**Michelle J. Hooth**
National Institute of Environmental Health
Sciences/National Toxicology Program
79 T.W. Alexander Drive
P.O. Box 12233, MD EC-35
Research Triangle Park, NC 27709
(919) 316-4643
hooth@niehs.nih.gov

**Libby Jewett**
Senior Science Policy Analyst
Center for Sponsored Coastal Ocean Research/
NOAA
1305 East-West Hwy
Silver Spring, MD 20910
(301) 713-3338 x 121
Libby.Jewett@noaa.gov

**Judy Kleindinst**
Biology Department
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
(508) 289-2745
jkleindinst@whoi.edu

**Jan Landsberg**
Research Scientist
Fish and Wildlife Research Institute
Florida Fish and Wildlife Conservation
Commission
100 Eighth Avenue SE
St. Petersburg, FL 33701-5095
(727) 896-8626
jan.landsberg@myfwc.com

**Cary Lopez**
Science Policy Analyst
Center for Sponsored Coastal Ocean Research/NOAA
1305 East-West Hwy
Silver Spring, MD 20910
(301) 713-3338 x170
Cary.Lopez@noaa.gov

**George Luber**
Epidemiologist
Health Studies Branch NCEH
Centers for Disease Control & Prevention
4770 Buford Highway NE
Chamblee, GA 30341
(770) 488-3429
gluber@cdc.gov

**Tiffany A. Moisan**
Laboratory for Hydrospheric Processes
NASA Goddard Space Flight Center
Wallops Flight Facility
Wallops Island, VA 23337
(757) 824-1046
tmoisan@osb.wff.nasa.gov

**Gina Perovich**
Environmental Scientist
USEPA, National Center for Environmental Research
1200 Pennsylvania Ave., N.W.
Washington, DC 20460-0001
(202) 343-9843
Perovich.Gina@epamail.epa.gov

**Mark Poli**
Principal Investigator
Integrated Toxicology Division
USAMRIID
Ft Detrick, MD 21702-5011
(301) 619-4801
mark.poli@det.amedd.army.mil

**Chris Scholin**
Monterey Bay Aquarium Research Institute (MBARI)
7700 Sandholdt Rd.
Moss Landing, CA 95039-0628
(831) 775-1779
scholin@mbari.org

**Tara S. Schraga**
U.S. Geological Survey
345 Middlefield Road MS496
Menlo Park, CA 94025
(650) 329-4381
tschraga@usgs.gov

**Kevin Sellner**
Executive Director
Chesapeake Research Consortium
645 Contees Wharf Road
Edgewater, MD 21037
(443) 482-2350
sellnerk@si.edu

**Mary Silver**
Department of Ocean Sciences
University of California
Santa Cruz, CA 95064
(831) 459-2908
msilver@ucsc.edu