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

Draft Interim Report
December 2006

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List of Acronyms

AOAC Association of Official Analytical Chemists

ART Analytical Response Team, NOAA

ASP Amnesic Shellfish Poisoning

AUV Automated Underwater Vehicle

AZP Azaspiracid Poisoning

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

CDC Centers for Disease Control and Prevention

CFP Ciguatera Fish Poisoning

COHHs Center for Oceans and Human Health, NSF/NIEHS

CSCOR NCCOS Center for Sponsored Coastal Ocean Research, NOAA

DOI Department of Interior

DSP Diarrhetic Shellfish Poisoning

EC European Commission

ECOHAB Ecology and Oceanography of Harmful Algal Blooms

ELISA Enzyme-linked immunosorbent assay

EPA Environmental Protection Agency

EUROHAB European Harmful Algal Bloom Program

FDA 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 Observing System of Systems

GOOS Global Ocean Observing System

HAB Harmful Algal Bloom

HABHRCA Harmful Algal Bloom and Hypoxia Research and Control Act

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

IAEA International Atomic Energy Agency

IEOS U.S. Integrated Earth Observing System

IOC Intergovernmental Oceanographic Commission

IOOS Integrated Ocean Observing System

ISSC Interstate Shellfish Sanitation Conference

MERHAB Monitoring and Event Response for Harmful Algal Blooms

MMC Marine Mammal Commission

NASA U.S. National Aeronautics and Space Administration

NCCOS National Centers for Coastal Ocean Science, 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 U.S. National Science Foundation

NSP Neurotoxic Shellfish Poisoning

OHHI Oceans and Human Health Initiative, NOAA

ONR Office of Naval Research

ORHAB Olympic Region HAB Monitoring Program

PCM Prevention, Control and Mitigation

PSP Paralytic Shellfish Poisoning

RCOOS Regional Coastal Ocean Observing System

RDDTT Research Development Demonstration and Technology Transfer

REASoN Research, Education, and Applications Solution Network

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 for 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 foodwebs. Harmful algal bloom or "HAB" species are a small subset of algal species that produce toxins and/or bloom to excess 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. HABs can also result in lost revenue for coastal economies dependent on seafood harvest or tourism, disruption of subsistence activities, loss of community identity tied to coastal resource use, disruption of social relationships and cultural practices, and other sociocultural and economic harms. Thus, HABs are a threat to coastal communities and economies as well as human and ecosystem health. Although economic impact assessments to date have been limited in scope, 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 *HAB 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* (PL 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 are being developed as a linked pair. The first, this *Prediction and Response Report,* specifically addresses both the state of research and methods for HAB prediction and response, especially at the federal level. State, local and tribal efforts are also described. This *Prediction and Response Report* was developed by soliciting input from federal agencies about their programs and analyzing a number of

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)

recently published reports[3-11]. In this process, accomplishments and areas for advancement were also identified.

This report is the first step in a process to create an innovative research and development plan for HAB prediction and response. The second report, the *National Scientific Research, Development, Demonstration and Technology Transfer Plan for Reducing Impacts from Harmful Algal Blooms* (*RDDTT Plan*), will establish research priorities and a plan for peer-reviewed, competitive prevention, control, and mitigation (PCM) efforts to advance current prediction and response capabilities.

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 other 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 of 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 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.

The Slocum Glider AUV with "Brevebuster," an automated sensor for detecting *Karenia brevis*. Photo: NOAA

3) Control: A number of new potential approaches to controlling some HAB species have been identified, including physical cell removal by clay flocculation, natural by-products 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 permitting processes developed for testing these methods in the natural environment.

4) Event Response: Several HAB event response programs have been established with the dual purpose of helping managers minimize impacts of events, mobilize resources, and providing data to enhance 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*)[9] stresses the need for better coordination. A National HAB Committee (NHC) has been formed, as recommend by *HARRNESS*[9], 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*[9], the *Harmful Algal Research and Response: A Human Dimensions Strategy* (*HARR-HD*)[10] 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 as in-kind support (e.g., NOAA Sea Grant). Using 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 U.S. have been conducted [1,4,12,13, 14.] 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[10].

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.
- Improving human and wildlife health reporting and guidelines. Many animals serve as sentinels of HAB events. Mechanisms for wildlife illness surveillance and reporting and public health

surveillance systems will enhance our ability to respond to HAB events.

Next Steps

As required by the legislation, a summary of this report 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 this preliminary *Prediction and Response Report*.

The next step in this process will be the development of the *RDDTT Plan.* Issues to be addressed in the *RDDTT Plan* will 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. A workshop will be held 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 this report with the FRN comments and the workshop proceedings will provide the basis for the *RDDTT Plan* (which will be published as a companion to this *Prediction and Response Report*). The workshop and subsequent *RDDTT Plan* will focus on the following broad issue areas: 1) infrastructure, 2) research priorities for prevention, control, and mitigation, 3) opportunities for social sciences in HAB response, 4) improving and coordinating event response, and 5) addressing additional areas raised in response to the FRN.

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 (P.L. 108-456) (*HABHRCA* 2004) reauthorized the *Harmful Algal Bloom and Hypoxia Research and Control Act* of 1998 (P.L. 105-383), reconstituted the Interagency Task Force on HABs and Hypoxia (Box 1), and requires five reports to assess and recommend research programs on harmful algal blooms (HABs) and hypoxia in U.S. waters (Box 2), including this *Prediction and Response Report*. This report reviews and evaluates HAB prediction and response techniques and identifies 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 (Box 3) in order to avoid overlap with two other reports in this series (Box 2), the *Scientific Assessment of Marine Harmful Algal Blooms* (Box 4) and the *Scientific Assessment of Freshwater Harmful Algal Blooms* (Box 5).

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 6). The IWG-4H streamlined the reporting process by linking the *Prediction and Response Report* with the *National Scientific Research, Development, Demonstration, and Technology Transfer Plan on Reducing Impacts from Harmful Algal Blooms* (*RDDTT Plan*) (Box 7).

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

- Department of Commerce, Co-chair
- Department of Health & Human Services, Co-chair
- Environmental Protection Agency
- National Science Foundation
- National Aeronautics & Space Administration
- Department of the Navy
- Department of Agriculture
- Department of Interior
- Food & Drug Administration, DHHS
- Office of Science & Technology Policy
- Council on Environmental Quality

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

- *National Assessment 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. Definitions (also see List of Acronyms, page viii)

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, due in December 2007 (Box 4).

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.

The *Prediction and Response Report* is the first step in a process to create an innovative research plan on prediction and response. The purpose of this report is

1) to detail federal, state, and tribal prediction and response-related research and impact assessments,

2) to evaluate prediction and response programs, and

3) to highlight options for prediction and response efforts and associated infrastructure.

The focus of this report 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 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[2,3,5,7,9] 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*)[9] report. In addition to drawing from general information on state programs detailed in *HARRNESS*[9], research into state prediction and response initiatives was conducted to make the state information as comprehensive as possible. Information on tribal prediction and response initiatives was derived from other recent reports.

The assessment of current prediction and response programs will lead to the development of the second report (*RDDTT Plan*) stipulated by the *HABHRCA* 2004 legislation. The *Prediction and Response Report* together with the *RDDTT Plan* will comprise a comprehensive evaluation

Box 4. *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 *Prediction and Response Report*. Progress related to research on HAB causes and dynamics will be covered in the *Scientific Assessment of Marine Harmful Algal Blooms* due to be completed in December, 2007.

Box 5. *HABHRCA* Report: *Scientific Assessment of Freshwater Harmful Algal Blooms*

The *Scientific Assessment of Freshwater Harmful Algal Blooms* will assess 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 will also address regulatory considerations, such as the current lack of regulations and guidelines on freshwater HAB toxins in drinking and recreational waters, and identify research priorities for creating a research plan to improve understanding, response, and management of HABs. It is due to be completed in December, 2006.

and strategy developed with input by multiple stakeholders to improve the national and local response to HABs in U.S. waters.

HABHRCA 2004 required that a summary of the *Prediction and Response 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 this report. The Federal Register Notice (FRN, Appendix V) specifically asked for commenters to provide feedback on the current state of prediction and response efforts and to suggest how those efforts might be enhanced. The IWG-4H will use this information to shape workshops as part of the *RDDTT Plan* process. In addition to the public comments, recommendations from *HARRNESS*[9] and feedback from federal agencies (in creation of the *Prediction and Response Report*) will also be used to develop the workshop topics. The workshop process proposed in this report will aid the IWG-4H in developing a coordinated, national research agenda to improve prediction and response efforts as requested as part of the *RDDTT Plan*. It will also lead to other recommendations for improving U.S. HAB response.

Box 6. Oceans and Human Health (OHH) Act 2004 (PL 108-447)

The 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. Harmful Algal Blooms are included as part of the program scope but the 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 OHH Act requires agencies to develop a 10 yr OHH implementation plan in coordination with the Inter-Agency Task Force on Harmful Algal Blooms and Hypoxia, established by *HABHRCA* 1998.

Box 7. 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* will be organized and conducted (01/07 - 04/07)
- Workshop Proceedings will be published and synthesized into *RDDTT Plan* (05/07 - 12/07)
- Final *Prediction and Response Report* and *RDDTT Plan* submitted as one report (12/31/07)

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 pervasive. All coastal states in the U.S. 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 U.S. and globally. In 2005, New England and Florida each experienced a HAB event that was more severe than any since the early 1970's (Boxes 8 and 9). There are also HAB species and toxins that have emerged recently as new threats in the U.S. 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 U.S. in the early 1990's when domoic acid was detected in Monterey Bay, California, and in razor clams on the Washington coast.

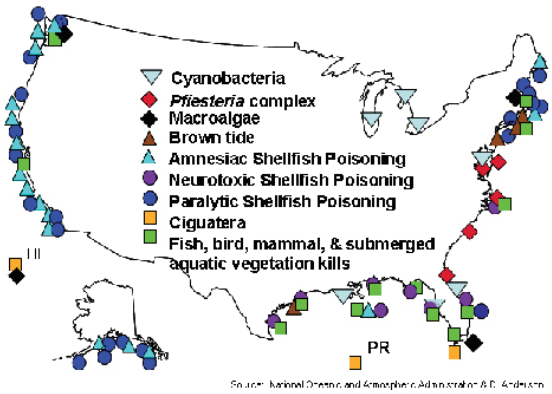


Figure 1. Major HAB events in coastal U.S. waters and the Great Lakes

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[11]. 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[21]. 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 future 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 non-toxic 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 non-toxic 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 to 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 U.S. 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 sub-tropical and tropical waters and is the most common finfish poisoning, with more than 400 fish species implicated as potential vectors[9]. Cyanobacterial toxins can also accumulate in

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

In spring of 2005, the most severe bloom of the toxic dinoflagellate, *Alexandrium fundyense*, since 1972 spread from Maine to Massachusetts. This bloom event resulted in extensive and, in some locations, unprecedented closures of shellfish harvesting areas to prevent Paralytic Shellfish Poisoning (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 FDA and declared a Fisheries Failure to allow emergency disaster relief for the region's commercial fishermen affected by the closures. Both Maine and Massachusetts issued disaster declarations.

A preliminary estimate of the economic impact due to lost shellfish sales in Massachusetts and Maine as a result of imposed closures is approximately $11 million (based on historical NMFS production numbers[44]). 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*[9])

Toxin	Vector	Short-term Health Consequences	Long-term Consequences of Toxin Exposure	Susceptible Regions
Ciguatoxins	Reef fish	Ciguatera Fish Poisoning: 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	Diarrhetic Shellfish Poisoning: 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	Neurotoxic Shellfish Poisoning: 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	Paralytic Shellfish Poisoning: 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	Amnesic Shellfish Poisoning: 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 & 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 & 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 & Continental U.S. ponds, lakes, and rivers
Cyanobacterial lipopolysaccharide/s	Drinking and recreational water	Abdominal pain, vomiting and diarrhea, acute dermatitis	Unknown	Great Lakes & Continental U.S. ponds, lakes, and rivers

the tissues of fish and shellfish, especially in the viscera, so the World Health Organization cautions against fish and shellfish consumption where large toxic cyanobacterial blooms occur[22]. 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 World Health Organization's advisory limit for drinking water[9]. Drinking water contaminated with low levels of cyanobacteria can have taste and odor problems due to non-toxic 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. Selected cyanobacteria and their toxins are included on the U.S. EPA's Contaminants Candidates List (http://www.epa.gov/safewater/ccl/ccl2_list.html), making them priority organisms and compounds for research to assess their occurrence in drinking water and their health effects to determine whether actions such as drinking water guidance, health advisories, or regulations are necessary. Legislative mandates in the *Safe Water Drinking Act* and the *Clean Water Act* require attention be paid to the presence of HAB toxins in drinking and recreational waters although no specific U.S. guidelines or regulations for these toxins currently exist.

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[32]. In 1999, Steidinger et al. 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

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 we do not know the potential public health impacts of these exposures.

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 foodborne 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 underreported, 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[23]. 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[24]. Fish and seagrass can also act as toxin vectors, posing threats to marine animals and potentially resulting in delayed or remote toxin exposure[25]. 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[26]. *Heterosigma akashiwo* is a raphidophyte that forms blooms and has killed large numbers of cultured salmon in Washington, presumably due to production of compounds that are toxic to fish[27,28]. Similarly, the "golden algae" *Prymnesium parvum* has caused fish kills in Texas inland waters since the 1980's[29] and is a problem in other states as well.

Degraded habitat quality is another ecosystem impact of toxic and non-toxic 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 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 loss of over 2000 acres of shoalgrass due to long term light limitation[30]. Macroalgal blooms also reduce sunlight penetration and can overgrow or displace seagrasses and corals[31]. 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 U.S. averages $82 million per year. This estimate, an update to those given by Hoagland et al. 2002[14], covers a broader time period (1987-2000) and employs the same analytical methods 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

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, e.g. Lake Champlain (1-2 reported annually), Northern California (9 reported in 2001), and Minnesota (several in 2004).

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[12, 32, 33] (Boxes 8, 9, and 12) highlight that this annual average for the Nation may be too conservative.

Box 11. What are the Economic Effects of HABs on the U.S. Economy? [1, 14]

TOTAL COST ($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)

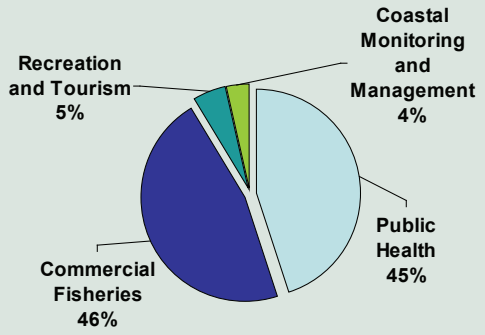
- Includes lost revenue due to closed fisheries, mortalities of shellfish and fish, some untapped fisheries (surf clams in Alaska and on Georges Bank)
- Does NOT include cost of delayed harvesting or changes in economic value (i.e., surplus losses)

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 State

Coastal Monitoring and Management ($3 million per year)

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



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"[34]. 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*[9] 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 efforts10. 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 4) and the *Scientific Assessment of Freshwater Harmful Algal Blooms* (Box 5). **Only proactive measures of prevention that apply current knowledge are considered in this *Prediction and Response 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 the following[3, 7, 35]:

Minimizing nutrients flowing into coastal and inland waters: GEOHAB[6,11] recognized increased nutrient pollution as one reason for the expansion of HABs in the United States and globally, but the report 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 non-point 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 decision makers 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 introduction of HAB species to new areas include release of ballast water, sediment dredging, and transfer of shellfish or finfish during aquaculture stocking procedures[3]. 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 the following:

Box 12. Algal toxins plague fisheries of Washington State

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 Amnesic Shellfish Poisoning (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[33].

Photo: Washington DFW

- Ballast water: assess the potential for introduction and apply techniques to eliminate HAB cells or cysts before ballast release.
- Dredging and dredge spoil disposal: assess HAB cyst distributions prior to dredging.
- Shellfish and finfish transfers from bloom-prone areas: assess risk of transfer and prohibit or develop a treatment procedure for those transfers that pose a risk.

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, the Natural Resources Conservation Service and USDA 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 (CEAP). 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 fresh water 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 nor ecologically desirable. Control strategies are challenging because of the potential costs, effectiveness, environmental impacts, and public perceptions. In the *Harmful Algae Management and Mitigation*[8] report, Anderson[35] acknowledged that lessons for HAB control can be learned from research that has been done to control terrestrial nuisance species. Anderson[35] 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 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[36]), oxidants, such as potassium permanganate[37], hypochlorite[38], or ozone[39], and barley straw[40]. 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[41]. A naturally produced by-product 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 can be used for control of specific HABs, at least on a small scale.

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 ELISA assay for domoic acid that was tested in the laboratories of NOAA NWFSC and the Quileute Tribe at LaPush, WA. This assay is quantitative and sensitive enough to measure concentrations of domoic acid in clams below action levels. It will be field tested (summer 2006) by resource managers and public health officials from Washington, Oregon, and California.

Genetic: Anderson[35] 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 4). 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.

Risk communication, public education and outreach: Risk communication research helps scientists, coastal resource managers, water utility managers, public health authorities, and other partners communicate forecasting and other information so that the public

Box 15. Simpler, More Sensitive Test for Brevetoxin

USAMRIID has recently developed an electrochemiluminescence (ECL)-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 AOAC multi-laboratory collaborative study to validate the assay as an official method is planned in the coming year.

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*[9] 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.

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 for method development, to generate reliable quantitative data on toxins, and to 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.

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 U.S. 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
NH 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
ORHAB
http://www.orhab.org

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 (AUV's), satellites, and/or aircraft (including unmanned aerial vehicles (UAV's)). 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[9] 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 U.S. 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.

Outreach

Outreach promotes community awareness of HAB issues. *HARRNESS*[9] and *HARR-HD*[10] 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, by imparting accurate perceptions of seafood, drinking water, and recreational safety within the community, and by 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.

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 (IEOS), the U.S. contribution to the Global Ocean Observing System (GOOS, http://www.ioc-goos.org/), and a contribution to the Global Earth Observation System of Systems (GEOSS).

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 (RCOOSs), 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 (GoMOOS), which has provided oceanographic data for use in conjunction with other data in order to monitor and predict *Alexandrium* bloom movement in the Gulf of Maine, offers a preliminary example of their application for enhancing HAB prediction.

Chapter 3

Prediction and Response Programs in the U.S.

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 *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 *Prediction and Response Report* focuses primarily on *federal* extramural and intramural efforts, which are detailed in Appendix I. Other national organizations, state and local governments, non-governmental 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 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 non-profit organizations. 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. International programs are detailed in Appendix IV.

Improved, well coordinated HAB prevention, control, and mitigation research programs and more sophisticated monitoring tools will enhance our 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[10]. 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 4) and the *Scientific Assessment of Freshwater Harmful Algal Blooms* (Box 5). Incorporating a more holistic, social sciences approach into HAB response will be considered in the *RDDTT Plan*.

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 prevention, control, and mitigation (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 prevention, control, and mitigation, 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 4), it is generally accepted that some HAB events are intensified by high nutrients[6, 11]. 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 run-off and erosion) or the use of wood chips in drainage ponds, may reduce HABs in fresh and coastal water ecosystems. USDA's SWAT (Soil and Water Assessment Tool) conservation measures, which include efforts to reduce erosion, to increase water flow in drought-stricken areas in the Southwestern U.S., and to improve nutrient management agricultural practices, have been adopted in some regions (Box 13). ECOHAB (EPA) 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 (NOAA-CCEHBR, ECOHAB), and their mode of action and specificity 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 – EPA, NOAA). 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 need.

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 (NOAA – NCCOS, 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 (NOAA - NWFSC). Recently, numerical models (NOAA-CSCOR, NIEHS/NSF) and drifter buoys (NOAA - CSCOR, NEFSC) have been used to track and provide early warning for *Alexandrium* blooms in New England.

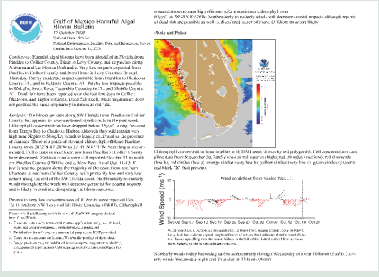
Monitoring

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 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 – NCCOS, NMFS; see Rapid Response 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 (NOAA, EPA) and through a cooperative agreement with 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, CSCOR; (Box 16)) or to monitor marine animal mortalities (NOAA-NMS) which help focus state monitoring efforts. With minimal resources, these networks of volunteers greatly improve the geographic 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 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. The NASA 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 e-mail 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

Between 2000-2005, the 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

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 [3,7] 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 all HAB species and toxins.

In the last few years many methods have been developed for detection of 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 (NOAA-AOML, NWFSC, CCEHBR, CCFHR, CSCOR, GLERL, CICEET; EPA; NIEHS; NIEHS/NSF COHH centers). 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, 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 SBIR 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 and taste and odor problems are also being explored (EPA, USGS) and further research is being planned (Box 5). 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, NOAA – CSCOR, CCEHBR).

Automated sampling devices that can be deployed either on fixed platforms or on AUVs (automated underwater vehicles) 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 p.4) (NOAA) and cyanobacterial-related taste and odor problems in Kansas (Box 20, USGS). Another study combining molecular probe and fiber optic technologies for rapid HAB detection may prove useful for automated detection and early warning

Box 21. First Time Measurement of Ciguatoxin in Blood Provides Method to Biomonitor Human Exposure

Human ciguatera fish poisoning has the highest public health impact of all HAB poisoning, exceeding cost estimates for all the shellfish poisonings combined by more than twenty-fold. At present there is 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 (ELISA), 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 (SPR) fiber optic probe coated with a molecularly imprinted polymer (MIP) that will provide fast, simple, and sensitive detection of the cyanotoxin, microcystin-LR, in the field.

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. 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 the development of models to predict HAB occurrence. Water quality monitoring is conducted by a range 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 6 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 the NOAA Marine Mammal Health and Stranding Response Program and the Working Group on Unusual Marine Mammal Mortality Events (NOAA NMFS, USFWS, MMC, EPA) for investigating unusual mortality events (UME's), the NOAA HAB Event Response Program for assisting state managers and researchers investigating HAB events, and the NOAA Analytical Response Team for providing toxin analyses during HAB events to investigate wildlife mortalities, food web impacts, and human poisonings. 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 NOAA-CSCOR, 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 specific HAB events. Non-

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 (EMPACT) 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 3 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 (DNR) 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

economic social impacts of HABs are much more difficult to quantify although efforts are underway to consider these more thoroughly[10]. Ongoing studies to identify animal (Box 26) and human populations at higher risk for adverse toxicity effects (NOAA-CCEHBR, NMFS; NIEHS; NSF/NIEHS- COHH) 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 5 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 these programs. Both funding programs have established a total of seven Oceans and Human Health 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 6) mandating 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 as well as an annual report to update Congress on all federal oceans and human health activities.

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 in order 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 for 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 OHHI, MERHAB, and ART programs. This work demonstrated that domoic acid bioaccumulates selectively in the amniotic fluid of pregnant female marine mammals, that it causes permanent and often unilateral brain damage, that it is responsible for extreme aggression in animals that survive, and that 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.

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, websites, written materials, satellite data, listserves, and broadcast e-mails 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 methodologies, 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 websites 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 websites and listserves 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[10].

Federal facilities for toxin analysis (CDC; FDA; NSF/ NIEHS COHH; 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, 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 at Austin are two large algal culture collections in the U.S. that maintain some HAB species and depend in part on federal funding (NSF, NOAA). 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. NIST has established the National Marine Mammal Tissue Bank (NMMTB) 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, automated underwater vehicles (AUVs), satellites, aircraft, and unmanned aerial vehicles (UAVs), are integral to the research, monitoring,

Box 27. Surveillance System for HAB Illness

CDC has developed the HAB-related Illness Surveillance System (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 & NSF	NIST	NOAA/ OAR	NOAA/ NOS	NOAA/ NMFS	NOAA/ NESDIS	NSF	USGS	USAMRIID
Information resources	Web-based HAB related illness surveillance system HAB website			Satellite data (ocean color, SST, and ocean surface topography)	Remote sensing data (University of Miami)		Web vido for assay demonstration (AOML) HAB event response website, list-server (GLERL)	National Office for Marine Biotoxins and HABs, Harmful Algae Page website (CSCOR) Harmful Algal Event Database (HAE-DAT) (CSCOR) HAB Bulletin (CCMA, COOPS) Database for HAB event response samples and analysis (CCEHBR)	Environmental Services Data and Information Management (ESDIM), Pacific HAB data, ORHAB database, website (NWFSC) 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) Culture facility (*Gamberidiscus toxicus* focus) and toxin analysis (PRCMB)			Algal taxonomy facility (CCEHBR) Toxin analysis facility (CCEHBR) Shared mass spectrometry facilities (CCFHR)	Scanning Electron Microscopy (SEM) facility (NWFSC) 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) Citizen-based monitoring networks (CCEHBR, CSCOR) National Office for Marine Biotoxins and HABs (CSCOR)	Educating Teachers at Sea (NWFSC) Red Tides Newsletter (NWFSC) 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) Algal reference materials and culture collection (CCEHBR)	Milford Culture Collection (NEFSC) Culture Collection (NWFSC)		UTEX Culture Collection of Algae at the University of Texas at Austin Center for Culture of Marine Phytoplankton (CCMP) at Bigelow Laboratory		
Toxins			Provide saxitoxin reference standard		Brevetoxin Standards			Toxin reference materials (CCEHBR) Ciguatoxin sampling kits to public health and wildlife managers (CCEHBR)					
Satellite and Airborne Sensors				SeaWiFS, MODIS-Aqua (Satellite-based) AVIRIS, MAS, MASTER, LIDAR (Aircraft-based) AMS (UAV-based)			Ocean Color Sensor (UAV- based, Environmental Technology Laboratory)						

AMS: Autonomous Modular Sensor
AVIRIS: Airborne Visible/Infrared Imaging Spectrometer
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 prediction of HABs. As coordinated networks of observing systems, IOOS and 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 2009, 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.

Box 28. Innovative Collaboration mitigates HAB impacts in Washington State

In 1999, the ORHAB, Olympic Region Harmful Algal Bloom, 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[46]. 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.

Photo: Vera Trainer, NWFSC

Cooperation/ Coordination

Growing cooperation among federal agencies and between federal, state, local and tribal agencies has enhanced HAB monitoring capability. Through multi-agency extramural programs (ECOHAB – EPA, NOAA, NASA, NSF; NIEHS/NSF COHH Centers), 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).

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 (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[9]. 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), the 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 is comprised of multiple federal agencies and state, academic, tribal, and local entities and provides a national forum for coordination of water quality monitoring, assessment, and reporting. Programs like the NOAA Monitoring and Event Response for Harmful Algal Blooms (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. Small Business Innovation Research (SBIR) programs in EPA and NOAA have motivated private industry to develop new technologies for HAB monitoring. The MERHAB (Monitoring and Event Response for Harmful Algal Blooms) program at NOAA 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 non-profit 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 or will be 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*[9] 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 (3) below. All of this information and recommendations from *HARR-HD*[10], which provides a detailed implementation plan for social science research critical to achieve the goals of *HARRNESS*[9], will be used to shape the next report, the *RDDTT Plan*, through the workshop process (see Next Steps). The *RDDTT Plan* will establish research priorities and put 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 approaches were identified and are organized into the broad categories planned for the RDDTT workshop (see Next Steps):

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 U.S., 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 socio-cultural 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 ground-water 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*[9]) 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[10].

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 will be discussed in the *Scientific Assessment of Freshwater Harmful Algal Blooms* (Box 5).

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[10].

ii. Provide a more rigorous social sciences approach to mitigating HAB impacts as recommended by *HARR-HD*[10]. 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[10].

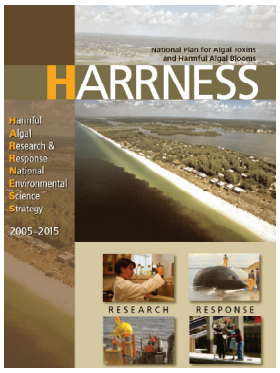
iii. Improve human HAB-related disease surveillance and reporting, incorporating a central repository for information and involvement of non-coastal state health departments since shellfish consumption is not restricted to coastal areas. Development and circulation of guidelines for human exposure to cyanotoxins (in both drinking water and recreational waters) and non food-related exposures to other algal toxins will be discussed in both the *Oceans and Human Health Implementation Plan* (Box 6) and the *Scientific Assessment of Freshwater Harmful Algal Blooms* (Box 5).

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 ability to respond to HAB events. This problem will also be discussed in both the *Oceans and Human Health Implementation Plan* (Box 6) and the *Scientific Assessment of Freshwater Harmful Algal Blooms* (Box 5).

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*[9]

HARRNESS[9] 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 due in 2007 (Box 4).



Prediction and Response-Specific Recommendations from *HARRNESS*[9]:

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 methodologies 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 Federal Register 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 harmful algal blooms; 2) suggestions for specific improvements in those efforts.

The majority of public comments were received were from the National HAB Committee (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 were summarized below and will be addressed in the final version of this report due December 2007. These comments will be used to inform the workshop to develop a plan for future efforts (described in Next Steps). Minor editorial comments were incorporated into this revised interim report and are not included in the public comment summary. Verbatim comments will be available at http://www.cop.noaa.gov/stressors/extremeevents/hab/habhrca/P_R_publiccomments.pdf until December 2007.

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 would 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 calls "bottom-up" controls on algal growth (e.g. nutrients, pollutants, etc.) 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 re-populate 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. Our 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, Box 13, which deals with *watershed nutrient reduction*, 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 our 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 in place 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 comment. 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, National Estuarine Research Reserves staffs, Sanctuaries staffs, and 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 communication of forecasting and other information to promote public perceptions and behaviors that reduce vulnerability 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 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 re-evaluating an area 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 HHS should be given the authority to open and close Federal waters, as it is more their decision than that of NMFS.

End Public Comment Summary

Next Steps: Setting Priorities for Improving Prediction and Response Efforts

The opportunities for advancement of prediction and response efforts identified in this *Prediction and Response Report* will form the basis for developing the *National Scientific Research, Development, Demonstration, and Technology Transfer Plan on Reducing Impacts from Harmful Algal Blooms* (*RDDTT Plan*, Box 2). *HABHRCA* 2004 mandates the creation of the *RDDTT Plan,* a coordinated national research agenda to improve prediction and response efforts. Issues related to HABs in freshwater ecosystems will be addressed in the *Scientific Assessment of Freshwater Harmful Algal Blooms* (Box 5).

In order to develop the *RDDTT Plan*, a comprehensive workshop will be held with representatives from all sectors of the HAB community, including federal and state management and research communities and private industry. The workshop findings describing options for each of the focus areas will form the basis of the *RDDTT Plan*, which will be written by the IWG-4H (Box 1). The following focus areas will be addressed as well as other topics that arise as a result of the FRN:

1) **Infrastructure for HAB research and response,**

2) **Research priorities for prevention, control, and mitigation** of HABs,

3) **Incorporation of social sciences in HAB response programs, and**

4) **Event Response Programs.**

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Appendices

Appendix I. Federal Prediction and Response Programs

A. Multi-agency Efforts

1. Centers for Oceans and Human Health (COHH)

The **National Institute of Environmental Health Sciences** (NIEHS) and the **National Science Foundation** (NSF) support four Centers for Oceans and Human Health: the University of Miami Oceans and Human Health Center, the Pacific Research Center for Marine Biomedicine (PRCMB), 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 oceans and human health research, including HABs (http://www.niehs.nih.gov/dert/cohh/).

At the **University of Miami Oceans & 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 PCR assays for four species of *Pseudo-nitzschia*. The Center also collaborates with ECOHAB Pacific Northwest and the Monterrey Bay Aquarium Research Institute to interface SPR (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 (PRCMB)** 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. ECOHAB

The Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) Program is a multi-agency program that includes **NOAA CSCOR (lead)**, **NOAA Sea Grant**, **NSF**, **U.S. EPA's Science to Achieve Results (STAR) Program**, **NASA**, and **ONR** (Box 29). Through competitive peer-reviewed research by partnerships of academic, state, federal, and non-profit 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.

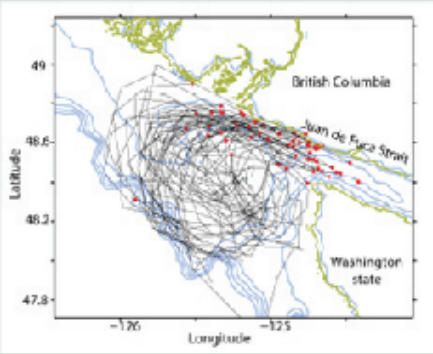
Box 29. Interagency ECOHAB Program Prediction and Response Efforts

- **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 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. The Small Business Innovation Research (SBIR)

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 (SPR) 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 Autonomous Underwater Vehicles capable of carrying sensors and taking water samples. Four NOAA funded phase I projects have been completed.

B. Agency Efforts

1. Department of Agriculture

USDA Intramural

The Agricultural Research Service (ARS) National Program (201: Water Quality and 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 non-point 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.

CSREES (Cooperative State Research, Education, and Extension Service) 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 (from website 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. Department of Commerce

2.1. National Oceanographic Atmospheric Administration (NOAA)

2.1.1. NOAA Extramural

2.1.1.1. Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET)

CICEET was established in 1997 as a partnership between the National Oceanic and Atmospheric Administration and the University of New Hampshire. CICEET uses the capabilities of UNH, the private sector, academic and public research institutions throughout the U.S., 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

Marine Mammal Health and Stranding Response Program

The John H Prescott Grant Program. This 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 recent realization that more than 50% of marine mammal unusual mortality events since 1998 were due to HAB toxins suggests that more funding is required.

Marine Mammal Unusual Mortality Event Fund. This 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

Research on animal health assessments. This program provides funds for health assessment work on marine mammals. 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.

2.1.1.3. National Ocean Service

2.1.1.3.1. Oceans and Human Health Initiative.

In 2004, NOAA established an Oceans and Human Health Initiative 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—the Great Lakes Environmental Research Laboratory in Ann Arbor, MI and the Northwest Fisheries Science Center in Seattle, WA (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)

MERHAB. The Monitoring and Event Response for Harmful Algal Blooms (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 a t: 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 Woods Hole Oceanographic Institution (see Non-governmental National Programs section) 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 International Oceanographic Commission (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

National Sea Grant College Program. Sea Grant 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[42]. 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 29).

2.1.2. NOAA Intramural

2.1.2.1. National Environmental Satellite, Data, and Information Service (NESDIS)

National Oceanographic Data Center (NODC).

National Coastal Data Development Center (NCDDC). The Harmful Algal Blooms Observing System (HABSOS) pilot project was a proof-of-concept 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 3 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.

2.1.2.2 National Marine Fisheries Service

2.1.2.2.1. NOAA Fisheries Science Centers

The Northwest Fisheries Science Center (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 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 (ESDIM) Pacific HAB data access project with NODC which compiles biological, chemical, and physical data for National HAB database, the global HAB database for the international PICES program, and creation of a local database for ORHAB partners. In addition, NWFSC contributes to outreach and education through education of PNW Teachers at Sea and ORHAB website and outreach materials.

The Northeast Fisheries Science Center (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).

2.1.2.2.2. Marine Mammal Health and Stranding Response Program

Marine Mammal Response and Health Assessments. This 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, the CSC HAB forecasting program, and the Marine Biotoxins Analytical Response Team in Charleston. 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 the 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/

2.1.2.3. National Ocean Service

2.1.2.3.1 Oceans and Human Health Initiative Centers of Excellence

The OHHI established three OHH Centers of Excellence: Hollings Marine Lab in Charleston, SC; Great Lakes Environmental Research Laboratory in Ann Arbor, MI; and the Northwest Fisheries Science Center in Seattle, WA.

Hollings Marine Laboratory (HML) - NOS. The HML promotes collaborative and interdisciplinary scientific research. It is operated as a partnership among the National Oceanic and Atmospheric Administration (NOAA), the National Institute of Standards and Technology (NIST), the South Carolina Department of Natural Resources (SCDNR), the College of Charleston, and the Medical University of South Carolina (MUSC). See CCEHBR (6.2.2.2.2) and NIST for more information on HML HAB research.

Great Lakes Environmental Research Laboratory (GLERL) – OAR. GLERL 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 2.1.2.4.2 for more information)

Northwest Fisheries Science Center (NWFSC) – NMFS. The West Coast Center for Oceans and Human Health 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 2.1.2.2.1 for more information)

2.1.2.3.2. National Centers for Coastal Ocean Science Center (NCCOS)

2.1.2.3.2.1. NCCOS Coastal Monitoring and Assessment (CCMA).

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.

2.1.2.3.2.2. NCCOS Center for Coastal Environmental Health and Biomolecular Research (CCEHBR)/ Hollings Marine Lab (HML).

The Marine Biotoxins Program.

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), 3) the Southeastern Phytoplankton Monitoring Network (SEPMN), 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

Analytical Response Team (ART). 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 coordinates with the **NMFS** Working Group for Unusual Marine Mammal Mortality Events (WGUMME) to investigate all marine mammal mortality events in U.S. coastal waters. *http://www.chbr.noaa.gov/default.aspx?category=mb&pageName=art*

2.1.2.3.2.3. NCCOS Coastal Fisheries and Habitat Research (CCFHR).

Researchers at the 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 U.S (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 non-toxic "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.

2.1.2.3.3. National Marine Sanctuaries (NMS)

The mission of NOAA's National Marine Sanctuaries is to serve as the trustee for the nation's system of marine protected areas, to conserve, protect, and enhance their biodiversity, ecological integrity, and cultural legacy. HABs have been identified as an information need in a number of National Marine Sanctuaries, and three have actively participated in HAB Prediction and Response Related activities. The Olympic Coast National Marine Sanctuary (OCNMS) contributes to the Olympic Region Harmful Algal

Bloom (ORHAB) partnership by maintaining moorings for monitoring from April through October and collecting water samples for collaborators at NWFSC. The Monterey Bay National Marine Sanctuary (MBNMS) 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. MBNMS's Sanctuary Integrated Monitoring Network (SIMoN) 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 National Marine Sanctuary collaborates with USF and NOAA CCMA to identify and track blooms in southwest Florida and the Florida Keys.

2.1.2.4. Office of Ocean and Atmospheric Research

2.1.2.4.1. Atlantic Oceanographic and Meteorological Laboratories (AOML).

Researchers at 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 Centers for Oceans and Human Health 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*.

2.1.2.4.2. Great Lakes Environmental Research Laboratory (GLERL).

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/HumanHealth/hab/EventResponse/) and a listserv "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)

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 National Marine Fisheries Service's Office of Protected Resources and the Alaska Marine Mammal Tissue Archival Project conducted by the U.S. Geological Survey (USGS).

3. Department of Defense

3.1. United States Army Medical Research Institute for Infectious Diseases (USAMRIID)

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. Department of Health and Human Services

4.1. Centers for Disease Control and Prevention (CDC)

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 5 state HABprograms funded by CDCthe range of interactions among marine and freshwaterand. state-basedinclude aerosol exposures tored tide,to develop a biological marker of ciguatoxin exposure, assessing the presence of cyaobacteriadrinking water sources, and investigating human exposures to cyanobacteria and cyanobacterialrecreational 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 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. Aswith the other public health surveillance systems supported by CDC, the HAB-related Illness Surveillance system (HABISS) is a secured website for data entry bystate 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. Food and Drug Administration (FDA)

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 foodborne illnesses from marine biotoxins.

FDA works closely with state programs, NMFS, and the Interstate Shellfish Sanitation Conference (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 NSSP (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[43]. 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 (FIU), a minority serving institution, and the University of Miami and 3) the four Centers, jointly funded with NSF, for Oceans and Human Health (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 ELISA 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. Department of Interior

5.1 U.S. Fish and Wildlife Service (USFWS)

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)

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 U.S. 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 (UKL). 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)

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 29).

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. Environmental Protection Agency (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)

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 & 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)

NSF Extramural

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 U.S. 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, non-profit, 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], http://ioc.unesco.org/hab/FINALeutroGEOHABCRP-low%20res). 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 U.S. 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:

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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 U.S. and 5) Opportunities for Advancement in Prediction and Response Efforts. Appendices include: Appendix I: Prediction and Response Programs in the U.S., 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 P & R 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 comprise 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 non profits. 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 P&R 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 U.S. 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 .

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.