HAB RDDTT

National Workshop Report

A Plan for Reducing HABs and HAB Impacts

Harmful

Algal

Bloom

Research,

Development,

Demonstration, &

Technology

Transfer

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Background: Cochlodinium polykrikoides bloom in Virginia. Photo courtesy of Christy Everett, Chesapeake Bay Foundation.

Upper left inset: Fish kill due to *Prymnesium parvum* bloom on Lake Granbury in Texas. Photo courtesy of Joan Glass, Texas Parks and Wildlife Department.

Upper right inset: Fish kill along Padre Island, Texas during 2006 *Karenia* bloom. Photo courtesy of Alex Nunez, Texas Parks and Wildlife Department.

Middle inset: Emergency shellfish harvesting closure sign. Photo courtesy of Washington State Department of Fish and Wildlife

Lower left inset: A mussel cage used in the Washington Department of Health's Sentinel Mussel Biotoxin Monitoring Program, photo courtesy of Liz Cox-Bolin and Frank Cox.

Lower right inset: Filtering for microcystin analysis in Lake Erie, photo courtesy of Steve Wilhelm.

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List of Acronyms

ART Analytical Response Team

CCMA NCCOS Center for Coastal Monitoring and Assessment, NOAA

CCMP Culture Collection for Marine Phytoplankton

CDC Centers for Disease Control and Prevention

CFP Ciguatera Fish Poisoning

CICEET Cooperative Institute for Coastal and Estuarine Environmental Technology

CSCOR NCCOS Center for Sponsored Coastal Ocean Research, NOAA

CUAHSI Consortium of Universities for the Advancement of Hydrologic Science

CYANONET Global Network for the Hazard Management of Cyanobacterial Blooms and Toxins in Water Resources

DMAC Data Management and Communication

DNA Deoxyribonucleic acid

DOD United States Department of Defense

ECOHAB Ecology and Oceanography of HABs Program at NOAA

EPA United States Environmental Protection Agency

FDA Food and Drug Administration

FTE Full Time Equivalent

GEOHAB Global Ecology and Oceanography of HABs

GIS Geographic Information System

GLERL Great Lakes Environmental Research Laboratory at NOAA

GOOS Global Ocean Observing System

HAB Harmful Algal Bloom

HABHRCA Harmful Algal Bloom and Hypoxia Research and Control Act

HABISS Harmful Algal Bloom Illness Surveillance System at CDC

HAE-DAT Harmful Algal Event Database

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

HARRNESS Harmful Algal Research and Response: a National Environmental Science Strategy

ICS Incident Command System

IOOS Integrated Ocean Observing System

ISOCHAB Interagency, International Symposium on Cyanobacterial Harmful Algal Blooms

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

JSOST Joint Subcommittee on Science and Technology

KAP Knowledge, Attitudes, and Perceptions

LTER Long Term Ecological Research

MERHAB Monitoring and Event Response for HABs Program at NOAA

MOU Memorandum of Understanding

NASA National Aeronautics and Space Administration

NBSB National Biomonitoring Specimen Bank

NCCOS National Centers for Coastal Ocean Science

NCEH National Center for Environmental Health at CDC

NEON National Ecological Observatory Network

NERRS National Estuarine Research Reserve System

NHC National HAB Committee

NIEHS National Institute of Environmental Health

NIH National Institutes of Health

NIST National Institute of Standards and Technology

NMFS National Marine Fisheries Service

NOAA National Oceanic and Atmospheric Administration

NRC National Research Council of Canada

NRC-CRMP National Research Council Certified Reference Materials Program

NSF National Science Foundation

ONR Office of Naval Research

OOI Ocean Observatories Initiative (ORION)

ORHAB Olympic Region HAB Partnership

PCM Prevention, Control and Mitigation

(List of acronyms continued on next page)

List of Acronyms
(continued)

PEET Partnerships for Enhancing Expertise in Taxonomy

R&D Research and Development

RDDTT Research, Development, Demonstration and Technology Transfer

RNA Ribonucleic acid

UME Unusual Mortality Event

UNESCO United Nations Educational, Scientific, and Cultural Organization

USCG United States Coast Guard

USDA United States Department of Agriculture

USFWS United States Fish and Wildlife Service

USGS United States Geological Survey

UTEX University of Texas Starr culture collection

WGUMMME Working Group on Unusual Marine Mammal Mortality Events

Executive Summary

Background

The marine and freshwaters of many countries are increasingly impacted by the environmental and socioeconomic problem of harmful algal blooms (HABs). HABs are proliferations of marine and freshwater algae that can produce toxins or accumulate in sufficient numbers to alter ecosystems in detrimental ways. These blooms are often referred to as "red tides," but it is now recognized that they may also be green, yellow, brown, or even without visible color, depending on the type and number of organisms present.

In U.S. waters, HABs are found in expanding numbers of locations and are also increasing in duration and severity. Further, HAB species or impacts have emerged that pose new threats to human and ecosystem health in particular regions. The expansion in HABs has led to increased awareness of impacts such as poisonous seafood, toxin-contaminated drinking water, and mortality of fish and other animals (including protected and endangered species), public health and economic impacts in coastal and lakeside communities, losses to aquaculture enterprises, and long-term aquatic ecosystem changes.

The 1998 Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA 1998) established research programs to address the U.S. HAB problem. When HABHRCA was reauthorized and expanded to include freshwater HABs in 2004 (HABHRCA 2004), it required four interagency reports and plans to assess U.S. HAB problems and update priorities for Federal research and response programs. The first report, the *National Assessment of Efforts to Predict and Respond to Harmful Algal Blooms in U.S. Waters* (Prediction and Response Report[1]), assesses the extent of the HAB problem in the United States, details Federal, state, and tribal prediction and response programs, emphasizing Federal efforts, and highlights opportunities to improve HAB prediction and response efforts and associated infrastructure.

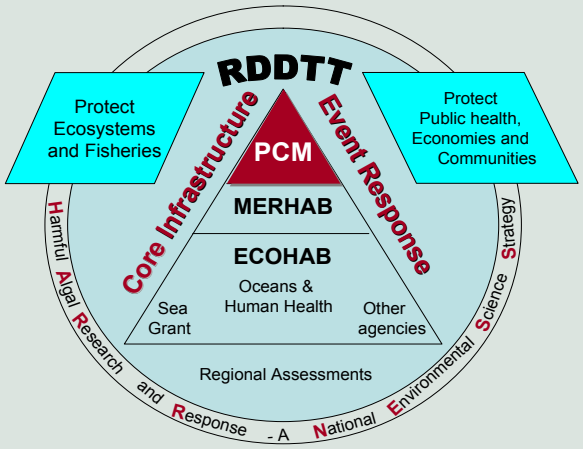
This Workshop Report provides a strategy in response to the needs outlined in the Prediction and Response Report[1]. It also addresses priorities laid out in the *Harmful Algal Research and Response National Environmental Science Strategy 2005-2015* (HARRNESS)[2], as well as other recent marine and freshwater HAB reports called for by HABHRCA 2004 or developed by the HAB management and research community. The *National Scientific Development, Demonstration, and Technology Transfer Plan on Reducing Impacts from Harmful Algal Blooms* (RDDTT Plan), called for by HABHRCA 2004, is derived from this Workshop Report, and appears as the final chapter in *Harmful Algal Bloom Management and Response: Assessment and Plan* [3].

Process for Developing the RDDTT Plan

Input for the RDDTT Plan was solicited from both the marine and freshwater HAB research and management communities during a workshop in

Box 1. RDDTT Program elements.

The diagram below illustrates the relationship of the three elements of the RDDTT Program with other HAB research and response programs. The RDDTT program is the practical "apex" of these research and development activities, and addresses the goals of protecting public health, economies, communities, ecosystems and fisheries. All programs build on HARRNESS[2].



Woods Hole, Massachusetts, June 22-25, 2007. This RDDTT Workshop Report summarizes the current status of the field, recommends a program to improve HAB prediction and response, and suggests an implementation process.

The workshop attendees proposed approaches for an RDDTT Program with three essential components:1) an extramural funding program focused on development, demonstration, and technology transfer of methods for prevention, control, and mitigation (PCM), 2) a comprehensive national HAB Event Response Program, and 3) a Core Infrastructure Program to support HAB research and response. All three components require social science research and call for the meaningful engagement of at-risk and affected communities. These components are interdependent and collectively are critical for improving future HAB response (Box 1).

Prevention, Control, and Mitigation (PCM)

The **PCM** component of the RDDTT Program focuses on moving promising technologies and strategies from development to demonstration and technology transfer for field application by end-users. The technologies will arise from HAB research conducted by programs such as the Ecology and Oceanography of Harmful Algal Blooms (ECOHAB), Monitoring and Event Response for Harmful Algal Blooms (MERHAB), Sea Grant, and Oceans and Human Health programs. The PCM program will support projects in three distinct stages. 1) The **Development** phase (Phase 1) advances and evaluates unproven but promising PCM technologies and strategies. 2) The **Demonstration** phase (Phase 2) tests, validates and evaluates new technologies in the field across a broad temporal and spatial scale. 3) The **Technology Transfer** phase (Phase 3) facilitates the transition of technologies and strategies to end-users. End-users, including local, state, and Federal resource and public health managers, nonprofit organizations, and a variety of businesses must be involved in all three phases. Projects can enter the extramural PCM program at any phase and would be selected through peer review competition. Socially responsible development and effective implementation are ensured by the inclusion of social science research in all phases.

Many promising options or strategies are already available to feed into the three PCM stages. Example focal areas within the *prevention* category include modifications of hydrodynamic conditions that are conducive to HAB formation and methods to avoid introducing HAB cells and cysts as invasive species. Several methods of *control,* or bloom suppression, through the removal of HAB cells or toxins by biological, chemical, or mechanical means are ready for further investigation. For example, mechanical removal by clay flocculation is one approach that has already been tested in pilot field studies, so may be ready for further Phase 2 evaluation. Similarly, biological control methods, for example pathogens specific for individual HAB organisms may be ready for Phase 1 development or Phase 2 testing. These efforts should be pursued in conjunction with research in risk communication in order to foster public understanding, trust, and participation in decision making about bloom control strategies. Many opportunities exist to apply *mitigation* strategies that can reduce the impacts of HABs. A few examples include new methods of monitoring and forecasting HAB cells and toxins; maintaining safe seafood, water, and beaches by limiting exposure to HABs and their toxins; preventing and treating human, as well as animal, disease syndromes; assessing the socioeconomic impacts of HABs and the effectiveness of PCM strategies; and advancing education and outreach.

Event Response

Management responses to HAB events to protect human and animal health and coastal economies usually occur at the state and local levels. However, HAB events can occur suddenly and overwhelm existing event response capabilities, especially in the case of a newly emerging HAB problem or a large-scale or persistent event. Although such events pose major management challenges, they also provide an unequalled opportunity to improve understanding of the causes and consequences of HABs in order to advance future HAB response efforts. Current Federal HAB

event response programs are effective for assisting managers and adding to the knowledge base, but are not adequate for the scale of the problems they must sometimes manage. For example, these programs were nearly overwhelmed in 2005 when multiple major U.S. HAB events occurred in different regions within several months of each other. Furthermore, Federal and state response programs are currently not well positioned to address anticipated increases in HAB frequency or intensity.

In response to these perceived needs, the proposed **Event Response** component of the RDDTT Program improves access to existing resources through better information sharing, communication, and coordination and provides essential new resources. A regionally based, Federal HAB Event Response Program is proposed with National Marine and Freshwater HAB Coordinators, possibly residing in the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Environmental Protection Agency (EPA), linked to a network of Regional HAB Coordinators. Coordinators would maintain web sites cataloging regionally available resources, assist in developing regional response plans, organize training and information-sharing workshops, and provide coordination during events if requested by regional, state, or local authorities. The Regional Coordinators would also request resources from other regions and, if needed, request funding from a national Event Response Contingency Fund, modeled after the current small NOAA Event Response Program (http://www.cop.noaa.gov/stressors/extremeevents/hab/current/fact-ev_resp.html). With this program in place a national Technical Assistance Fund would provide extramural funds for activities designed to improve response to future events; activities would be selected by competitive peer review.

Box 2. Outline of RDDTT components.

1. Prevention, Control, and Mitigation

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

2. Event Response

a. Provide immediate assistance during events and improve response capacity**
b. National and regional coordinators and regional network of resources***
c. Contingency Fund—expanded from and modeled after current Event Response (http://www.cop.noaa.gov/stressors/extremeevents/hab/current/fact-ev_resp.html)
d. Technical Assistance Fund—competitive peer reviewed extramural program* to enhance response capacity

3. Core Infrastructure

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

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

Core Infrastructure

Advances both in basic knowledge and in methods and tools have led to significant new opportunities for responding to HABs to reduce or prevent their impacts. However, as HAB research and response has matured, the infrastructure needs of the community have also increased. These core infrastructure requirements form the foundation upon which the science and its management applications depend. Many of the associated costs are far greater than can be borne by individual investigators or end-users. The needs for critical infrastructure were identified in the first HAB National Plan in 1993[4] and are strongly reiterated in HARRNESS[2], the revised national plan for 2005-2015. Thus, a **Core Infrastructure Program** is proposed.

Researching and implementing new PCM strategies and improving event response will not

be possible without enhancing core infrastructure, including 1) increasing availability of adequate analytical facilities, reference and research materials, toxin standards, culture collections, tissue banks, technical training, and access to data, 2) improving integration of HAB activities with existing monitoring and emerging observational programs, and 3) enhancing communication and regional and national coordination. Two complementary approaches are proposed to accomplish these goals: 1) establish an interagency, competitive, peer reviewed extramural funding program that will support core infrastructure needs and 2) develop a regional infrastructure network with national and regional coordinators to leverage existing resources, encourage coordination, and foster active communications with users and stake holders within and between regions.

RDDTT Program Implementation

Implementation of the three components of the RDDTT Program, summarized in Boxes 1 and 2, is proposed in phases in order to address the most immediate needs and build programs in an orderly manner based on accomplishments. In the first phase (FY 2009-2013) the PCM Program component should be fully implemented and the Event Response and Core Infrastructure Programs partially implemented. In the next phase (FY 2014-FY2018), the latter two programs can be fully implemented.

Implementation requires both changes in legislation authorizing HAB research and response programs and in corresponding appropriations. NOAA and EPA will be expected to take lead roles because of NOAA's mandates concerning marine, Great Lake, and estuarine waters, and EPA's mandates concerning clean recreational waters, shellfish bed protection, and safe drinking waters. Separate authorization and appropriation will be necessary to establish both marine and freshwater HAB programs because of differing authorizing Congressional committee purviews, although they should be coordinated. When HABHRCA is reauthorized, the RDDTT Program should be listed along with the existing ECOHAB and MERHAB Programs, and the three components of the RDDTT Program need to be individually specified. To fully implement the RDDTT Program requires funding of $6.5 million (FY 08) to $10.5 million (FY 13) authorized and appropriated for each of the marine and freshwater RDDTT Programs. Since many agencies—such as the National Science Foundation, Food and Drug Administration, National Aeronautics and Space Administration, Office of Naval Research, Centers for Disease Control and Prevention, National Institutes of Health, U.S. Fish and Wildlife Survey, U.S. Department of Agriculture, and U.S. Geological Survey—are also involved in HAB research and response[1], it will be necessary to specify that the RDDTT Program is an interagency program and that funds be appropriated to facilitate the participation of other agencies with a major role. Most of the components of the RDDTT Program can be instituted through peer reviewed, competitive programs, but the coordinators and regional networks will be part of Federal HAB programs and the Event Response Program will be modeled after current event response programs. This report provides specific guidance about needs and priorities for each of the three components of the RDDTT Program.

Benefits of Implementing the RDDTT Program

Full implementation of all components of an RDDTT Program as outlined in this report will yield many benefits for public health and resource managers and for residents, resource users, businesses, and other stake holders in at-risk and affected coastal communities. It will also address many of the frustrations people living in HAB-impacted communities experience and will provide them with new strategies to deal with the problems.

Full implementation will not be simple and will require substantial investment. The socioeconomic costs of not addressing these needs, however, greatly exceed the initial investment. The fully-implemented RDDTT Program will link science and management to achieve vastly improved mitigation, control, prevention, and education.

Chapter 1

Introduction

By Q. Dortch, P. Glibert, E. Jewett and C. Lopez

1.A. The Increasing Magnitude of the U.S. HAB Problem

The marine and freshwaters of the United States and those of many countries throughout the world are increasingly impacted by the growing environmental problem of HABs. HABs are proliferations of marine and freshwater algae (including cyanobacteria and non-photosynthetic algae-like organisms) that can produce toxins, causing human illness and massive animal mortalities, or accumulate in sufficient numbers to alter ecosystems in detrimental ways. These blooms are often referred to as "red tides", but it is now recognized that HABs may also be green, yellow, brown, or even without visible color.

Like much of the world's coastlines, nearshore marine waters of the United States have experienced increases in the number, frequency, and type of HABs in recent years. Freshwaters are also experiencing more HAB events, with increasing fears for drinking water contamination and recreational exposure. Impacts include human illness and mortality following direct consumption or indirect exposure to toxic shellfish or toxins in the environment, as well as dramatic fish, bird, turtle, and mammal mortalities. Closure of beaches and fisheries to protect public health can result in loss of recreational opportunities, disruption of subsistence activities and cultural practices, conflict among resource users, loss of community identity tied to coastal resource use, and social stress in affected families and communities[5]. Economic costs associated with public health, fisheries, recreation, and tourism impacts, as well as diversion of funds to monitoring and management can be significant for local communities[6]. Equally important are the devastating impacts HABs may have on ecosystems, leading to environmental damage that may reduce the ability of those systems to sustain species due to habitat degradation, increased susceptibility to disease, and long term alterations to community structure. Whereas thirty years ago these problems were scattered and sporadic, today virtually every

Box 3. Major HAB events in U.S. coastal waters and the Great Lakes.

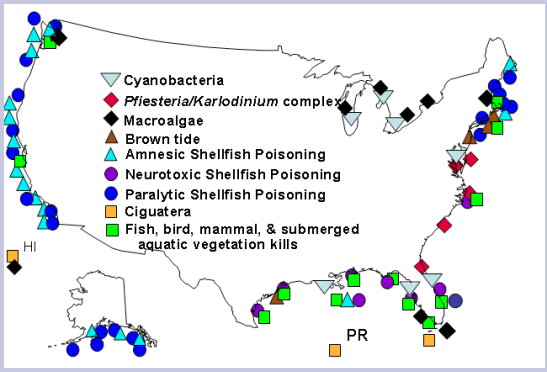
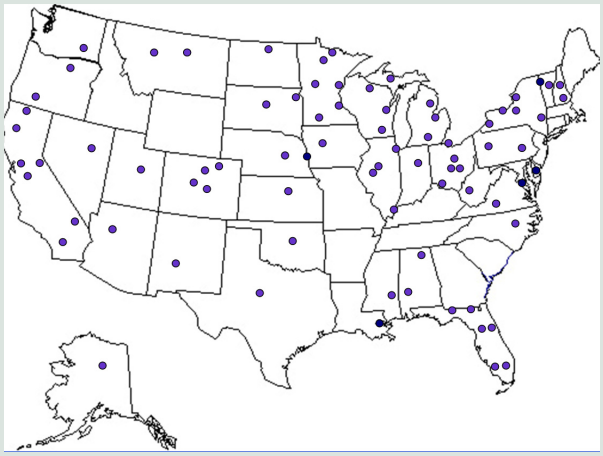


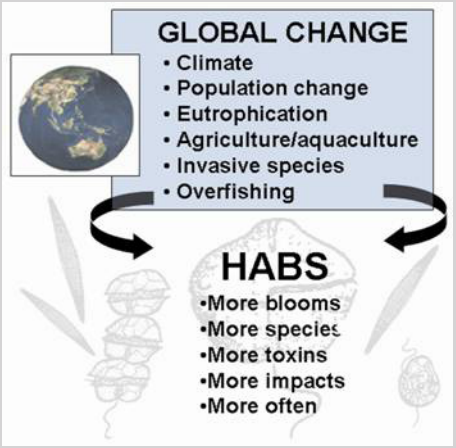
Image Source: NOAA and D.M. Anderson

Box 4. Cyanobacterial HAB outbreaks in the United States.

The map shows the approximate location of some freshwater cyanobacterial HAB outbreaks documented in the United States. Dots are geneographically general representations of outbreaks and may represent events occurring in more than one waterbody within a state (from the Freshwater HAB Report[13]).



Box 5. Potential impacts of global change on HABs.



U.S. state is threatened by harmful or toxic algal species (Boxes 3 and 4). Other global changes may exacerbate this problem (Box 5). This increased threat has placed an unprecedented strain on state programs, which must increase responsibilities with shrinking budgets and personnel. In short, HABs are leading to increased concern about poisonous seafood, toxin-contaminated drinking water, mortality of fish, endangered species, and other animals, economic impacts to coastal and lakeside communities, losses to aquaculture enterprises, strain on shrinking state and local resources and long-term aquatic ecosystem changes.

1.B. Addressing the HAB Issue

The U.S. HAB research and management community is well organized, with a long history of careful planning to improve HAB response (Boxes 6 and 7). Many different Federal agencies address the HAB problem through a variety of extramural and intramural research programs (Box 8). The priorities for these research programs are guided by numerous reports and plans (Box 7), especially the *Harmful Algal Research and Response National Environmental Science Strategy 2005-2015* (HARRNESS)[2] and the reports developed in response to the 2004 reauthorization of the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA 2004).

1.C. Guidance from the 2005 U.S. National HAB Plan: HARRNESS[2]

The last decade of research on harmful algae and their impacts in the United States was guided by the first HAB National Plan[4]. That plan served as the foundation for the development of numerous national, state, and local programs and for the considerable advancement in scientific knowledge on HABs during the 1990's. However, as the HAB knowledge base grew, so too did our understanding of the degree of scientific and management complexity. Management of HABs involves a diverse array of scientists, managers, agencies, and legislatures operating at various governmental levels. Support for their activities was guided by diverse national and international programs. The HAB community, which includes scientists, managers, and those with commercial interests in seafood safety, recognized the need to strengthen coordination among agencies, partners, and stakeholders, and launch a new approach to address these issues. Thus, HARRNESS[2] (Box 9) provides a vision and a framework for actions over the next decade. HARRNESS[2] reflects the views of both the research and the management communities, and is designed to lay the foundation for increased coordination by highlighting and justifying the needs and priorities of research and management, the strategies and approaches for addressing them, and the additional capacity building that is required to achieve them. The companion report, *Harmful Algal Research and Response: A Human Dimensions Strategy* (HARR-HD[5], Box 9), establishes social science research needed to achieve the goals of HARRNESS[2].

1.D. Legislative Background

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 of 1998 (P.L. 105-383), reconstituted the Interagency Task Force on HABs and Hypoxia, authorized research programs, and stipulated generation of four reports to assess and recommend research programs on HABs in U.S. waters. Responsibility for implementing both HABHRCA 2004 and the Oceans and

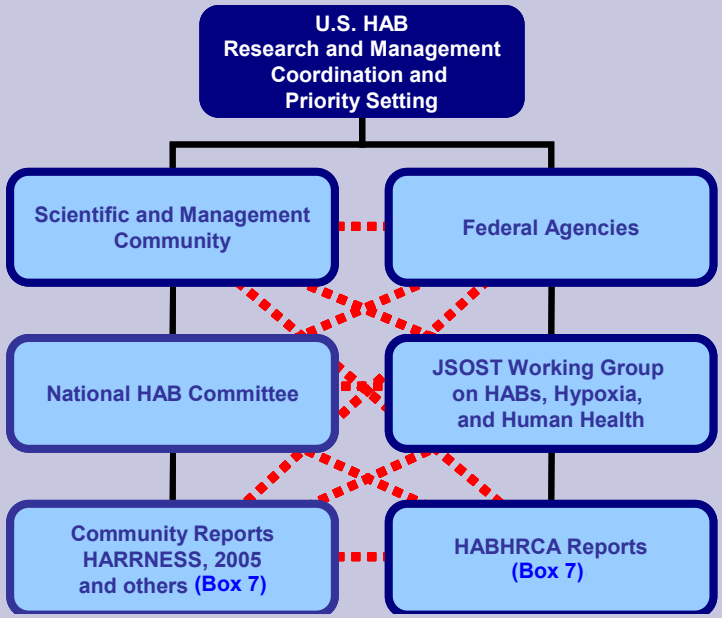
Human Health Act of 2004 was given to the Joint Subcommittee on Ocean Science and Technology (JSOST) Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health (IWG-4H). As described in the legislation, two of the mandated reports are concerned with managing HABs and HAB impacts: 1) the *National Assessment of Efforts to Predict and Respond to Harmful Algal Blooms in U.S. Waters* (Prediction and Response Report)[1] and 2) the *National Scientific Research, Development, Demonstration, and Technology Transfer Plan on Reducing Impacts from Harmful Algal Blooms* (RDDTT Plan).

The Prediction and Response Report[1] was the first step in the process to create an innovative plan to improve HAB prediction and response. The report assesses the extent of the HAB problem in the United States, details Federal, state, and tribal prediction and response programs, emphasizing Federal efforts, and highlights opportunities to improve HAB prediction and response, as well as associated infrastructure. These opportunities for advancement were based on a survey of Federal agencies with HAB programs, needs identified in HARRNESS[2], and public comments on the draft Prediction and Response Report[1], which was published in the Federal Register in September 2006. The opportunities for advancement fall into four main categories: 1) infrastructure, 2) programs for research and implementation of prevention, control, and mitigation, 3) event response, and 4) human dimensions. These opportunities overlap the needs outlined in the community-developed HARRNESS[2] plan, as they are based on the increasing concern about HABs and their effects.

The RDDTT Plan is the second step in the process to develop a strategy to address needs identified in the Prediction and Response Report[1]. Because HABHRCA 2004 calls for wide community involvement in the development of reports and plans, a community RDDTT workshop was held, resulting in this workshop report. Following this workshop, the IWG-4H developed the RDDTT Plan, drawing from the recommendations of this workshop report and Federal agency interests and needs to design an RDDTT Program for reducing HAB impacts, as required by HABHRCA. The RDDTT Plan was combined with the Prediction and Response Report[1] to produce the *Harmful Algal Bloom Management and Response: Assessment and Plan*[3] which describes current prediction and response efforts, assesses the opportunities for advancement, and provides a plan to promote better management of HABs and their impacts

HABHRCA 2004 also calls for a *Scientific Assessment of Freshwater Harmful Algal Blooms* (Freshwater HAB Report)[13]. Most freshwater HAB problems are caused by cyanobacteria, though there are serious problems in mid-west lakes and reservoirs due to the haptophyte *Prymnesium parvum*. An International Interagency Symposium

Box 6. Structure and interactions of activities to prioritize HAB research and management in the United States.



Box 7. Reports and plans providing guidance for U.S. HAB research and response. The HABHRCA column indicates reports written in response to the original legislation in 1998 or the 2004 reauthorization (see 1.D.).

Title	Year	HABHRCA
Marine Biotoxins and Harmful Algae: A National Plan (National Plan)[4]	1993	
ECOHAB: The Ecology and Oceanography of Harmful Algal Blooms - A National Research Agenda [7]	1995	
Harmful Algal Blooms in Coastal Waters: Options for Prevention, Control, *and Mitigation* [8]	1997	
National Assessment of Harmful Algal Blooms in U.S. Waters[9]	2000	1998
Prevention, Control, and Mitigation of HABs A Research Plan[10]	2001	
Harmful Algal Research and Response, A National Environmental Science Strategy 2005-2015 (HARRNESS)[2]	2005	
Harmful Algal Research and Response: A Human Dimensions Strategy (HARR-HD)[5]	2006	
National Assessment of Efforts to Predict and Respond to Harmful Algal Blooms in U.S. Waters (Prediction and Response Report)[1]	2007	2004
Interagency Oceans and Human Health Research Implementation Plan: A Prescription for the Future [11]	2007	
Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs (ISOCHAB Workshop Report)[12]	2008	2004*
Scientific Assessment of Freshwater Harmful Algal Blooms (Freshwater HAB Report)[13]	2008	2004
HAB Research Development Demonstration and Technology Transfer National Workshop Report (RDDTT Workshop Report, this report)	2008	2004*
HAB Management and Response: Assessment and Plan [3]	2008	2004
Scientific Assessment of Marine Harmful Algal Blooms [14]	in review	2004

**Reports from community workshops convened to provide input into HABHRCA 2004 reports.*

on Cyanobacterial Harmful Algal Blooms (ISOCHAB) was held in 2005, resulting in a workshop report[12] that outlines the research needs for responding to cyanobacterial blooms. Both the Freshwater HAB Report[13], and the ISOCHAB Workshop Report[12] on which it is based, influenced the development of the RDDTT Plan, in particular by pointing out the absence of specific programs focused on freshwater HABs.

1.E. RDDTT Workshop Process and Workshop Report

The RDDTT Workshop was organized by a Steering Committee (Appendix I) selected by the IWG-4H. The Steering Committee consisted of representatives of Federal agencies on the IWG-4H with expertise on HABs and representatives of the HAB research and management community from the National HAB Committee (NHC, Box 6).

The main subject areas of the Workshop were the opportunities for advancement identified in the Prediction and Response Report[1]: programs for research and implementation of prevention, control, and mitigation (PCM) strategies, event response, and infrastructure. Recommendations from HARR-HD[5], which identified human dimensions research critical to prevent and respond to impacts of HABs, were incorporated into all subject areas.

The process of selecting and inviting participants to contribute to the Workshop was designed to ensure breadth of expertise in the subject areas, geographic coverage, and community sector (management and research, Federal, state, local, tribal, and private industry). Before inviting

participants, the Steering Committee developed a list of sub-topics in each of the subject areas the RDDTT Plan would address. They then listed multiple experts in each of those sub-topics and chose participants (Appendix II) based on the criteria above. The Steering Committee assigned each participant to a workgroup and chose a workgroup lead. Prior to the workshop, workgroups developed topical status reports and detailed agendas to guide their discussions.

The RDDTT Workshop was held June 22-25, 2006 in Woods Hole, Massachusetts, and consisted of a half-day of plenary talks and two and a half days with alternating workgroup and plenary discussions (Appendix III). The first plenary talk described the HABHRCA requirements and the process for producing the RDDTT Plan. The next two provided information critical to the Workshop process from two recent plans, HARRNESS[2] and HARR-HD[5]. Finally, talks outlined the current state of HAB prediction and response in the three focus areas of infrastructure, PCM, and event response. Workgroups then met to propose approaches for moving forward to improve HAB management and response. Because of the wide array of expertise in all of the workgroups, ideas developed in individual workgroups were presented to all the participants in daily plenary sessions in order to more fully develop concepts. The discussions were captured by rapporteurs, and on the day after the workshop, workgroup leads, rapporteurs, and the speakers edited the workgroup reports, which constitute Chapters 2-5 of this report.

This report provides a plan for developing a RDDTT Program that would include PCM, event response, and infrastructure components and is designed to reduce the frequency and intensity of HAB events and their impacts. In essence this report offers recommendations for implementing many of the priorities outlined in HARRNESS[2], HARR-HD[5], the Prediction and Response Report[1], the ISOCHAB proceedings[12], and the Freshwater HAB Report[13].

1.F. Next Step: RDDTT Program

To address the needs outlined in the Prediction and Response Report[1] and achieve the overall goals and objectives of HARRNESS[2], a new program is required that will complement existing programs. This Workshop Report provides a comprehensive plan for the RDDTT Program.

The three essential components of the proposed RDDTT Program include:

1) a peer reviewed, competitive extramural funding program focused specifically on PCM, (Chapter 2);
2) a more effective HAB Event Response Program, (Chapter 3);
3) a Core Infrastructure Program, focused on solving a long list of infrastructure deficiencies (Chapter 4).

All three components, as described in the following chapters, are interdependent and critical for improving future HAB response (Box 1).

The proposed PCM Program focuses on moving promising technologies and strategies from development through demonstration to technology transfer. It will draw on the research generated from other research programs conducting HAB research, such as Ecology and Oceanography of Harmful Algal Blooms (ECOHAB), Monitoring and Event Response (MERHAB), Sea Grant, and the various oceans and human health (OHH) programs. There is a strong need for a program to support development of technologies and strategies that have not yet been proven in the field. The program is designed with three distinct stages: 1) Phase 1—Development will be the stage for making progress on unproven but promising projects, 2) Phase 2—Demonstration will be the phase in which technologies are field tested, validated and evaluated across broad temporal and spatial scales, and 3) Phase 3—Technology Transfer will facilitate the transitioning of technologies and strategies to end-users. End-users, including local, state, and Federal resource and public health managers, nonprofit organizations, and a variety of businesses, must be involved in all three phases. Projects can enter at any phase and would be selected through peer

Box 8. Agencies involved in HAB research and response.

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

review competition. Social science research is included in all phases to ensure socially responsible development and effective implementation of PCM technologies and strategies.

In an effort to improve "rapid" response to HABs as they are occurring, resources at the regional and Federal levels can be enhanced and better structured to assist state, local, and tribal governments with newly emerging or unusually difficult HAB problems. The proposed Event Response Program recommends the establishment of a Technical Assistance fund, modeled after the current National Oceanic and Atmospheric Administration (NOAA) Center for Sponsored Coastal Ocean Research (CSCOR) Event Response Program, and a Regional Assistance fund, a peer reviewed, competitive extramural funding program to improve response capacity. There is a need for HAB National Coordinators in both NOAA and the U.S. Environmental Protection Agency (EPA) to deal with marine and freshwater HABs, respectively. These HAB Coordinators would

facilitate organization of both regional and national resources to be made available when states, tribes, or academics request assistance.

The Core Infrastructure Program addresses the infrastructure deficiencies that impede the implementation of new technologies. Infrastructure needs are varied and the approach to each depends on the type of infrastructure. The major infrastructure needs include 1) availability of adequate analytical facilities, reference and research materials, including instrumentation, toxin standards, technical training, and access to data; 2) integration of HAB activities with existing monitoring and emerging observational programs; and 3) mechanisms for communication and regional and national coordination.

Two complementary approaches are proposed to accomplish these goals:

- Establishment of an interagency, competitive, peer reviewed extramural funding program that will support Core Infrastructure needs; and
- Development of a regional network with national and regional coordinators to leverage existing resources, encourage coordination and foster active communications with users and stake holders within and between regions.

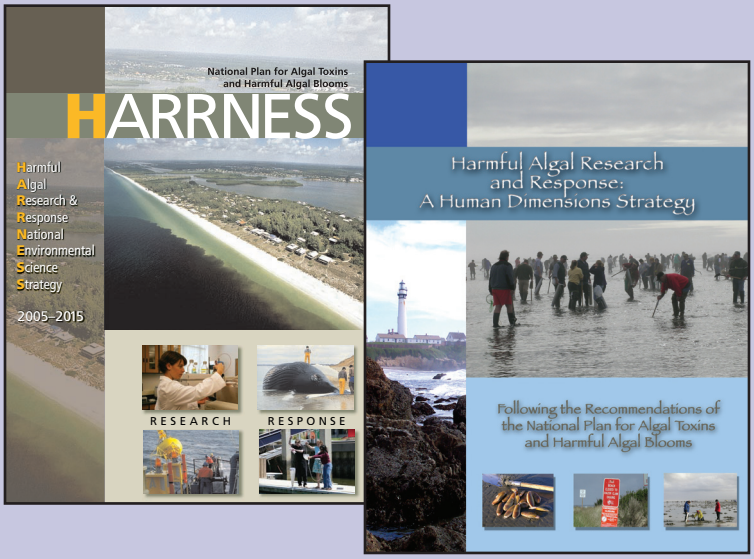
1.G. The Role of Existing HAB Programs for RDDTT

It must be emphasized that achieving the RDDTT goals identified in the Prediction and Response Report[1] and HARRNESS[2] will depend on full and sustained funding of existing extramural and intramural programs that already support HAB research and response (Box 8). The extramural, interagency (NOAA, EPA, National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), Office of Naval Research (ONR)) ECOHAB Program, the NOAA and National Institute of Environmental Health Sciences (NIEHS)/NSF OHH programs, and the NOAA Sea Grant programs fund fundamental research on ecological, physical, chemical, and human health issues related to HABs. Intramural research conducted within Federal agencies are a major component of the U.S. HAB research effort and some agencies already carry out operational HAB prediction and response activities (Box10). The NOAA MERHAB Program is also essential to continue to build long-term HAB response capacity and establish partnerships, leading to more effective monitoring programs which are critical for successful mitigation strategies. The OHH programs provide the linkages between the scientific and biomedical communities through support of interdisciplinary research in areas where improved understanding of marine processes and systems has the potential to reduce public health risks. These efforts must be sustained or, in the case of freshwater HABs, established to continue the advancement of new knowledge that will fuel new technologies and strategies. They must also be supplemented with the new initiatives described in the following chapters in order to advance our ability to detect, monitor, predict, mitigate, and prevent HABs.

1.H. The Benefits of Implementing the RDDTT Program

Full implementation of all the components of an RDDTT Program as outlined in this report will

Box 9. The HARRNESS[2] and HARR-HD[5] reports.



yield many benefits, both for the public health and resource management communities and for residents, resource users, business, and other stake holders in at-risk and affected coastal communities. It will also address many of the frustrations people living in HAB communities experience and provide new strategies to address these frustrations. These benefits include the following (adapted from HARRNESS[2]):

- Healthy fisheries industries selling seafood that is safe with respect to biotoxins;
- Reductions in the frequency of toxigenic or large, unsightly and noxious accumulations of algae;
- Ecosystems that are less threatened by invasions of nonindigenous HAB species;
- Mitigation of bloom impacts using a suite of practical, previously tested strategies;
- Environmentally benign strategies to suppress and prevent HABs;
- Sophisticated, yet less expensive, easy to operate instruments for HAB detection;
- Teams of scientists, managers, and community leaders prepared to respond to events;
- Improved prediction and early warning of blooms and HAB impacts due to better predictive models, networks of moored automated observing systems, and satellite surveillance capability for detection and tracking over large distances;
- Improved human health and ecosystem risk assessment;
- Effective means of educating and warning the public.

Earlier research has already led to benefits, like the examples in Box 10, but the pace of new advances will be greatly increased with a dedicated program.

Full implementation will not be simple and will require substantial investment. The socioeconomic costs of not addressing these needs, however, greatly exceed the initial investment. Although individual benefits relate to specific aspects of the currently impaired ecological health of our aquatic ecosystems and the threatened public health of our citizens, the greatest benefit is in cross-linking science and management to achieve improved mitigation, control, prevention, as well as an educated and informed public.

Box 10. Examples of operational products.

The **Gulf of Mexico HAB Operational Forecast System (or HAB Bulletin)** is the first example of forecasting being operationalized for a HAB 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 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 notices can be issued to protect beachgoers, boaters, and others from respiratory illness. Necessary mitigation actions, such as closing shellfish beds, can also be initiated before a bloom becomes a health hazard.

CDC's Harmful Algal Bloom-related Illness Surveillance System (HABISS) is designed to capture human and animal health data as well as environmental data for HABs in fresh, estuarine, and marine waters. HABISS is located on the CDC National Center on Environmental Health (NCEH) Rapid Data Collection platform. The system is web-based and currently has seven modules for data entry, including physical information about the bloom event and medical information about algal toxin-related human and animal illnesses. NCEH hosted a HABISS workshop to expand the capability to an additional five states with HAB issues. It is anticipated that, after a few years of data collection, HABISS will allow state and local health agencies to forecast where blooms are likely to occur and implement the relevant exposure-mitigation and illness-prevention strategies to protect public health.

Chapter 2

Prevention, Control, and Mitigation Workgroup Report

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2.A. Background

The diversity of HAB events and their effects present a significant challenge to those responsible for managing resources in marine and freshwater systems. The strategies needed to protect public health, manage fisheries and protected and endangered species, and minimize socioeconomic and ecosystem losses vary considerably among locations and among HAB types. A recent review[15] highlights many strategies adopted by countries and commercial enterprises to monitor and manage HABs in marine coastal waters. Other recent reports highlight the challenges and research needs associated with management of freshwater HABs[12,13]. Here, the objective is to provide a perspective on some of these strategies, emphasizing the distinctions between management actions that fall into the categories of prevention, control, and mitigation[8,16]. The elements of a prevention, control, and mitigation (PCM) program are then proposed, as well as priority research areas, a program structure, and possible implementation steps.

2.A.1. Current status

2.A.1.a. Prevention

Prevention refers to environmental management actions taken to reduce the incidence and extent of HABs prior to their initiation. Several problems are immediately apparent in this regard. Perhaps most importantly, our knowledge of why HABs form in many areas is limited. It is therefore difficult to regulate or control the critical factors, since they are often unknown. This knowledge gap argues for substantial and sustained research on all aspects of HABs, including their ecology, physiology, and oceanography, concurrent with a focused program on PCM. All too often managers and agency officials view these topics as fundamental or basic science issues that have little direct practical utility, but in reality, conceptual models of bloom initiation, development, transport, and decline are essential for the design and implementation of effective prevention strategies. However, solid conceptual models exist for only a few areas with recurring HABs in the United States [17,18,19,20].

Another potential problem that arises with the concept of HAB prevention is that even if we know that certain environmental factors trigger or support blooms of a specific HAB organism, there are both societal and practical limitations on what we can feasibly do to modify or control those factors[16]. For example, it might be known that a particular HAB is influenced by the outflow of a river system but HAB prevention is unlikely to justify alteration of that flow. It is nevertheless important to factor the possible impacts on HABs into large-scale policy decisions on such issues.

There are three general categories of actions that can lead to bloom prevention[16]. These include: regulating the flow of materials into aquatic systems (mainly nutrients and freshwater); modifying hydrodynamic conditions (e.g., freshwater flow, water column mixing, tidal exchange, retention time); and, restricting activities that might introduce HAB species into environments where they do not naturally occur (e.g., ballast water). Several specific examples of these strategies, some of which have already been successful in reducing the frequency of HABs, are outlined below.

Reduction in nutrient inputs. As plant-like organisms, HAB species require certain types and

amounts of nutrients to proliferate. The rapid increase in nutrient inputs, particularly nitrogen compounds, into coastal waters throughout the world reflects the growing disposal of sewage from expanding populations, increased use of chemical fertilizers in agriculture, and increased fossil fuel combustion[e.g., 21,22,23,24,25,26]. Of considerable concern, particularly for coastal resource managers, is the potential relationship between the apparent expansion of HABs and such human activities[25,26,27,28]. There is now consensus on a number of specific aspects of the relationship between eutrophication and HABs[29] as well as a broad consensus that many significant questions and challenges remain[30]. One example of the relationship between nutrients and HABs comes from the Seto Inland Sea in Japan, where the number of visible red tides decreased to levels approximately one-third of their former frequency following strict pollution controls instituted in 1974[31]. A second example comes from Tolo Harbor in Hong Kong, where sewage inputs to the harbor were diverted and as a result, the phytoplankton community shifted from dinoflagellate (i.e., common HAB-forming organisms) to diatom dominance[32]. A third example comes from the Black Sea, where nonpoint source pollution from agricultural activities led to an increase in HABs following heightened fertilizer inputs in the 1970s and '80s. A decrease in those inputs in the early 1990s was followed by a reduction in HABs[33,34]. In this instance, the change was not a deliberate policy designed to prevent HABs or other water quality deterioration, but instead a socioeconomic impact reflecting the politically-motivated breakup of the former Soviet Union and the subsequent loss of agricultural subsidies. A highly notable example from North America is the successful restoration of regions within the Laurentian Great Lakes from eutrophic or "dead" status in the 1970's (dominated by filamentous cyanobacteria) to more mesotrophic (i.e., far less polluted) conditions following voluntary reductions in phosphorus loading from municipal waste discharges by the United States and Canada[35].

These examples demonstrate that by implementing specific environmental controls or by modifying human behavior through socioeconomic changes[e.g 35], regulation of point and nonpoint sources of pollution has the potential to reduce or prevent certain types of HABs. Nutrient reduction strategies should therefore be encouraged in the context of HAB prevention, and there are many reasons in addition to HABs that justify such policy decisions. As stated in the report, *Harmful Algal Blooms in Coastal Waters: Options for Prevention, Control, and Mitigation* [8], "….conscientious pursuit of goals for reductions of pollution - including excess nutrients – which have been established for much of the bays and estuaries of the United States could well yield positive results in terms of reductions in HABs." Research is needed to document and understand the link between HABs and nutrient inputs in particular areas so that appropriate policy actions can be promoted. Studies are also needed to identify socioeconomic factors (e.g., demographic, sociopolitical, cultural, scientific, and technological) driving human behaviors that contribute to nutrient pollution.

Modification of hydrodynamic conditions. Human structures and activities (e.g., dams, reservoirs, stream channelization) can profoundly affect freshwater flow. This, in turn, can impede or promote the growth of certain HAB species by diluting pollution loads and altering water column stratification, the latter being an important determinant of phytoplankton community composition. Activities that either reduce or increase freshwater flow to coastal waters can thus affect HABs and such projects need to be scrutinized for possible impacts. In freshwater systems mechanical means of water column mixing have been used to reduce water column stratification[12] which decreases the occurrence of HABs.

As with HAB prevention through controls of anthropogenic nutrient inputs, there are no cases to our knowledge where water diversion, retention, or release projects have been initiated predominantly to reduce HABs in a given area, though it is possible that such activities could achieve that result. Here again, conceptual and numerical models of HAB development and transport are

needed that identify the role of freshwater flows or tidal exchange in regulating bloom dynamics, as is socioeconomic research into various water management options and their implications (e.g., cost/benefit analysis, stakeholder perceptions). Only with information of this type can informed policy actions be taken that might prevent or reduce future HAB events.

Prevention of species introductions. One area of HAB prevention, defined by a reasonably clear cause and effect relationship, relates to accidental introductions of toxic or harmful species to new regions through ballast water discharge, shellfish seeding, or other such human activities. There are examples in the literature of cases where the appearance of HABs has been linked to these introductions[e.g., 37,38], and current regulations on ballast water discharge do recognize the need to limit the transfer of HAB species[39]. Similar restrictions on the transfer or relaying of shellfish stocks can accomplish similar goals and limit accidental introductions.

On the one hand, there is a general consensus that prevention is the preferred management strategy for HABs. On the other hand, it is one of the more difficult options to develop and implement. Presently, there are very few efforts aimed at preventing blooms, so this management strategy remains largely hypothetical. Areas for future attention with respect to bloom prevention include: development of conceptual models of HABs by region; identification and quantification of the specific influence of anthropogenic nutrient inputs on HABs in certain areas as well as the underlying socioeconomic factors; studies of the importance of freshwater flows and tidal exchange in HAB dynamics in specific regions; careful consideration of HAB incidence and dynamics in the siting of aquaculture operations; identification of the effects of overfishing and other ecosystem disruptions on HAB incidence; and, elucidation of strategies (e.g., public policy, economic incentives, education) for changing human behaviors that may promote HABs.

2.A.1.b. Control

Bloom control or suppression is as challenging and controversial as HAB prevention. The concept of control refers to strategies that kill HAB organisms or destroy their toxins directly, remove cells and toxins from the water column physically, or limit the growth and proliferation of the organisms. These strategies intend to reduce the impacts of HABs on people and commerce by targeting the causative agents themselves, reducing their numbers, and minimizing their effects on the environment and commercially important resources. This is one area where HAB science is rudimentary and slow moving[40].

There are five general categories or strategies that can be used to control or suppress HAB species and their toxins:

Mechanical control. One form of mechanical control is the removal of HAB cells from the water by dispersing clay over the water surface. Clay particles aggregate with each other and with HAB cells, removing them through sedimentation. In countries such as Korea, where a fish-farming industry worth hundreds of millions of dollars is threatened by HABs, this control strategy makes sense economically and socially, and so the work has progressed[41] and clay dispersal is now a part of standard HAB management and response. In other geographic areas, the cost/benefit rationale is not as clear. For example, research on clay mitigation has proceeded quite far in the United States[42,43], but a significant barrier exists with respect to the ability to obtain permits, environmental clearances, funds, and society's agreement to employ this strategy on more than an experimental scale.

Biological control. There are a variety of organisms that could theoretically be used to control HABs[44], but biological control has many logistical problems and is far from the application stage. Biological control is used extensively in agriculture, such as in the release of sterile males or the use of pheromones to control insect pests[45], but there is still considerable opposition to the concept of releasing one organism to control another in marine or freshwater systems. Despite frequently cited examples where such an approach has had negative long-term consequences on land, there

are many cases where the approach has been both effective and environmentally benign[e.g., 45]. The concept deserves consideration in aquatic systems subject to HABs and their impacts.

Chemical control. This approach relies on the release of chemicals toxic or lethal to HAB organisms, including the potential development of species-specific chemical control agents. Chemical control was attempted in 1957 against the Florida red tide organism using copper sulfate delivered with crop dusting airplanes[46]. This effort is often viewed as a failure, but the red tides were dramatically reduced for several weeks and when they did recur, their cell concentrations were significantly lower. The uncharacterized collateral mortality of other marine organisms due to the broad lethality of the copper may be the main obstacle to repeating such strategies. Chemical control has not been actively pursued by the HAB research community, presumably because of the general perception that it will be difficult and perhaps impossible to find an environmentally acceptable chemical that would target a particular HAB species, yet not cause widespread and unacceptable mortality of other organisms. Nonetheless, certain naturally-derived algicides generated from aged barley straw or ryegrass have begun to attract attention for freshwater applications, although with mixed success[47], and commercial products are available.

Genetic control. The genetic engineering of species that are purposely introduced to alter the environmental tolerances, reproduction, or other processes in the undesirable species is another potential avenue for HAB control. The issues surrounding this strategy are similar in many ways to those associated with biological control - specifically, concerns about the possible negative impacts of introducing a nonindigenous and/or genetically altered organism to an area. There are numerous examples where genetic approaches have been used successfully in terrestrial agriculture, such as the engineering of plant crops so that they are capable of producing their own insecticides. Similar genetic manipulations might be used on aquatic pests such as HABs. It might be possible, for example, to engineer a HAB species so that it no longer produced toxin. Likewise, one can envision genetic manipulations that might make a particular bacterial strain more pathogenic towards HAB cells.

Environmental control. The last category of control strategies involves physical or chemical modification of the environment so that either the target species is affected and/or a natural or introduced bio-control species is enhanced. For HABs, this might involve the large-scale manipulation of nutrient levels in coastal waters through pollution control policies, as described above under the Prevention category. On shorter time scales, environmental manipulation becomes more difficult to envision, but might include efforts to alter water circulation or residence time, such as through dredging or opening of channels. Another approach might be aeration or other means to disrupt stratification, again leading to beneficial changes in phytoplankton community composition. The latter is particularly effective against cyanobacterial blooms in freshwater systems.

In general, society's concerns loom large for HAB control. For example, at a 2006 public forum on the state of red tide research in the Gulf of Mexico, stakeholders (e.g., coastal residents) expressed a range of attitudes toward HAB control. Some were highly supportive of bloom control efforts, while others expressed concern over interfering with natural processes and potential negative impacts on environmental or public health. One issue of particular concern is the fate of toxins, since cell removal could result in release of toxins into the water. Clearly, it will be important to assess the risks (environmental, public health, and socioeconomic) of HAB control strategies and apply social science research to effectively engage stakeholders in weighing these risks against the expected benefits of transitioning research to application. Nonetheless, we should not rule out HAB control strategies on the basis of hypothetical impacts and public opposition, but rather should pursue the research and testing, as well as social science studies, needed to obtain the data on which to base such decisions. Indeed, as the HAB problem continues to worsen in many areas of the world, the pressure for, and

the tolerance of, bloom control or suppression strategies are likely to increase.

Regardless of the technical and social challenges, there are signs of progress in the field of bloom control. Until recently, examples of HAB control research and application in the United States were sparse. Now, we can point to a number of current research projects that focus on control strategies (e.g., clay dispersal, ozonation, barley straw), or that address questions that might have applications for HAB control or suppression in the future (e.g., algicidal viruses and bacteria as well as dinoflagellate parasites). There are, however, no examples of marine HAB control being practiced in the United States at the present time and only a few techniques are being used on a small scale in freshwaters. At the current pace of research and development, options for bloom control may not be in place for many years unless a concerted effort is made to encourage and promote these kinds of studies. By comparison, the United States lags behind countries like Japan, China, South Korea, and Australia in pursuing and implementing control strategies. In fact, some of the strategies being tested in this country were adopted from Asia and Australia (e.g., clays, nutrient sequestration, barley straw), where these methods have become a routine component of HAB management in marine and freshwater systems.

Despite the need (and mandate) to investigate control and suppression strategies, a significant impediment to progress in the field may come from the reluctance of the U.S. scientific community to engage in this type of research or to advance promising technologies from the laboratory to the field. Although more funding has become available in recent years, options remain limited. Some areas for future attention include research on public knowledge, attitudes, and perceptions of HAB control. These would guide education and outreach efforts that can inform the scientific community and other stakeholders of the risks and efficacy of control strategies. Examples from Asia and other regions should be used to point out the benefits and possible impacts of bloom suppression. New interdisciplinary collaborations among stakeholders and decision makers such as scientists, engineers, risk assessment and communication experts, social scientists and managers should be promoted to deal with the complex task of evaluating the risks/benefits of control strategies and moving promising approaches from concept to field testing and implementation. Moreover, effective communication among all stakeholders should be encouraged to maintain the flow of accurate information while building public trust and understanding, thereby minimizing perceptions that could unnecessarily impede research.

2.A.1.c. Mitigation

Many of the management actions taken to respond to HABs can be termed mitigation—i.e., responding to an existing or ongoing bloom by taking steps to "prevent, limit, delay, or slow the rate of" undesirable impacts on the environment, human health, or human economies and communities[48]. This is the area of PCM management where the most immediate potential exists to reduce impacts, given that many such activities are already underway, several of which are noted below.

Monitoring. Routine monitoring programs for toxins in shellfish are currently conducted in numerous U.S. states and in more than 50 countries[15]. The detection of dangerous levels of HAB toxins in shellfish leads to harvesting restrictions that keep contaminated product off the market. Phytoplankton monitoring is increasingly being used by state agencies to provide warning before shellfish become toxic. For example, the Olympic Region Harmful Algal Bloom partnership (ORHAB, http://www.orhab.org/), developed with funding from MERHAB, monitors *Pseudo-nitzschia* along Washington beaches to provide early warning of toxicity in razor clams[49]. Likewise, citizen monitoring groups have been established in many coastal states as a low cost option for early warning[1].

Aquaculture and fishery-specific approaches. Mitigation of HAB effects on aquaculture can, depending on specific operation, be accomplished by moving fish or shellfish from the affected area. For example, fish net pens may be towed away from sites of intense HAB activity. Though

expensive and occasionally costly with respect to lost or damaged fish, this remains a primary tool used by fish farmers to combat HABs[50]. Minimizing the impact of HAB toxins in shellfish can be achieved by processing shellfish in such a way as to reduce toxicity to an acceptable level—e.g., by the removal of scallop viscera and the marketing of only the adductor muscle, which generally contains little or no HAB toxins.

Forecasting. Another mitigation strategy involves the forecast or prediction of blooms and subsequent communication of this information to stakeholders, allowing officials, industry representatives, and the general public to take appropriate actions to avoid HABs or minimize their impacts. Satellite remote sensing is now used operationally to detect HABs caused by *Karenia brevis* in the Gulf of Mexico, and with simple transport models, forecasts are now issued of impending landfall or exposure (Box 10)[51]. However, this capability is not easily transferred to other HAB species, as most HABs cannot be as readily detected by satellites. For other HABs, remote sensing applications rely on detecting the water masses in which the cells reside—using sea surface temperature for example[52].

Education and outreach. Mitigation can also be achieved through public education and outreach. The impacts of a HAB can be reduced greatly if correct and timely information is released through news outlets and other communication channels. Public information, however, must be carefully planned and outcomes and reactions anticipated. Effective messages must be developed using a detailed understanding of the needs, concerns and knowledge of the targeted audiences. Properly done, a relatively low cost effort can achieve significant positive results by reducing over-reactions and misunderstandings. Poorly done communication efforts can increase audience concern and reduce agency trust. Other community responses include offering alternative recreation opportunities and governmental or private programs providing social assistance, economic relief, or alternative job opportunities to temporarily unemployed fishermen.

Treatment of Health Impacts in Humans and Animals. Many HAB toxins are known to be so highly toxic that small amounts can cause death within minutes or hours. Current monitoring has done an excellent job of protecting human health, as evidenced by the rare occurrence of severe human illness or death. However, human and animal HAB poisoning incidents do occur (Box 11) and methods of treatment are needed. At present standard medical care remains supportive therapy. Use of cholestyramine, a non-absorbable polymer with anion-exchange binding capacity approved by the Food and Drug Administration (FDA) to lower cholesterol levels, may greatly enhance toxin elimination rates in humans exposed to some HAB

Box 11. Examples of circumstances leading to human health impacts from HABs.

Effective state monitoring programs leading to appropriate state management actions, such as closing shellfish harvesting, prevent most human illness that could be caused by HABs. However, under some circumstances, human health impacts do occur.

Newly emerging HAB problems: In 2002, the first incidence of illness associated with saxitoxin in puffer fish was reported in Florida. Federal and state agencies responded quickly to identify the cause of the threat, a dinoflagellate called *Pyrodinium bahamense*, and the extent of the illnesses. Since 2002, twenty-eight cases of human illness associated with saxitoxin in puffer fish from Florida have been reported and recreational harvesting of some puffer fish is now banned[53].

Monitoring not feasable: Ciguatera Fish Poisoning (CFP), from consumption of contaminated tropical reef fish, is the most common illness associated with algal toxins but is also likely the most underreported, partly because of the ambiguity of the symptoms. Monitoring for CFP in finfish is not practical or effective because of the spatial and temporal patchiness of toxin-contaminated fish and the lack of a reliable and simple test kit. For this reason, efforts focused on improving diagnosis and treatment of ciguatoxin exposure is critical.

Ignoring harvesting bans: In 2006 multiple cases of neurotoxic shellfish poisoning were reported in Lee County, Florida. Most occurred because clams were harvested from closed areas by tourists (http://www.doh.state.fl.us/disease_ctrl/epi/Epi_Updates/2006/10-20-2006.pdf) and several required hospitalization.

toxins[54] and is currently being tested for several toxins. Mannitol has been used to treat ciguatera fish poisoning and may also be effective for brevetoxins.

In addition, little is known about the health effects associated with repeated exposures to low levels of HAB toxins as humans might receive through recreational activities, drinking water, or consuming shellfish from areas with chronic low levels of toxins. For example, it is now established that aerosolized brevetoxins can cause respiratory effects in people working or recreating near the water when the Florida red-tide organism is blooming. Beach warnings are now provided to warn of the risk of exposure and several promising treatments have been developed[55].

2.A.1.d. Current Status Summary

Effective management of HABs and their impacts requires a comprehensive, multi-pronged approach that must include strategies for prevention, control, and mitigation. Great strides have been made in some aspects of PCM, particularly in the area of mitigating bloom impacts. HAB prevention remains predominantly a conceptual approach at this point in time, though there are promising activities underway that may begin to show results. Progress is the slowest in the formulation and implementation of bloom control or suppression strategies. As the problem of HABs continues to expand, the need to find practical, cost-effective, and long-term solutions will undoubtedly increase as well. Therefore, resources must also be directed to prevention and control efforts. This may be achieved by developing new programs and funding mechanisms, changes in infrastructure, and facilitating collaborations among natural and social scientists, engineers, and risk experts. A sociopolitical and ethical debate will also be needed to evaluate the risks and benefits of investing public funds into prevention and control options.

2.B. The Prevention, Control, and Mitigation Component of RDDTT Program

2.B.1. Rationale

The development of PCM strategies for HABs has been identified as a priority need since the publication of the reports, *Harmful Algal Blooms in Coastal Waters: Options for Prevention, Control and Mitigation* [8] and *Prevention, Control, and Mitigation of Harmful Algal Blooms: A Research Plan* [10]. The *National Assessment of Harmful Algal Blooms in U.S. Waters* [9] report noted "there are currently no national research initiatives to promote efforts in prevention, control, and mitigation of HABs and their impacts." A call for applied research to develop PCM tools was also made in the HABHRCA 2004 reauthorization, HARRNESS[2], the ISOCHAB proceedings[12], and the Prediction and Response Report[1].

To date, however, no dedicated funding has been allocated to transition promising PCM technologies and strategies (identified through basic research programs and funding agencies, such as ECOHAB, the NSF/NIEHS Centers for Oceans and Human Health, the NOAA Oceans and Human Health Initiative, NSF, and National Institutes of Health (NIH); see Box 8 for complete list), into a demonstration phase and ultimately operational use. MERHAB provides funding for technology transfer of a subset of tools specific to monitoring and prediction. The evolution of PCM tools from concept to operational use requires substantial resources, analogous in scale to carrying out a clinical trial for a promising drug, a process often termed the "valley of death" because of its high risk and the frequent lack of sufficient funding. Traversing the "valley of death" requires both the motivation ("push") on the part of researchers to take on this risk and the desire ("pull") from end-users needing the operational tool (Box 12).

Box 12. Traversing the Valley of Death.

"…transitioning from R&D to the market--a stage in business development so perilous that it's often called the Valley of Death. Traversing it requires an intelligent blend of public and private sector investment, targeting the most promising innovations." *Forbes.com*

A component of the RDDTT program dedicated to PCM that funds applied development, demonstration, and technology transfer is needed to translate promising ideas into a wide range of operational tools and ultimately positive outcomes for the environment and society. This component will uniquely address both the technical and socioeconomic aspects of technology/strategy development, providing a clear track for the successful transition of PCM tools to operational status. Funding for this type of activity is not readily available in other HAB programs. The PCM component represents the culmination of the transition from basic research to operational prevention, control, and mitigation needed to protect human and ecosystem health, economies, and community vitality.

2.B.2. Description of PCM Component of RDDTT Program

The PCM component proposed here consists of discrete phases that will: 1) develop strategies and technologies for PCM; 2) demonstrate and validate their utility under field conditions; and 3) transfer and transition that knowledge and technology to end-users in an operational context. The integration of individual phases within the PCM component and the manner in which they benefit from end-user input and involvement is depicted in Box 13. The PCM component of the RDDTT program will place significant emphasis on technology transfer, whether through collaboration with the private sector to commercialize technologies, or through collaboration with public-sector partners to develop an effective outreach and information dissemination program. Regardless of the pathway, PCM will be committed to the development, demonstration, and ultimate transitioning of information and technology into the hands of end-users and decision makers.

The PCM component of the RDDTT Program will have three phases:

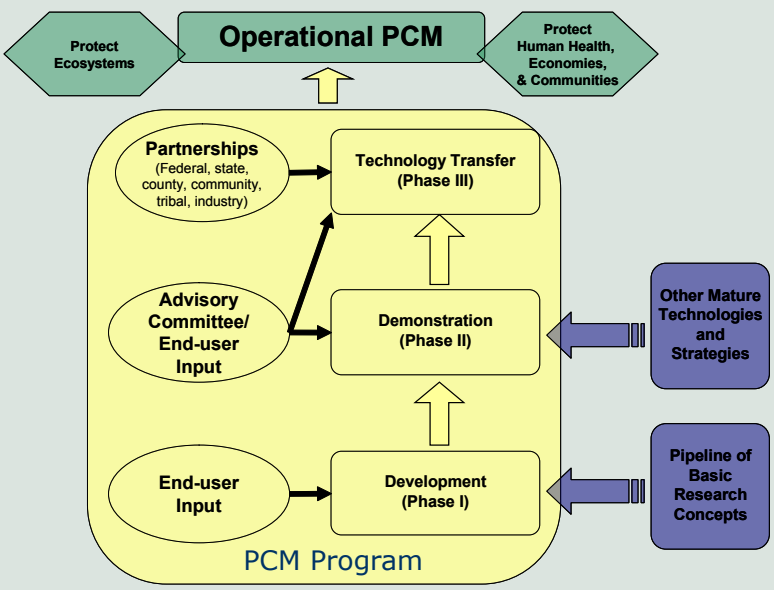
Development (Phase 1): This phase is proposed to support a competitive, peer reviewed grant program for development and evaluation of promising PCM technologies and strategies, including human dimensions research advancing PCM. Phase 1 projects will establish the suitability of a technology, approach, or product for achieving PCM goals and objectives. All successful Phase 1 proposals must demonstrate active discussion of their research plans with relevant end-users and involve these individuals or agencies in the evolution of the PCM concept from research and development through operational use. The goal of these interactions is not to establish "support," but rather to learn about the challenges facing these managers and confirm the relevance of the proposed research in addressing these challenges.

Demonstration (Phase 2): This phase is proposed for field testing, validation, and evaluation of PCM strategies across a range of temporal and spatial scales. In addition to scientific and engineering studies related to HAB PCM, assessments of socioeconomic costs and benefits as well as educational/outreach activities needed to support evaluation and implementation of these strategies should be addressed. All successful Phase 2 proposals must establish the feasibility and potential effectiveness of the proposed PCM technology or strategy either through the successful completion of a Phase 1 PCM project or the equivalent outside of the formal PCM program. Phase 2 and 3 projects will be guided by an external advisory committee (see details below).

Technology Transfer (Phase 3): This phase is proposed to support the formation of partnerships and the ultimate transitioning of validated PCM technologies and strategies to end-users. All successful Phase 3 proposals must include education, training, and capacity-building. Phase 3 projects will have either successfully completed a Phase 2 Demonstration project or undergone a comparable process.

All PCM projects will be extramural, competitive, peer reviewed and funded through an annual request for proposals that will ensure priorities for research and implementation are based both on societal needs and scientific promise of effectiveness. End-user input to proposals in all phases and external advisory committee guidance for Phase 2 and 3 projects will facilitate technical success and maximize socioeconomic benefits and opportunities. The membership of

Box 13. Diagrammatic representation of PCM structure.



the external advisory committee should include the PCM program manager, an appropriate human dimensions specialist (e.g., risk communication specialist, anthropologist, economist), members of the intended user community, and others as needed. Involvement of these researchers and user groups throughout the PCM development, demonstration, and implementation processes will ensure that projects with the most societal relevance are supported and brought into operational use.

The PCM component will, in its first years, emphasize Phase 1 development projects, but will evolve to include demonstration (Phase 2) and technology transfer (Phase 3) as initial projects mature. Funding for Phase 1 projects should be sustained to ensure a continued flow of new ideas and approaches to the program. Promising technologies and strategies, developed with funding from other programs, will be able to enter later phases.

2.B.3. PCM Priorities

Several previous reports have highlighted major impediments to progress in the prevention, control, and mitigation of HABs and have identified priority topics and approaches to address these issues[5,8,10]. Specific activities under these categories are described below, along with a rationale for their inclusion. This list is intended to be a guide for establishing future funding priorities and is certainly not comprehensive. As the PCM component of the RDDTT Program matures, new areas for investigation will become apparent, others will become operational, and still others will be considered less likely to achieve their intended outcomes. These are organized according to the categories of prevention, control, and mitigation outlined in *Harmful Algal Blooms in Coastal Waters: Options for Prevention, Control, and Mitigation*[8], augmented with social science elements under the heading of human dimensions.

2.B.3.a. Prevention

Modification of nutrient inputs

Many different agencies are involved in developing management strategies to reduce nutrients in freshwater and marine systems to improve water quality. We strongly support these efforts and recognize that the PCM program should not carry out redundant work. In areas where linkages have been established between HABs and anthropogenic sources of nutrients, efforts should be made to include HAB reduction as a driver for policy decisions.

Modification of hydrodynamic conditions

Objective:

Examine the effectiveness of altering flow rates and hydrodynamics in reducing the formation and frequency of HABs, and the environmental impact of these activities, in marine and freshwater systems.

Rationale:

Hydrodynamic conditions (e.g., flow rate, circulation, water column mixing) can have a significant influence on the development,

persistence, and transport of HABs. Therefore, modifying these conditions as part of a management strategy (e.g., dredging, channel construction, dam building, forced water-column mixing) has the potential to reduce or prevent blooms and minimize their impacts.

Minimize or prevent introductions of invasive HAB species, their cysts, and organisms that facilitate the success of HAB species

Objectives:

- Evaluate the effectiveness of existing technologies (e.g., molecular, immunological, rapid/automated enumeration) for identifying, quantifying, and assessing the viability of HAB species/cysts and HAB-promoting species in ballast water and other vectors, such as bivalve aquaculture.
- Evaluate existing ballast water treatment strategies and methods (e.g., ballast water exchange, biocides, mechanical removal) for efficacy in removing or killing HAB cells and cysts.
- Develop models to estimate the probability that a nonindigenous HAB species would become established in a new habitat following introduction via ballast water or other vectors.

Rationale:

There is compelling evidence that HAB cells and their cysts can be transported across wide geographic ranges through several vectors, notably ballast water, and become established in the new environment. Therefore, efforts should focus on preventing their introduction prior to delivery into a new habitat and predicting the likelihood of their success in a given area.

2.B.3.b. Control

Eliminate or reduce the levels of HAB organisms and their toxins

Objectives:

- Evaluate various options for destroying and/or removing HAB cells and toxins through chemicals, biological agents (e.g., viruses, bacteria, parasites, grazers), and mechanical means (e.g., flocculation, filtration, skimming, ultrasonic disruption), as well as approaches involving genetic engineering (e.g., reducing toxicity of HAB species) and environmental manipulations similar to those outlined above (see Prevention section).
- Characterize the short- and long-term environmental impacts of these control strategies on natural communities and the environment.
- Determine the fate and effects of toxins released through application of individual control measures.
- Develop technical and engineering solutions to large-scale application of various control options.
- Conduct knowledge, attitudes, and perceptions (i.e., KAP) studies on the community acceptability of HAB control for developing outreach materials to educate the public about HAB control initiatives.

Rationale:

Current management approaches consist mainly of strategies for responding to the presence of HABs cells and toxins to minimize their adverse effects (i.e., mitigation). Strategies to directly control or reduce the concentration of organisms as well as the toxins they produce are generally lacking and should be pursued as part of a comprehensive management program. Studies of social issues related to bloom control strategies are needed as well.

2.B.3.c. Mitigation

There are many different types of mitigation activities that can reduce the impacts of HABs. These can be grouped under several general categories.

Monitoring of HAB cells and toxins

Objective:

Develop sensitive, quantitative, field deployable assays and sensors for HAB cells, toxins, and relevant toxin metabolites.

Rationale:

The ability to detect HAB cells, toxins, and relevant metabolites in the field is a critical component of any mitigation program. Field detection capabilities will allow responders to

rapidly determine toxin/cell concentrations and thus support regulatory decisions and mitigation efforts. Moreover, sufficiently sensitive methods that enable detection of HAB organisms at pre-bloom concentrations can provide an early warning to managers and increase the lead time for responding to an event.

Objective:

Develop satellite and aircraft remote sensing capabilities for HABs that can be utilized in monitoring and management programs.

Rationale:

Currently available and emerging remote sensing technologies can be adapted for HABs in order to expand the spatial and temporal monitoring capacity in areas impacted by HABs. These capabilities can also support early warning systems for locations downstream of existing blooms.

Objective:

Integrate HAB and toxin detection technologies into emerging U.S. and global ocean observation systems.

Rationale:

Existing and emerging ocean observations systems represent an infrastructure with direct spatio-temporal relevance and application to HAB monitoring. Integrating HAB organism and toxin detection technologies into such systems already adapted for physico-chemical measurements would yield a spectrum of physical, chemical, and biological data in support of real-time or near real-time monitoring capabilities. Information streams from these observation systems could also be incorporated into data assimilative predictive models for HAB forecasting. This issue is addressed in further detail in Chapter 4 of this report.

Disease surveillance, clinical characterization, and therapeutic guidance in humans and animals

Objective:

Develop and validate biomonitoring methods of toxin exposure and identify and utilize biomarkers for toxin exposure effect and disease status.

Rationale:

Measurement of toxins in tissues and fluids of postmortem or living humans and animals (biomonitoring) remains the definitive means to confirm exposure. Biomarkers of toxin exposure, effect and disease status are critical to understanding the disease process and will support case identification and classification, disease surveillance, and clinical care decisions.

Objective:

Enhance disease surveillance for human and animal illnesses and deaths resulting from HAB toxin exposure by supporting existing surveillance systems such as the Harmful Algal Bloom Illness Surveillance System (Box 10).

Rationale:

Disease surveillance will assess the temporal and spatial relationship between HAB events and human illness, and identify risk factors associated with HAB toxin exposure in support of disease prevention efforts.

Objectives:

- Produce clinical therapeutic guidance for the spectrum of illnesses associated with exposure to HAB cells and toxins.
- Develop case definitions for the spectrum of illnesses resulting from exposure to HAB cells and toxins.
- Develop communication and outreach programs to make information on HAB poisoning syndromes available to the medical and veterinary community in a timely manner.

Rationale:

In many cases, medical and veterinary professionals are unfamiliar with the symptoms of HAB-associated illnesses and their treatment. Better definition and communication of case descriptions and recommended therapeutic actions can greatly reduce incidence and severity of illnesses.

Drinking water monitoring and treatment

Objectives:

- Establish guidelines for safe levels of HAB toxins in drinking and recreational water.

- Monitor source water for HAB cells and toxins, and develop real-time monitoring systems for toxins and cell fragments during water treatment.
- Develop supplemental water treatment processes for toxins.

Rationale:

Neither regulatory nor guideline levels for HAB toxin concentrations in finished drinking water or recreational waters have been established in the United States. Water should be monitored during treatment to determine whether supplemental treatment processes are needed to prevent toxins from entering the finished water stream. Supplemental treatment processes for water utilities are also needed to reduce toxin concentrations to safe levels.

Forecasting

Objectives:

- Develop data assimilative predictive models that can forecast HABs in a cost-effective and timely manner.
- Develop food-web based models for the fate and effects of HAB toxins.
- Model long-term risks to ecosystems from exposure to HAB toxins.
- Develop models of socioeconomic costs of HAB impacts and the cost effectiveness of PCM strategies to support decision makers.

Rationale:

Models are needed at various levels for effective HAB management. The application of *in situ* observations from coastal observing system and remote sensing platforms will improve HAB model forecast accuracy, and information on toxin dynamics in different food web compartments is critically important for managers charged with the protection of public and ecosystem health. Quantifying HAB toxin impacts on habitat degradation and the sustainability of coastal and freshwater ecosystems is also an essential aspect of resource management. Furthermore, providing information on economic impacts of HABs on coastal communities, as well as the risks/benefits of PCM strategies to economies, aquaculture enterprises, etc. will be necessary to develop cost-effective management strategies.

Relocation of aquaculture and wild-capture resources

Objectives:

- Develop predictive models for the probability of transfer of nonindigenous HAB species through the relocation of certain aquaculture and wild-capture species.
- Develop and evaluate strategies to relocate, primarily, aquaculture resources during severe HAB events to unaffected areas where HAB impacts will be minimized.

Rationale:

Cells of some HAB species can remain viable in both external (e.g., skin, shells) and internal (e.g., digestive tract) association with aquaculture organisms during normal transport for commercial purposes. Certain tissue compartments of these same organisms can also retain toxins for extended periods. Accurate models of these processes will aid in avoiding or reducing the possibility that relocated HAB species become established in receiving waters. Cost effective strategies (e.g., plankton surveys, hydrographic models, mechanics of relocation) are also needed to guide the effective relocation of fishery resources in order to reduce economic losses due to HABs.

Harvesting bans and closures

Objectives:

- Develop effective risk communication to improve public safety.
- Develop and support strategies to better delineate the optimum size of closure areas due to HAB toxin accumulation.

Rationale:

The public confusion that sometimes accompanies harvest bans and closures can be minimized by effective risk communication, thereby enhancing the ability to protect public health. In addition, the economic effects of harvesting closures can be reduced by strategies that effectively delineate and minimize the optimum size for closures. This can be

achieved by improving the timely collection and availability of spatial, temporal, and species-specific data on HABs and their toxins.

Fishing and processing practices

Objectives:

- Establish toxin loads in different tissue compartments for commercially harvestable resources and their impacts on the nature of saleable products (e.g., roe-on scallops).
- Evaluate processing methods that reduce toxin concentrations to below regulatory action levels.
- Facilitate the application of new sampling and analysis strategies that would provide access to currently restricted resources (e.g., dockside testing protocols for resources on Georges Bank, Geoduck harvest in Alaska).

Rationale:

Determining the anatomical distribution of toxins in seafood may allow the salvage of a saleable product by discarding the contaminated tissues. Identifying processing methods (e.g., canning and retort methods) that reduce toxins to a safe level will also minimize the loss of product while ensuring seafood safety. Implementation of these and other strategies would allow areas at risk for closure to be harvested with measures in place to reduce economic loss while ensuring protection of public health.

Education and outreach

Objective:

Develop an understanding of public knowledge, attitudes, and perceptions of HABs, and use that understanding to produce effective communication messages for education/outreach programs.

Rationale:

Education and outreach for HABs involve communicating complex and often uncertain scientific information (e.g., warnings and forecasts) to diverse stakeholders. It is important to assess audience characteristics (e.g., knowledge of HABs, perception of risks) in order to foster trust in decision making agencies, encourage risk-protective behaviors, and engage communities in decision making and monitoring. Social science research informing interagency coordination and fostering media relations to deliver effective messages will also play a critical role.

Community responses to social and economic impacts

Objective:

Assess and build community resilience to maintain social and economic benefits during HABs.

Rationale:

Closure of beaches and fisheries to protect public health in response to HABs can result in loss of recreational opportunities, disruption of subsistence activities and cultural practices, conflict among resource users, loss of community identity tied to aquatic resource use, and social stress in affected families and communities. It is important to build community capacities to respond to blooms (e.g., develop alternative recreational opportunities to sustain tourism).

Intervention to reduce wildlife mortality

Objectives:

- Evaluate and apply species-specific therapeutics and rehabilitation strategies for intoxicated animals to minimize mortality due to HABs.
- Investigate the feasibility of moving endangered species from high-risk, HAB affected areas.
- Investigate the effectiveness of hazing strategies to discourage animals from entering HAB-affected areas.
- Investigate the feasibility of immunizing animals against HAB toxins.
- Develop integrated contingency plans to determine the feasibility of small scale treatments (e.g., clays) or management strategies (e.g., lowering salinity) to minimize marine animal exposure to HAB toxins along transit routes.

Rationale:

In the past decade, HABs have been identified as the most frequent cause of marine animal mortality events. Rehabilitation of intoxicated animals and their release requires knowledge of appropriate therapeutic interventions as well as a prognosis for their post-release survival. Translocation of highly endangered animals to HAB-free areas may be feasible, yet entail significant effort and investment while raising questions of societal values regarding human intervention. Hazing strategies (e.g., noise, airboats, and airplanes) have been used successfully to discourage migrating birds from landing in lakes affected by botulism and oil spills. Applicability of these strategies as a cost-effective approach to HAB mitigation should be investigated. Since certain algal toxins may elicit antibody production, which may allow for the development and future implementation of vaccination strategies. Furthermore, some HAB events are predictable and coincide temporally and spatially with marine animal movements in specific areas. Proactive management actions may assist in minimizing impacts to large numbers of animals.

Human Dimensions

Objectives:

- Measure and anticipate the social and economic costs and benefits (intended and unintended) of PCM strategies to inform societal decision-making, including the justified level of investment.
- Develop an understanding of public knowledge, attitudes, and perceptions of PCM to produce communication strategies that promote public trust, awareness, and risk-reducing behaviors.
- Identify and evaluate approaches (e.g., economic incentives, laws, and education) for facilitating changes in human behaviors/attitudes needed to develop and implement PCM strategies.
- Conduct "institutional analysis" (i.e., research on the nature, strengths, and weaknesses of how people work together) to improve the coordination of researchers, decision-makers, and stakeholders involved in PCM research and implementation.

Rationale:

Human dimensions research brings to bear tools of the social and behavioral sciences and the humanities to enhance HAB response and is critical to ensure socially-responsible development and effective implementation of PCM strategies.

2.B.4. Initiation of the PCM Component

The HABHRCA legislation addresses a clear national need when it recommends an interagency "research, development, demonstration, and technology transfer program on methods for the prevention, control, and mitigation of harmful algal blooms." Implementation of a PCM program will clearly require the cooperation and participation of multiple Federal agencies with mandates that range from public health protection to the management of HABs and their impacts on marine and freshwater systems.

We recommend that the wording in the HABHRCA reauthorization bill clarify that the proposed PCM program be an interagency competitive, peer reviewed grant program funded through a partnership of NOAA, EPA, FDA, Centers for Disease Control and Prevention (CDC), NIH/NIEHS, NSF, U.S. Department of Agriculture (USDA), U.S. Fish and Wildife Survey (USFWS), U.S. Geological Survey (USGS), NASA, and the Department of Homeland Security. Furthermore, funds should be authorized for each agency that participates in a substantial manner, but this may require separate authorizing legislation due to Congressional committee jurisdictions.

Workshops to exchange knowledge and approaches across natural and social science disciplines and agencies are recommended as the first step in initiating the PCM component. For example, much can be learned from prior research on control and mitigation strategies used for terrestrial and aquatic nuisance species. In this regard, **we recommend a workshop be convened to which experts in HAB control, as well as control strategies for insects, aquatic vegetation, other pest infestations, and bioremediation strategies used for oil spill and pollution events, be invited**.

Chapter 3

Event Response Workgroup Report

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3.A. Introduction

Human uses of inland, coastal, and ocean waters for subsistence, livelihood, commerce, and recreation are increasing. While there are many benefits, the impacts of the human use of these resources have caused increases in the occurrence and severity of HABs. For example, in 2005, HAB events occurred throughout the United States with the events in the Gulf of Maine and Florida being the most severe since the early 1970's (http://www.cop.noaa.gov/stressors/extremeevents/hab/current/fact-ev_resp.html).

In order to mitigate the impacts of HABs, there is an urgent need to further develop the capacity for anticipating HAB events and responding rapidly. The range of stakeholders involved in event response depends upon the nature of the HAB, the geographic area affected and the implications for human, fish, and wildlife health. States, counties, tribes, and academic researchers are generally the first responders. The aquaculture industry in some instances has also acted as front line responders providing helpful data to state managers. When HAB events occur on small, localized scales, the capacity and financial resources of individual states usually are sufficient to respond quickly and effectively. A good example of this kind of response capacity is the Maine shellfish monitoring and closure program. Under normal conditions, the state is able to mitigate adverse public health outcomes through the imposition of a system of carefully timed and positioned shellfish closures. Many other states have also had successful programs in place to manage shellfish closures for many years. However, this capacity is now being regularly exceeded as the scale of events grows.

As HABs are increasingly occurring at much larger scales and greater frequency, have greater scope of impact, or involve species that are new to state or regional waters, the capacity for responding rapidly is sometimes inadequate or nonexistent. In addition, freshwater HAB events are occurring in states that have never before needed a capacity for response. These frequently toxic freshwater blooms can threaten public water supplies and lead to widespread recreational impacts. In marine systems, large-scale HAB events can lead to widespread closures of shellfisheries in states that may not have the equipment, personnel, or financial resources to monitor, evaluate, and mitigate impacts adequately.

The insufficient capacity for adequate responses to new or large-scale HAB events is due to inexperience, lack of resources, and the unpredictable nature of such events. It is costly and time-consuming to develop a response capacity for events that are sporadic or rare, have increased in frequency and scale, or for which damages are very uncertain. These characteristics argue strongly for a regional approach to event response, in order that experience and capacity within a region or even across regions can be brought to bear quickly and effectively. In effect, such a program helps a region, or even the Nation, deal with the significant public health effects, ecological impacts, and economic damages that could arise from unusual, unpredictable, and devastating HAB events.

Both Federal legislation and numerous recent reports have stressed the need for improved event response. The 1998 Clean Water Act requires the implementation of a coordinated response system to support state and local efforts during

HAB events and HABHRCA 2004 requires a plan for programs to reduce the frequency and intensity of HAB events and their impacts. Further, HARRNESS[2] calls for the development of early warning systems, response plans, and methods to reduce exposure and for improving the coordination of responses across local and regional scales. The Prediction and Response Report [1], required by HABHRCA 2004, recommended that improving and coordinating event response should be part of the RDDTT Plan.

The HAB Event Response component has two elements: the rapid response required during and immediately after a bloom event, and the capacity building activities required to assure more efficient and effective response for future blooms. Other programs, such as the NOAA MERHAB Program, contribute to long-term capacity building, so the primary focus of this report is to address the need for rapid event response, although some elements also contribute to capacity building.

3.B. Current Status of HAB Rapid Event Response

3.B.1. Role of State and Local Governments

The primary responsibility for event response resides at the state, county, municipal, and tribal level for both coastal and freshwater HABs. State Departments of Health, Marine Resources, Environment, Natural Resources, Agriculture, Fish and Wildlife, and, in the case of freshwater HABs, county and municipal agencies, may be involved in HAB response. States respond to HAB events to protect public health, to mitigate impacts on local economies, to determine cause for fish and wildlife mortalities, and to manage ecosystems.

States are responsible for safety of any seafood products harvested for commercial sale and recreational harvesting. FDA oversees state shellfish sanitation plans to ensure overall product safety. Given that some regions have been experiencing blooms of the same HAB species on a recurring basis for many decades, the affected states and tribes generally have good response capacity and organizational relationships not only within the state but with regional Federal entities and even neighboring states. In areas experiencing emergent HAB problems or with recurrent blooms of significant magnitude, states may not have sufficient capacity or expertise to respond effectively.

Responsibility for freshwater HAB event reponse rests with either state or local governments. The level of state response varies due in part to a lack of Federal regulation for freshwater HAB toxins. It should be noted, however, that EPA is in the process of considering regulations for the most prevalent toxins[12,13], which may drastically alter response to freshwater HABs. Cyanobacterial HABs can occur in a wide spectrum of freshwater bodies from small ponds to the Great Lakes, making response efforts logistically problematic. Contamination of drinking water sources by cyanotoxins has potentially serious public health implications. Some states have organized monitoring programs especially for recreational and drinking source waters[13], but others resist or do not have adequate resources even when livestock, wildlife, and pets experience mortalities.

3.B.2. Role of Federal Event Response

3.B.2.a. Mandatory Federal Response

There are only two instances that require a Federal response. If a bloom that threatens public health occurs in Federal waters, then FDA can request that NOAA National Marine Fisheries take appropriate action, such as temporarily closing a commercial fishery. Additionally, if Federally protected species are involved, the appropriate Federal agency (NOAA, USFWS, or USGS) responds. However, in both cases states are often involved as well. In all other cases the role of the Federal government is to provide assistance at the request of state and local governments.

3.B.2.b. 1999 Federal Event Response Plan for Harmful Algal Blooms

In 1999, the Federal Event Response Plan for Harmful Algal Blooms: An Initial Focus on *Pfiesteria*, Fish Health, and Public Health was created through a memorandum of understanding (MOU) as an effort to organize an interagency, Federal response to HABs after the *Pfiesteria*

events of 1997. It was requested by the White House Council on Environmental Quality in order to plan future responses to *Pfiesteria*. Although the plan was never invoked (given its voluntary character and perhaps its focus on *Pfiesteria*), it stimulated coordination and communication between agencies that had not interacted before on HAB issues and formed the basis for the current NOAA event response efforts. This plan is recognized as a resource for future HAB event response organization at the Federal level.

The *Pfiesteria* plan was an effort to organize Federal response to *Pfiesteria* when states requested assistance. It designated a National Event Response Coordinator (at NOAA) and identified key contacts in each Federal agency including the FDA, CDC, and EPA. The plan recognized that some responses could be handled at the regional level through the network of EPA Regional Offices. The National Coordinator at NOAA was tasked with coordination between the states requesting assistance, regional contacts and other Federal agencies. This plan provides a sound framework for HAB event response organization at the Federal level.

3.B.2.c. Federal Programs to Assist State and Local Response

Some services exist at the Federal level to supplement state response. One of these is the NOAA CSCOR Event Response Program (http://www.cop.noaa.gov/stressors/extremeevents/hab/current/fact-ev_resp.html). The program has the dual purpose of providing assistance, either as funding or expertise, for managing events and advancing the understanding of HAB events. Funding is provided to assist states or independent researchers to collect data, conduct trainings, and enhance or expand monitoring in coastal and estuarine waters, upper reaches of estuaries and the Great Lakes.

NOAA also has organized an Analytical Response Team (ART), located at the Center for Coastal Environmental Health and Biomolecular Research. For toxin identification and quantification, a suite of toxin class-specific assays is first employed to quickly determine the presence of specific toxic activity. Quantitative instrumental analysis is then used to determine the toxin composition and concentration in samples. For algae, light and scanning electron microscopy may be used for identification in water samples and gut contents and feces of animals where appropriate. ART responds annually to between 10 and 25 HAB events and provides analysis without charge. On occasion, funding support has been offered by NOAA to state analytical laboratories to assist with toxin analyses of marine mammals during HAB events (e.g., Florida Fish and Wildlife Conservation Commission) upon recommendation by the Working Group on Unusual Marine Mammal Mortality Events (WGUMMME). The Core Infrastructure Program proposed in the next chapter addresses the inadequacy of the current capacity for toxin analysis.

Due to the increased number of marine mammal mortality events attributed to biotoxins, the response to these events requires coordination between marine mammal-focused emergency services and those responding to the HAB itself. The Marine Mammal Health and Stranding Response Program, established by the Marine Mammal Protection Act, is jointly administered by NOAA National Marine Fisheries Service (NMFS) and the USFWS. Unraveling causal factors when HAB toxins are implicated is often difficult, but the methods developed for assessing HAB impacts in protected species may prove useful in evaluating outbreaks in humans. The functional organization of this program is described below as a possible model for HAB rapid response.

The NOAA Center for Coastal Monitoring and Assessment (CCMA) has been involved in developing algorithms to detect HABs using satellite imagery and, once detected, to forecast bloom transport and geographic extent of impacts. Frequently, CCMA will be contacted in the event of a suspected bloom to analyze imagery. Bulletins, for example, for the Gulf of Mexico (Box 10), are continuously available to the public (http://tidesandcurrents.noaa.gov/hab/).

Other Federal agencies are also involved depending on geographic location of the bloom and whether the bloom is a risk to public health or

affects species in state or Federal waters. The FDA is responsible for the safety of fish and shellfish harvested in Federal waters. FDA laboratories are frequently contacted to provide toxin analysis during HABs in state waters. In response to the *Pfiesteria* events in the 1990s, the CDC began development of the HAB-related Illness Surveillance System (Box 10) which is at the pilot stage in several coastal states.

Currently, there is no organized Federal responsibility for responding to HABs in inland freshwaters outside the Great Lakes. Since the number and severity of freshwater blooms have been increasing, this is a significant gap.

3.B.2.d. Possible Models for HAB Response

The NOAA CSCOR HAB Event Response Program, mentioned above, is the only program dedicated to rapid HAB response. A partnership between CSCOR and the U.S. National Office for Harmful Algal Blooms, it provides generally small amounts of immediate funding as well as assists state and local governments to find partners with appropriate expertise. It was developed in response to the 1999 Federal Event Response Plan described above. Some examples of the types of activities funded over the past four years include: 1) investigating linkages between animal mortalities and HAB events, 2) taxonomic training, 3) investigating potential emerging HAB problems, 4) intensified sampling to protect human health, and 5) coordination of sampling and information flow (for examples, see http://www.cop.noaa.gov/stressors/extremeevents/hab/current/fact-ev_resp.html#accomp).

The Marine Mammal Stranding Program presents a possible model for organizing rapid event response. The stranding program is mandated by legislation and is jointly administered by NOAA and the USFWS. Using set criteria, a Working Group of 12 national and international experts, comprising the WGUMMME, reviews the data from an event to determine if an unusual mortality event (UME) is occurring. The review must occur within 24 hours and, if a UME is declared, response is activated in the affected region through a network of affiliated partners, which rely heavily on volunteers to respond. Roles are assigned according to a predetermined emergency response structure with both on- and off-site coordinators. Communication with each other and the public is a necessary component of the response. Most recently, the internet listserver service ("Incident News") provided through the NOAA Incident Command System (ICS) was used to post information both for the public and for coordination between agencies involved in response. This program is considering adopting the ICS as the primary organizational tool for response. ICS was adapted by the Department of Homeland Security as a rapid response tool for any level of government (http://www.nimsonline.com/homeland_security_nims_fact_sheet.htm). Funds for UME response need to be mobilized quickly, accomplished through deposits in a foundation outside the Federal government. Finally, this program has a strong research component and relies on researchers to help determine the causes and processes underlying the UMEs.

As a result of the die-off of 149 manatees during the 1996 *Karenia brevis* red tide, the state of Florida created its own state contingency marine mammal mortality response plan in collaboration with USFWS and NOAA marine mammal stranding program. The plan, prepared by the Florida Fish and Wildlife Conservation Commission, is a good example of cooperation between state and Federal agencies in response to a coastal problem caused by HABs[56].

Oil Spill Response (NOAA, EPA, and U.S.Coast Guard or USCG) may be another model for response, although the highly centralized and uniform approach to spills may not apply to the more diverse nature of HABs. All oil spill response is coordinated through the National Response Center. Some funds are pre-competed by EPA for researchers to study wildlife impacts during and after a spill. This peer reviewed, competitive approach to disbursement of rapid response research funds could be potentially useful in HAB response as well. Funds to cover the cost of clean up are either provided by the responsible party or from the Oil Spill Liability Trust Fund, which is managed outside Federal government.

3.C. HAB Event Response—A Regionally Based Federal Program

3.C.1. Program Rationale

In order to improve response to HAB events, we propose a national program designed to coordinate these efforts. This program would have a regional structure to coordinate responses to HAB events. The need for such a program is based on the following rationales.

- **Improved response capacities**. Individual states are not always able to respond adequately and rapidly to HAB events, particularly if they involve new toxic algal species or widespread, long lasting blooms. This inability may be due to limited or exhausted agency capacity or a lack of experience or expertise. Participation in a regional program would provide opportunities for states to utilize the resources (equipment, technology, expertise, and experience) from other states and/or Federal agencies for enhancing or building rapid monitoring, diagnostic, and response teams. Moreover, with national coordination, expertise and laboratory services from other parts of the country could be used to improve the capacity of the event response team (e.g., 2007 Texas ciguatera fish poisoning event; 2005 Massachusetts red tide event (*Alexandrium fundyense*); 1987 North Carolina red tide event (*Karenia brevis*)). Reliance upon regional or national coordination has the added advantage of allowing existing teams in the affected communities and states to focus their efforts and resources on managing the hazard in their own areas.
- **More efficient resource management.** The number, frequency, and type of HABs have increased in coastal waters in recent years. Freshwaters are also becoming burdened with HAB events. It is nearly impossible for one state or community to maintain the resources for monitoring, detecting, analyzing and and responding to all possible types of HAB outbreaks and the associated illnesses they potentially cause in people, fish, wildlife, and the environment. A national program for regionally coordinated HAB event response assures that existing state resources can be complemented as needed, by other non-state capacity. Economic efficiency is enhanced through the sharing of equipment and labor that are not fully utilized within a region (e.g., in 2006 Maine Department of Marine Resources exchanged analytical services for equipment from New York; Mississippi informs Louisiana about the development of a red tide event; Florida assists in toxin testing for other Gulf States).
- **Enhanced interstate and intergovernmental coordination.** Some HAB problems or HAB-affected resources and impacts cross state boundaries, state-Federal boundaries, or are the ultimate responsibilities of Federal agencies. Consequently, there is a need for coordinating interstate, intergovernmental, and interagency notification and responses to HABs (e.g., 2005 Federal and state shellfish closures in the Gulf of Maine during the large-scale red tide event; need for interagency coordination and clarification of responsibilities during the 2007 Texas ciguatera fish poisoning event). Social science studies would be beneficial to assess existing approaches to coordination and identify opportunities for improvement[5].
- **Improved risk communication.** As the National Science and Technology Council explains in its report, *Grand Challenges for Disaster Reduction*[57], to be effective in protecting human well-being, scientific information must be communicated so that people understand the risks, trust the messages, and respond appropriately. There is a critical need for formal communication plans at the local, regional, and national levels with pre-tested messages and delivery strategies, and protocols for coordination[58]. Coordination can prevent conflicting and confusing messages and approaches at the time of an acute event, alleviate unnecessary fear and prevent "re-inventing" messages and strategies thereby improving the efficiency of response in the next event.
- **More accurate environmental characterization.** There is a need for mapping associated environmental variables and modeling some HAB phenomena at the local and regional level. This will allow for more accurate understanding of the HAB event and improved forecasting for affected communities. Mapping and forecasting capabilities exist in the Gulf of Mexico, Chesapeake Bay and are under development in the Gulf of Maine, Great Lakes and Puget Sound regions.

- **Increased standardization of data**. There is a need for a national program of regionally coordinated HAB event response for standardized data collection. Databanks should be developed for toxins, economic variables, human dimensions data on perception and attitude, and standardized medical and veterinary data. Systematic data collection eventually would become institutionalized and available as a permanent record.
- **More efficient information distribution.** With national coordination, information can be acquired more efficiently and distributed more rapidly, including information about bloom types and characteristics, HAB distributions and toxin impacts, species affected, agencies involved (agency responsibilities, jurisdictions, mandates, funding resources), and capacities (state equipment, personnel, and experience).
- **More effective public policy.** Sharing of information between researchers, states and national policy makers and decision makers is needed to develop effective public policy.
- **More effective management of living resources.** National or regional coordination combined with scientific expertise and consensus interpretation about HAB events can provide managers with increased knowledge, guidance, and with the capacity for contingency planning. One goal is to minimize impacts on critical resources and allow for appropriate management strategies to be developed to protect species from exposure to HABs and their toxins and thereby minimize impacts on critical resources.

3.C.2. National Event Response Program: Federal Level

3.C.2.a. Staffing

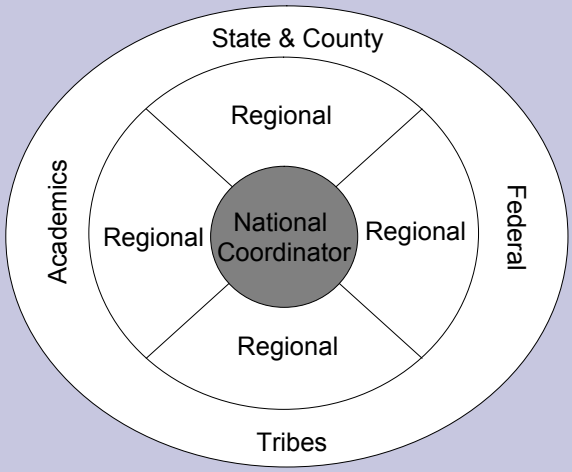
Due to the widespread distribution of many different HAB species and toxins in the United States, which sometimes span several states or occur in states unprepared to respond, there is a need for national coordination in agencies that have purview over marine and freshwater systems (Box 14). EPA and NOAA should share this responsibility and coordination between the two agencies is critical. Several staffing options are possible. To ensure coordination, the ideal structure would have one central coordinator (housed at one or the other agency) and two deputy coordinators—one in NOAA and one in EPA. Another possible structure would have two coordinators—one in each agency who would communicate on a frequent and regular basis. In either case, the coordinators would be Federal employees. The Core Infrastructure component also calls for National Coordinators. Coordination of both Event Response and Core Infrastructure could be could be conducted by the same people, since there is overlap in responsibilities.

3.C.2.b. Role of Federal Coordination

Establish Federal network of services

If national coordination is enacted, when a request for assistance with a HAB event is received, access to and information about services available throughout pertinent Federal agencies would be made available through the National Coordinator(s). In preparation for this, the National Coordinator(s) would need to inventory services available across Federal agencies, as done in the 1999 *Pfiesteria* Plan (see 3.B.2.b). It may be necessary to generate MOUs between NOAA/EPA and other Federal agencies to ensure timely response. The list of agencies to be contacted to establish institutional relationships includes, but is not limited to, NOAA, EPA, CDC, FDA, USCG,

Box 14. Diagram of proposed Event Response component, focus on national coordination.



USGS, USFWS, USDA, ONR, Army Corps of Engineers, and NASA. Also, depending on the office in which the National Coordinator is located, it will be important for this person or persons to make necessary connections with other offices to ensure working knowledge of available expertise and services. For example, within NOAA, it will be necessary to be in working communication with CSCOR, CCMA, National Marine Sanctuaries, and laboratories in the National Ocean Service, NMFS (multiple programs and regional laboratories), and the National Estuarine Research Reserves System (NERRS). The National Coordinator(s) would make necessary connections with the U.S. Integrated Ocean Observing System (IOOS), both during an event to capitalize on relevant data but also operationally in an on-going process to ensure that IOOS is incorporating sensing systems relevant for HAB detection (also see Chapter 4).

Create and oversee a regional structure

The National Coordinator(s) would also oversee the creation and facilitation of a regional communication and response structure. However, the regional structure is not intended to override state response but rather serve as a resource for states in the event of a HAB that strains existing resources and capabilities. This regional structure should be established in such a way to provide equivalent support for both marine and freshwater events. Event response has many common elements and the intent is to facilitate cross-fertilization and synergies among agencies and states. Response can be best organized by regions because of commonality of requirements, access to resources, and familiarity with the events. Coordination at the regional level is essential. The National Coordinators will work with state and regional entities (including IOOS regions, EPA regions, FDA regions) to identify regional boundaries and coordinators. The appropriate MOUs, terms of reference, etc. will be established to assure the linkage with Regional Coordinators.

An immediate and critical role for a National Coordinator(s) is to ensure that needs assessments are conducted at the regional level. The primary objective of a needs assessment is to determine the informational and resource gaps that must be addressed to respond adequately to an event. Needs assessment includes an inventory of what tools and methods are required, deficiencies in training and expertise, funding shortfalls, communication and evaluation needs, and any other resources that are lacking or insufficient in quantity, time, and geographic distribution. In the state section of this plan, there is a list of response activities that should be considered. Communication with the proposed Core Infrastructure Program, which plans to assess, organize, and expand infrastructure availability at the regional level, will be important to avoid duplication of effort and assure adequate resources in an event response.

Foster guidelines development

For some HAB events, particularly those in freshwater bodies and when an emerging or unknown organism is present, there may be a lack of sufficient guidelines or action plans for response and management to protect public health or minimize resource impacts. In addition, there are regional discrepancies in event response readiness and operational guidelines. The National Coordinator(s) would compile, evaluate, provide access to, and develop guidelines that can be used by partners and stakeholders. The intent is not to challenge or change existing guidelines or action plans. Rather, the National Coordinator(s) will provide a clearinghouse for existing policies that can be shared among the Regional Coordinators and states, initiate a forum for evaluation and optimization of procedures, and provide leadership for the development of nonexistent guidelines or update existing guidelines that were identified as critical in a needs assessment. Guidelines are especially needed for HABs in freshwater systems.

Conduct outreach, networking, education, communication, and training

A primary responsibility of the National Coordinator(s) would be to conduct outreach, education, and communication about HABs. The National Coordinator(s) would work with regional coordinators to ensure the states in each region are fully aware of the goals, objectives, and resources of the National Event Response Program. The

National Coordinator(s) would cultivate a network of HAB specialists throughout the states and regions that understand the issues and needs and can respond to events as they unfold. The national program would also be the central clearinghouse of information, probably most effectively through a web site that provides an inventory of resources available in the various states, tribes, academic institutions, and through other partners.

Effective communication in a HAB event is a major challenge. The goal of the National Event Response Program is to build institutional capacity to improve effectiveness and efficiency of HAB crisis communication and outreach. Although communication with the various parties involved in a specific event is probably best handled at the state or local level, the national program would provide assistance as requested to support the delivery of clear, consistent and appropriate messages to managers, media and the public. The National Coordinator(s) might also assist in facilitating communication among the agencies during the event. Assistance from specialists in Risk Communication is needed to help the HAB community develop formal communication plans at the local, regional, and national levels with pre-tested messages and delivery strategies, and protocols for coordination[58]. Design of communication messages requires a detailed understanding of the target audiences and stakeholders, and pre-testing with small groups of stakeholders similar to the target audience.

Training can dramatically improve future event responses. Training should include technical training in monitoring and assessment approaches, and toxin screening, but also training (e.g., from Risk Communication specialists) to improve the communication and coordination abilities of specific individuals in appropriate agencies.

Develop and administer two Event Response Funding Programs

It is recommended that two funds be established to support event response: (1) a Contingency Fund that would be used to respond to unexpected, new, or expanded HAB events, and (2) a Technical Assistance Fund that would fund on-going activities to improve responses to future HAB events.

The Contingency Fund would be available to support response activities that cannot be accommodated in the region because a state does not yet have an appropriate program to meet the need and/or the regional capacity is not available or is exceeded in a prolonged or new event. An expedited proposal process should be established, and states, tribes, or academic institutions could apply (see current CSCOR event response). Criteria for ranking proposals would need to be established. A Technical Assistance Fund should be available to fund activities designed to improve responses to future events. This fund would support the development of new guidance and training modules, research that might improve future event response (especially human dimensions research), and enhanced infrastructure capacity in states where that is currently lacking.

Evaluate and implement improvements to Event Response

An important responsibility for the National Coordinator(s) will be to ensure that lessons learned during event response are documented and used to plan for future events. This should happen at both the regional and national level. The role of the National Coordinator(s) in regional response evaluation will be to ensure that event response documentation on protocols, resources, and contacts are maintained at the regional level by the Regional Coordinator(s) and shared with the National Coordinator(s). In addition, the National Coordinator(s) should conduct an annual review to evaluate national/regional HAB event response, determine where services were not sufficient, and thus provide future directions.

3.C.3. National Event Response Program: Regional Level

3.C.3.a. Staffing Regional Coordination

In order to effectively organize a coordinated regional system, multiple Regional Coordinators would be required for both freshwater and marine HABs. The Regional Coordinator position will function mainly as a facilitator and liaison

for the various agencies and teams (see 3.D.) involved in an event (Box 15). The person in this position will require excellent organizational and communication skills, the ability to forge and maintain interagency relationships and agreements, and the ability to build a functional, dynamic team that may change from event to event, or possibly change during a single event.

Regional Coordinator(s) require long-term Federal support as well as an adequate budget to carry out coordinating functions. Coordinating functions includes funding for infrastructure (see Infrastructure section), training, communications, and emergency resources (staffing, supplies, equipment, easily accessible funds, and other needs). In this respect, it will be important for the Regional Coordinator to maintain a close working relationship with the Core Infrastructure Regional Coordinators, described in Chapter 4 and in fact, these may be the same person. They are most likely to reside in NOAA and EPA regional offices or labs, but other arrangements are also possible. Regional coordinators will have responsibilities both during an event and between events.

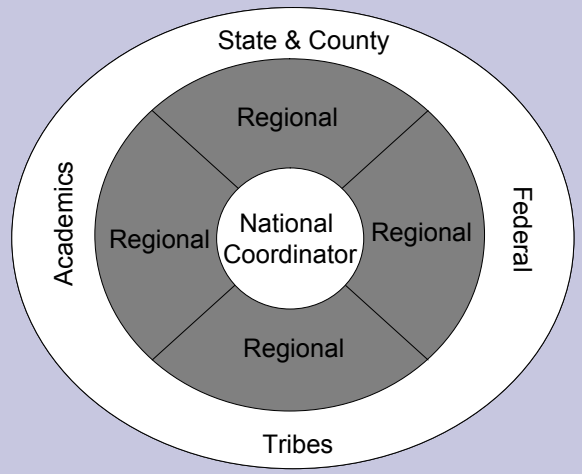
3.C.3.b. Role of Regional Coordination

Event Response responsibilities

In the case of a HAB event, which is within the scope of a state's ability to manage without outside assistance, the Regional Coordinator should receive a courtesy notification of the event, in order to communicate this information to the rest of the regional community.

In the case of a HAB event, which is either a new event, or an exceptionally severe event requiring supplemental resources, the Regional Coordinator may receive a request for assistance from either a state, tribal, or Federal agency within the region. The Regional Coordinator will consider whether the request could be handled with inter-regional resources, and if so, will direct the entity seeking assistance to the appropriate teams. If the request for assistance could not be managed with existing regional resources, then the Regional Coordinator will contact other regions to seek the required resources, or will contact the National Coordinator to seek further assistance.

Box 15. Diagram of proposed Event Response component, focus on regional coordination.



Inter-event responsibilities

Pre- or post-event responsibilities will include facilitating additional training for the regional teams, including but not limited to, communications skills. The Regional Coordinator will also be responsible for creating and maintaining new relationships with other agencies or entities that may provide additional resources during a HAB event, and will maintain an accurate, up-to-date inventory of regional resources and contact information. The Regional Coordinator will also be responsible for coordinating regular meetings of the regional and state stakeholders, in order to maintain a consistent level of preparedness, enhance communication skills and to share information to improve future event responses. Open communications and access to critical data that aids in the interpretation of the event must be shared between personnel responding and evaluating the HAB event. The regional coordinator will:

- **Facilitate rapid response to new or unusual HAB events.** In certain situations, a state may be inexperienced in responding to a HAB or an experienced state may need additional resources to respond to an unusually large, unique, or dynamic HAB event. In these cases, the state may request assistance from the region.

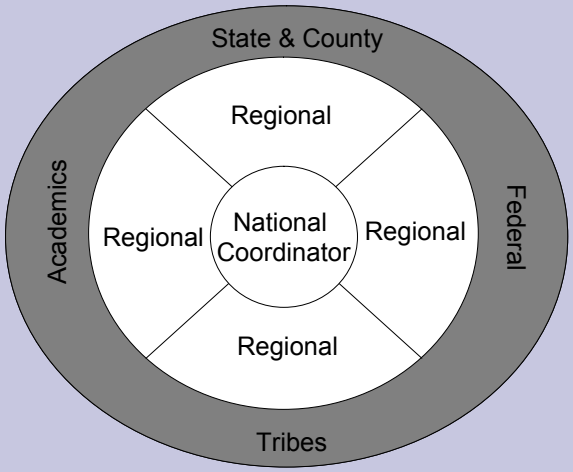
- **Provide liaison function with other states in a region and National Coordinators.** The primary goal here is communication and facilitation of any unmet needs in the area where the HAB is occurring.
- **Facilitate readiness before, during, and after events, including education, training, debriefings, review, reappraisal of existing plans and resources, personnel, equipment, and information about regional infrastructure.** Regional coordination will allow a greater level of awareness of existing resources. Through the enhanced communication structure, state program managers can be informed of emerging issues and new technology.
- **Help guide management actions (intrastate and interstate):** Regional coordination will facilitate a clear and effective response in cases where an incident spans one or more boundaries such as county or state borders. Regional coordination can assist in ensuring that the counties and states affected by the same or a similar HAB species provide consistent messages to the public. It can also facilitate the collection of consistent data in each jurisdiction and ensure that a single post-event report is prepared.
- **Develop regional specific contingency plans to address specific needs and resource capabilities:** With detailed assessment of resources such as technical skills, laboratory facilities, vessels, and the region can be better prepared for new or unusual harmful algal bloom events. Planning can focus on the unique challenges and resources within the region. The development of broad contingency plans in advance of HAB events can maximize the opportunity to gather data as an event unfolds, assess the situation, and communicate results in an orderly, succinct, and timely fashion.

3.C.4. National Event Response Program: State Level

3.C.4.a. State Response Programs

For the most part, many states have the existing infrastructure to respond to known HAB species, evaluate their impacts and communicate potential concerns to the public (Box 16). The basic response elements in place include operational personnel from the medical, fish and wildlife, environmental, diagnostic, data, assessment and planning, and communications communities (e.g., Box 17). Depending upon the type of HAB and the number and extent of species affected, each of these various components may be required for response, and subsequent follow-up and evaluation, but they are not envisaged as supplementing (unless so requested by the states) already existing infrastructures. If response capacity is exceeded, a state has no existing infrastructure, or a new or emerging HAB is encountered, then additional logistical assistance and support may be requested from the region. National involvement will depend upon the resources that might be available in one state to assist another state (or tribe). Through regional and Federal coordination, resources should be made available to the states within each region to respond rapidly (on a relatively short-term basis) to a HAB event in a neighboring state. This plan must also ensure that resources would be made available through the national and regional systems of coordination to allow a regionally based academic institution or a Federal lab or center (e.g., the NOAA Northwest Fisheries Science Center) to respond rapidly and assist in an unusual HAB event.

Box 16. Diagram of proposed Event Response component, focus on state and local response.



3.C.4.b. Elements of a State HAB Response

The following types of response are usually deployed or should be considered when a HAB outbreak occurs. The role of the Event Response Program proposed herein is to enhance state and local government capacity to provide these types of response at the request of those governments. Use of the terms "group" and "team" refer to functions and expertise needs that will be met by one or more people; the same person may have multiple functions during an event and other responsibilities when an event is not occurring.

Box 17. Oregon Interagency Task Force on Cyanobacteria.

Over the past several years in Oregon, the response to cyanobacterial blooms in recreational freshwater bodies has been inconsistent and piecemeal. In part, this is reflected by the numerous agencies that have jurisdiction over lakes and reservoirs, many with variable levels of interest or resources. To provide a coordinated response to bloom events, several stakeholders in Oregon developed a taskforce including city, county, state, and Federal agencies, along with business and academic partners.

This interagency taskforce developed guidelines for sampling and monitoring, opening and closing recreational areas, as well as public outreach and media communication. This effort was bolstered in the early stages by the involvement of EPA and CDC personnel who attended an interagency meeting for training purposes. Since the formation of the taskforce, the response to bloom events, especially consistency in opening and closing areas and information provided to the public, has been greatly improved. However, several needs, both resource and informational, still exist[59].

Response Group

- *Medical Response Team* will provide medical evaluations and symptomatic treatment. The medical team will also assist with community education, case definition and identification, collect health data for public health officials and the CDC, and define research needs as necessary. During the event, the medical team may provide medical advice to response personnel as deemed necessary. During event follow-up, the medical team may also assist with surveillance, clinical characterization, and therapeutic guidance if indicated.
- *Wildlife Response Team* will consist of primary first responders and investigative experts to provide detection coverage, response, live animal care, and necropsy evaluations. The response will be scaled up from local response as the need arises and depending on the number of animals or species involved. In the case of endangered species, specific response efforts or mitigation measures may be implemented by the wildlife team.
- *Management Team* will be comprised of the relevant government officials and, is responsible for implementing official action on public water supplies, fishery closures, conducting product recalls, closure of recreational waters, postage of signage to protect public health, clean-up of beaches or shorelines, and possibly providing treatments to sick animals at rehabilitation facilities (see Wildlife Response Team).
- *Fisheries Team* will provide field support for detection, collection and assessment of the fishery situations including assessing fish kills and shellfish or benthic species mortalities, collecting live biota in areas of the HAB, and collecting diagnostic or control samples from biota as needed, using standard collection protocols. Samples will be used for toxicity testing, to assess the role and impact of the HAB in the mortality events, and for crop insurance follow up.
- *Environmental Data Collection Team* (HABs, water quality, satellite imagery**)** will collect appropriate water quality, habitat, and living resource samples on a scale appropriate for the event. This team will have multi-disciplinary components, some of which will be on site (or at the event) and others remote (even outside of the region or state). The team may also identify relevant historical data to compare and contrast impacts from the event and to determine potential causes or contributing factors.
- *Socioeconomic Data Collection Team* will compile sociocultural and economic data on resources, communities, and industries that are affected by HAB events on an on-going and consistent basis. Although this effort would not necessarily be a part of the rapid response to an individual bloom, it is important to determine the sectors or communities that are directly or

indirectly impacted. This would be most easily done during or just after an event.

Diagnostic Group

- *Analytical Lab Teams* (toxins, infectious pathogens, pathology) will provide the analytical support that is appropriate for the event, which may include toxin analysis, HAB species identification, histology and pathology, etc. They will be comprised of one or several existing entities within the region, including but not limited to state, Federal, academic, or private labs. The intent for all response efforts is to assign cause; therefore, a range of diagnostic tests may be conducted to determine the role of HAB toxins or other bioactive compounds (e.g., pesticides). This group might also collect unique data that could increase understanding and guide responses to future events.
- *Data Management Team* will have access to all the data involved in an event response (analytical, remote sensing, GIS, etc.) and may be comprised of one or more members within a region who have access to and familiarity with the most current GIS or other information in the region. This information may be in the form of existing state GIS inventories, or on-going research projects at state, Federal, or academic institutions. The team may also be required to collect and project emerging data from the HAB event in a form that is meaningful to other response team members.

Communication Group

- The *Communication Group* will convene trained risk communication teams, which are fully integrated into the event decision/management structure. The group may assess current information from the various response teams and, in consultation with key managers and decision makers, develop clear and concise messages, define the immediate status of the situation and potential impacts, safety precautions and other appropriate actions and disseminate the information to the media and public. Designing effective messages and strategies for delivering complex information to various stakeholders and the public requires a detailed understanding of the various target audiences. Effective messages must be built on audience knowledge, understanding, concerns, and needs with a goal of building trust in the HAB event managers and researchers.

Assessment and planning group

- The *Assessment and Planning Group* will provide a thorough analysis of the response to the HAB event. This may include, but not be limited to, an assessment of the potential event causes and contributing factors, both short and long-term impacts on human, wildlife and environmental health, how response to the event was handled from the tactical and strategic point of view with recommendations for improvements in efficiency and communication where appropriate. The group may also be responsible for conducting debriefings after the event to identify shortfalls, successes, and possible ways to improve future event responses. The team may also identify areas of research based on observations and data from the event. They may also identify new questions that have emerged during and after the event for potential HAB research.

A HAB Event Response Program is needed to augment the primary response responsibility that resides at the state, county, municipal, and tribal level for both coastal and freshwater HABs. By improving coordination between the Federal government and between those involved in HAB response and research within a specific region, this program will better utilize the existing infrustructure—speeding and improving response to HAB events around the Nation.

Chapter 4

Core Infrastructure Workgroup Report

By P. Glibert, G. Boyer, J. Ramsdell, K. Sellner, L. Backer, W. Carmichael, R. Dickey, C. Heil, B. Kirkpatrick, J. Kleindinst, G. Langlois, J. McDowell, K. Steidinger, M. Tamburri, and V. Trainer

4.A. Introduction

The past decade has resulted in tremendous advances in the community's understanding of HAB dynamics, from physiology and toxin expression to bloom transport and economic impact. The general increase in knowledge has been matched by rapid expansion in the capability for toxin and species detection using laboratory, hand-held, and in- and above-water technologies. Advancements in both basic knowledge and in methods and tools have led to significant new opportunities for furthering understanding and for protecting human health. However, as the field has matured, the infrastructure needs of the community have also increased. These core needs form the foundations upon which the science and its management applications depend. Many of the associated costs are far greater than can be borne by individual investigators or end-users. As described below, these needs cross-cut science and management and bridge individual agency interests. While in some cases they may intersect with the goals of other U.S. programs already in place, existing programs are inadequate to meet these requirements. The critical needs described below identify those intersections with an ultimate goal of growing a greater community through collaboration.

The Core Infrastructure needs were presented in detail in HARRNESS[2], the U.S. National Plan for HABs (Box 18), but the approach for specifically meeting these needs was not described. Specific approaches for meeting these needs are detailed to achieve three main goals: 1) insure availability of adequate analytical facilities, reference and

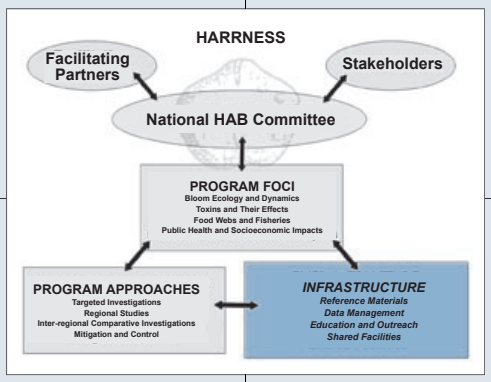
Box 18. Summary of infrastructure needs from HARRNESS[2].

Reference Materials

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

Data Management

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



Education and Outreach

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

Shared Facilities

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

research materials, 2) improve integration of HAB activities with existing monitoring and emerging observational programs, and 3) enhance mechanisms for communication and networking at the regional and national level. Herein we provide the details of how such needs should be met. Only by developing mechanisms for ensuring a strong core foundation can improved mitigation, control, prevention and education emerge.

4.B. Analytical, Reference and Research Materials

One of the most fundamental requirements for expanding frontiers of knowledge, assuring conformity of methods, and training new scientists and technicians is the availability of adequate analytical facilities and reference materials. Analytical facilities are essential for the development of new analytical methods and sensor technologies. They provide access to expensive equipment in situations where their individual purchase may not be justified, yielding an overall savings in community research funds. Toxin reference materials are highly purified toxins whose properties (i.e., mass, purity, stability) are sufficiently characterized to be used for the calibration of instruments, the assessment of methods, or for assigning concentrations to materials. Certification of a reference material establishes its accuracy within a stated level of confidence and is essential in the modern regulatory environment. Other research materials include items such as HAB cultures, isolated cell cultures, purified but not certified toxins, molecular probes, genetic material, and animal and human tissue samples. Shared research materials such as these are critical to develop and verify new techniques, assure uniformity of analyses, and allow retrospective analysis of HAB events as technology improves.

Training also plays an important role in basic infrastructure as a highly qualified workforce is essential to respond to HAB events. Training includes advanced courses, workshops, and mentoring opportunities. This training can be integrated with analytical facilities and repositories to provide specialized techniques involving instrumental methods and effective utilization of research material. Sponsored mentoring and career development awards are effective for more in-depth training, to rebuild expertise in disappearing skills such as taxonomy, as well as re-tooling established researchers to take on emerging technologies. Continual training assures maintenance and expansion of workforce skill sets and promotes succession and technical advancement necessary to continue to meet the expanding research and management needs of the HAB community.

4.B.1. Current Status

At present, several state, Federal, and academic laboratories routinely analyze water and tissue samples for the majority of toxins present in U.S. waters. Numerous additional laboratories can identify HAB species by microscopic and molecular techniques. Various laboratories provide services for ancillary water quality measurements. Academic, non-governmental organizations, and for-profit industries have the expertise and experience to design and operate fixed and autonomous HAB sampling and monitoring devices. Most of this capacity is adequate for routine monitoring within our existing regulations. However, existing resources are not necessarily adequate for event response, to meet new emerging regulations, or consistently available to all interested users. Existing opportunities to expand analytical infrastructure and instrumentation capability are few.

In terms of toxin reference materials, there are a number of current limitations. The U.S. National Institute of Standards and Technology (NIST) relies by informal agreement on the production of some HAB toxin certified reference materials by Canada's National Research Council Certified Reference Materials Program (NRC-CRMP). The NRC-CRMP certifies and distributes certified reference materials for many of the marine toxins and, over the last several years, has worked with HAB scientists in Australia, New Zealand, Ireland, and Finland to certify and distribute certified reference materials for additional marine and freshwater toxins. NIST provides mainly inorganic standards in the United States and has an informal agreement with NRC to avoid duplication of effort. Therefore, NIST does not produce or distribute

Box 19. The availability of selected marine and freshwater HAB toxins.

Toxin	Form of Toxin Available		Source	U.S. Need
	Certified/Standard Reference Material	General Reference Material		
Marine Toxins				
Brevetoxins (including PbTx-1,2,3,6,7,9 and some metabolites)	No	Some	Commercial	High
Ciguatoxin	No	Yes		High
Dinophysistoxins	No	No	available in tissue	
Domoic Acid	Yes	Yes	NRC, Commercial	
Okadaic Acid	Yes	Yes	NRC, Commercial	
Paralytic shellfish poisoning toxins (including saxitoxin, neosaxitoxin, decarbamoyl STX, gonyautoxins 1-4 and selected others)	Some (11 of 20 congeners)	Some	NRC, FDA	
Palytoxin	No	No		High
Pectenotoxin-2	Yes	No	NRC	
Yessotoxin	Yes	No	NRC	
Freshwater Toxins				
Anatoxin-a	No	Yes	Commercial	
Anatoxin-a(S)	No	No		High
BMAA	No	Yes	Commercial	
Cylindrospermopsin	Yes	Yes	NRC, EPA	
Microcystins (including microcystin LR, RR, LA, YR, LW and LF)	No	Yes	NRC, Commercial	
Saxitoxin	Yes	Yes	NRC, FDA	

HAB toxin certified reference materials. The U.S. EPA and FDA also have small programs to develop and validate analytical methods for certain cyanotoxins and, as part of these programs, provide certified or reference materials for a limited number of freshwater (microcystins, cylindrospermopsin) and marine (saxitoxin) toxins. However, standard reference materials are noticeably unavailable for several toxins, such as brevetoxin and ciguatoxins, limiting factors for both research and protection of human safety in some areas.

Culture and tissue collections represent another important source of core research materials. At present the National Marine Mammal Tissue Bank maintains the long-term storage of tissues from marine mammals and a number of harmful algal species are maintained at the Center for the Culture of Marine Phytoplankton (CCMP) and University of Texas Starr collection (UTEX). These collections are expensive to maintain and need to expand to accommodate the new HABS in U.S. waters. Many individual investigators maintain their own collections, but adequate staff

and facilities are not available to incorporate these cultures into the national culture collections, resulting in a critical lack of duplication as insurance against permanent loss of a culture. Determination of the genetic code and DNA sequences for several harmful algal taxa are underway; however, sequencing the total genome of most harmful algal species is still a future development to be encouraged.

Current training opportunities in HAB techniques in the United States are limited and have been available primarily through the international community. The UNESCO Intergovernmental Oceanographic Commission Harmful Algal Bloom Program offers regular training courses in identification/taxonomy and enumeration of marine HAB species. U.S. participation in many of these programs has been limited due to travel costs and their focus on non-U.S. issues. Although there have been a few laboratory training courses for toxin detection offered recently in the United States, in general, advanced training for instrumental methods, detection technologies, and species determination is largely unavailable, leading to a serious lack of national preparedness.

4.B.2. Proposed Approach

4 B.2.a. Analytical Facilities

Analytical facilities provide capabilities for method development and validation, analyses for regulatory action, and analyses in support of environmental monitoring and disease surveillance and research. Analytical facilities house a wide variety of instrumentation to perform analyses for toxins, algae, and environmental chemistry. Facilities also serve as venues for training and professional development, and communicating advances to networks of interested laboratories. Analytical facilities are critical in expanding the frontiers of knowledge, assuring conformity of methods, providing support for overflow analyses during unusual events, and to enhancing the skills of scientists and technicians that require access to state-of-the-art instrumentation.

Requested Infrastructure: The Core Infrastructure Program should establish a network of available analytical facilities, facilitate cross-laboratory validation of methods, and ensure that information and data are easily shared among facilities. Included in this would be an inventory and integration of existing facilities/programs, the capacity to respond to an HAB events of different geographic extents and of different priorities, and their ability to operate in a regulatory environment.

4.B.2.b. Analytical Instrumentation

Modern methods of analysis for HAB toxins and organisms often require highly specialized and expensive equipment. The demands for instrumentation and staff needed for regulatory monitoring can usually be predicted and incorporated into existing operations and maintenance budgets. However, analytical equipment needs to be continuously updated in academic, Federal and state laboratories. While smaller research instrumentation can be included in basic research and operations grants, some equipment costs are simply too large or too specialized to be borne through these existing funding systems. NSF has addressed this problem through their Major Research Instrumentation Program (http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5260). This program assists in the acquisition or development of major research instrumentation that is, in general, too costly for support through other NSF programs. Proposals may be for a single instrument, a large grouping of instruments, or multiple instruments that share a common or specific research focus. A similar mechanism needs to be established for equipment serving the HAB community. This equipment should serve the needs of multiple users, and the mechanism and support for its maintenance and proper operation should be determined at the time of acquisition. Examples of these types of equipment include, but are not limited to, high performance liquid chromatography equipment with mass selective detection needed for the separation, identification, and quantitation of toxins, scanning electron microscopes for identification of HAB species, and DNA sequencing instrumentation that forms the basis of the modern molecular nucleic acid-based

techniques. Providing for these basic instrument needs would also expand our research capabilities, increase our ability to respond to new and emerging threats, and serve a valuable function in augmenting our surge capacity in the case of a HAB or bioterrorism event response.

***Requested Infrastructure*:** The Core Infrastructure Program should establish an interagency competitive extramural funding program that would allow state, Federal, and academic researchers to obtain major equipment needed to update and replace capital instrumentation necessary for HAB research and monitoring, modeled after the similar NSF program.

4.B.2.c. Toxin Reference Materials

Different grades of toxin reference materials are needed, depending on the specific application. Reference and certified reference materials are defined by the International Organization for Standardization (ISO/IEC, 1993). The U.S. NIST refers to reference materials and standard reference materials with the same definition. For the purposes of marine and freshwater toxins, standard reference materials are highly purified toxins whose property value(s) (i.e., mass, purity, stability) are sufficiently homogeneous and well established to be used for the calibration of an apparatus, the assessment of a measurement method, or for assigning concentrations to materials. Certification of a reference material establishes traceability to it for accuracy determination with a stated level of confidence. Toxin reference materials are essential for calibration of analytical measurement of toxins and the validation of new liquid chromatography-mass spectrometry (LC-MS) methods, which are cornerstones for the confirmation of toxins where certainty is absolute, such as regulatory decisions. These materials require the highest amount of effort, often involving multiple methods for purification, characterization, and certification. They are the most expensive but are also utilized in small unit quantities.

Purified freshwater and marine toxins without the requirements for standard and certified reference material, described here as general reference materials, are also a critical component of HAB studies. General reference materials may require a high degree of purity but require a lesser degree of certification and their cost is correspondingly lower. They are typically used in test kits, whole animal toxicology studies, pilot studies of fate and removal in water treatment processes, where large quantities of material are needed. Some applications may not require the same degree of purification as others, but all require a certain level of chemical characterization. General reference materials are not provided through the NRC-CRMP, but are available in limited quantities through a number of commercial suppliers. Unfortunately many of these toxins become commercially available only after a health event has stimulated the demand for these toxins. This limits the development of analytical methods and the basic health data needed to properly respond to the event. A current example of this type of compound is palytoxin where the development of new analytical methods and determination of its biological effects and metabolism are needed to determine if it is a health threat. Other examples of such priority toxins at this time include ciguatoxin (Pacific and Caribbean origin), selected brevetoxins from algae (PbTx-3 and PbTx-7), brevetoxin metabolites from fish or shellfish, and the freshwater toxins anatoxin-a and anatoxin-a(S) (Box 19).

***Requested Infrastructure*:** The Core Infrastructure Program should continue collaborations with Canada's NRC-CRMP to provide the U.S. HAB community with certified analytical standards. The United States should identify an institution that can serve as an alternate in the event that NRC is no longer able to provide certified toxin standards in the United States. Funding mechanisms are needed for (1) the initial bulk production of the toxins by contributing organizations; (2) initial testing by NRC and the certification process; and (3) distribution and replacement costs to ensure an uninterrupted supply of toxins.

***Requested Infrastructure*:** The Core Infrastructure Program should establish a procedure to make available bulk toxins for

methods development and animal exposure studies. This should include a mechanism for identifying toxins for production with an emphasis on eliminating current roadblocks to research and development of our understanding of HABs, as well as an effort to predict future health and safety needs. A mechanism for funding the preparation of limited amounts of bulk toxins to ensure availability of materials should be in place. These materials may also serve as a source for the certified reference material program

4.B.2.d. Culture collections

Culture collections serve as the repository of living organisms. The two main culture collections for algae in the United States are the CCMP (The Provasoli-Guillard National Center for Culture of Marine Phytoplankton) and UTEX (The Culture Collection of Algae at the University of Texas). These national collections are complemented by many individual investigator collections and international culture collections (e.g., UTCC or University of Toronto Culture Collection of Algae and Cyanobacteria). Maintenance of these culture collections and the sharing of these resources are expensive. These national and regional culture collections must be maintained and new technologies for preservation of viable cells (i.e., cryopreservation) and networking to facilitate sharing of HAB organisms must be developed. Cryopreservation (or similar technology) is essential for ensuring not only longevity of cultures but genetic integrity of algal isolates. Sharing of collections, either individually or through CCMP, is encouraged through some funding programs (e.g., ECOHAB), but missing is an inventory of the many smaller culture collections maintained by individual investigators. Future Federal funding opportunities may wish to include language that will assure depositing of cultures in national collections. However, the additional demand from depositing cultures into national collections such as CCMP or UTEX will require more support to maintain these collections. Policies for distribution, accessibility, and survivability of these existing collections are a critical need to ensure their viability and harmful algal culture availability in the future. Some cultures, such as *Pfiesteria*, for example, create additional complexities for maintence as they are not true "algae" and must have additional substrates to grow beyond standard media. These species also have quite different physiological properties when maintained on different substrates.

***Requested Infrastructure*:** The Core Infrastructure Program must ensure sufficient support is available to allow national collections, such as the CCMP and UTEX, to acquire and maintain HAB isolates by supplementing the NSF Living Stock Collections Program (http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=9189). Small regional and species specific culture collections also require support where unique growth requirements prevent routine culture maintenance in the national collections. Support must also be provided for long term maintenance of collections through cryopreservation and other developing technologies.

***Requested Infrastructure*:** The Core Infrastructure Program must encourage investigators to isolate and deposit new HAB organisms in these culture collections and to submit the appropriate metadata regarding their original isolation. Policies are needed to reward these efforts and to address the intellectual property issues regarding patenting organisms that might restrict their scientific use.

4.B.2.e. Molecular Techniques and Associated Databases

Molecular techniques are the basis of the modern scientific revolution. They include techniques for the detection and identification of organisms through their nucleic acid (DNA or RNA) signatures, techniques for determining which members of a community contain the genes responsible for toxin production or other metabolic pathways, as well as the use of modern techniques for the determination or detection of toxins and organisms. Existing funding programs (e.g., ECOHAB, OHH programs, and MERHAB) may support the development of these molecular probes

and assays; however, the training, validation, and technology transfer associated with their operational use (e.g., in public monitoring programs) is generally outside the scope of individual grants. Individual investigations can often provide considerable information on specific genes and targets; however, a more complete understanding of those factors affecting toxin production may be obtained through sequencing of the entire genome, or in the case of organisms such as dinoflagellates whose genomes may be too large to sequence directly, through the use of expressed sequence tags (ESTs).

***Requested Infrastructure*:** The Core Infrastructure Program must ensure sufficient support is available to advance our understanding of the molecular basis of toxin production and identification of HAB species. Policies are needed to address the intellectual property issues regarding patenting organisms and their genomes that might restrict their scientific use and to reward investigators for depositing DNA, RNA, and protein sequences from harmful algal species in the national and international databanks.

4.B.2.f. Tissue Collections

Separate from the reference materials associated with the HAB toxins and toxic organisms are the tissues from species exposed to HAB events. HABs directly impact both human and environmental health in complex ways. Assessing these impacts requires evaluation of complex physiological interactions in a variety of different tissue matrices (e.g., blood, muscle, gut, brain, liver, lung) to assess the environmental impacts of exposure to the toxins. The collection and archiving of both clean and contaminated animal and human tissue samples is a major need (Box 20). Currently, national repositories for such tissues are limited, and include the National Marine Mammal Tissue Bank, which maintains the long-term storage of tissues from marine mammals for retrospective analyses, the National Biomonitoring Specimen Bank and the Marine Environmental Specimen Bank. These latter two repositories are maintained by NIST. Other examples of tissues needed for HAB research include fin fish tissues collected from different regions (both toxic and nontoxic), certified contaminated shellfish (e.g., NRC-CRMP MUS-1 domoic acid-containing mussel tissue), clinical samples, etc.

Box 20. Purpose of specimen banking.

The NIST website explains "*environmental specimen banking is the long-term preservation of representative environmental specimens for deferred analysis and evaluation. A systematic well-designed specimen bank program is not only a valuable component of real-time monitoring and basic research, but it also enables investigators to extend their research into the past and provides for future verification of analytical results. Formal environmental specimen banks are recognized internationally as integral parts of long-term environmental monitoring and research.*" http://www.cstl.nist.gov/projects/fy06/ee0683908.pdf

***Requested Infrastructure*:** The Core Infrastructure Program must identify both a hosting agency (i.e., repository) for these materials and mechanisms for long-term, sustained funding to support HAB-related human and animal tissue banking.

***Requested Infrastructure*:** The Core Infrastructure Program must provide for tissue repository(s) that include well established banking protocols, a chain-of custody system, maintenance of associated sample data (both metadata and associated environmental and toxin data), appropriate facilities for long-term storage and security, protocols for sample provision, and data sharing.

***Requested Infrastructure*:** The Core Infrastructure Program must also provide a mechanism to promote participation in human and animal tissue banking programs.

***Requested Infrastructure*:** The Core Infrastructure Program must encourage the development of appropriate partnerships and cooperation at the state, Federal, and international community levels. CDC and FDA are important Federal partners in this activity, particularly in the collection and deposition of human clinical samples.

4.B.2.g. Training

The need for short term and comprehensive training was recognized in HARRNESS[2] to ensure the next generation of HAB taxonomists, ecologists, and chemists. Specific training is needed in identification of HAB species as well as use of analytical instrumentation, molecular and chemical techniques, and field sampling methodology. In addition, advanced training is needed in other areas such as the handling and interpretation of continuous data, visualization techniques (GIS, remote sensing imagery), design and development of analytical methods, and statistical interpretation of information. Training courses, where appropriate, may also provide certification in these techniques to ensure compatibility between operators and laboratories.

Under the umbrella of training are included short term and advanced courses, workshops, and mentoring. Specific training opportunities should, in some cases, be integrated with the regional analytical facilities and repositories to provide specialized techniques involving instrumental methods and effective utilization of research material. Training developed in conjunction with national symposia maximizes the transfer of knowledge from experts on particular subjects of interest to the HAB research community. Sponsored mentoring and career development awards are effective for more in-depth training (e.g., NSF's Partnerships for Enhancing Expertise in Taxonomy or PEET), to rebuild expertise in disappearing skills (such as taxonomy, including morphology, ultrastructure, chemical constituents, and genetics), advancing capabilities in remote sensing data interpretation and visualization, as well as 're-tooling' established researchers to take advantage of emerging technologies. Having an established training infrastructure assures maintenance and expansion of these skill sets and promotes succession and technical advancement necessary to continue to meet the research needs of the HAB community as well as the needs of public officials in safeguarding public and coastal living resource health. Taxonomists with expertise in both molecular and classical techniques are essential to ensure continuity and expertise in support of future HAB research and monitoring to protect our coastal populations.

***Requested Infrastructure*:** The Core Infrastructure Program must encourage technology transfer through the use of training in areas such as instrument and analytical techniques, taxonomy, and molecular identification of HAB species. This would include, but not be limited to, short training workshops located in the United States, longer academic courses, professional mentoring (similar to PEET), and participation in workshops.

4.B.2.h. Standard Operating Procedures and Interlaboratory Validations

Multiple analytical facilities and personnel require extra care to ensure results are comparable with other agencies and facilities. Method validation, standardization of procedures, and inter-laboratory calibration are all procedures to ensure compatibility of results and creation of shared data bases. Comparisons must be made across different regions, HAB toxins and tissue matrices. Smaller scale validations may also be required to address factors such as extraction efficiency and matrix interference. The end results of these efforts should be readily accessible to all and in a format where amendments can be incorporated and notes on their use can be shared between analysts.

***Requested Infrastructure*:** The Core Infrastructure Program should establish at least one validated method for each toxin of importance in the United States. Some methods may need to be validated for a single application while others may be useful across multiple sample types. These studies should include toxin preparation, matrix preparation, distribution, and data analysis. Use of these applications in different circumstances may require amendments to ensure these methods are valid and acceptable for their end application.

***Requested Infrastructure*:** The Core Infrastructure Program should establish standard operating procedures for collection and detection of all HAB toxins. In addition, mechanisms to provide funding for inter-laboratory

performance exercises are needed to ensure different analytical facilities are conducting measurements on common toxins, algal species, and environmental indicators within acceptable limits of confidence.

4.B.2.i. Maintenance of and Access to Long Term Monitoring Databases

Databases are collections of related records, data, and/or pieces of information that serve as the backbone of our understanding of HABs and their impacts (Box 21). They identify experts, assess long-term trends in occurrence in space and time, indicate impacted wildlife or human populations, record impacts by harmful algae/toxins, elucidate the socio-economic effects of toxin exposures, and provide distribution maps for HAB events. The design, construction, population, and maintenance of databases is a complex infrastructure task involving database design, data compilation, technology transfer between multiple platforms (e.g., data in hardcopy, multiple database programs), documentation of data quality and techniques (metadata), and the design of appropriate user interfaces. Older data sets often present a special problem because access may be limited due to storage in outdated data structures, even though they contain irreplaceable information, especially in terms of current issues of global and long term climate change.

For the HAB community, the database infrastructure should include a readily available network of national information, analytical facilities, repositories, wildlife and human health disease registries, historical HAB records (and associated data), and socio-economic factors associated with HAB events. Expanding community access to other data sets is becoming increasingly important to compare responses to similar events across the Nation. Issues associated with handling data are more complex than ever before, with vast quantities of data being collected at tremendous rates. Some of this data collection may fall under the guise of Data Management and Communication (DMAC) and IOOS. However, HAB relevant issues will require specific input by the HAB community. Care needs to be taken in moving forward to ensure that "new" data are in a format compatible with the new data storage system and are accompanied by the appropriate metadata. The U.S. National Office of Harmful Algal Blooms at the Woods Hole Oceanographic Institution currently maintains several HAB-related databases (experts, maps), and a variety of species-specific HAB databases are maintained by state agencies responsible for HAB monitoring (e.g., Florida HAB Historical Database, Maryland Department of Natural Resources). The CDC also has initiated a HAB-related illness surveillance system (HABISS) for reports of HAB-related illnesses. Other international HAB databases include the global network for hazard management of cyanobacterial HABs (CyanoNet, http://www.cyanonet.org/) and the Intergovernmental Oceanographic Commission's Harmful Algae Event Data Base for the North Atlantic and North Pacific (http://www.iode.org/haedat/).

Box 21. Importance of public data.

"*Science thrives on open access to compilations of data in electronic or other databases*" [60]

***Requested Infrastructure*:** The Core Infrastructure Program must coordinate with existing programs to ensure continued access and maintenance of existing databases. Mechanisms to do so may include a technical advisory committee under the NHC to determine how and if long-term HAB-related databases currently in existence should be maintained, and, perhaps, through long-term support for the National HAB Office.

***Requested Infrastructure*:** The Core Infrastructure Program must ensure that other databases such as tissue banks, culture lists, analytical services, socio-economic data, and wildlife and human health impacts are also compiled and linked to these established national and regional sites.

4.C. Monitoring and Emerging Observational Programs

Field monitoring is increasingly being conducted from buoys, airborne or satellite remote sensing, ships, ferries, and high frequency radar arrays.

Box 22. Maryland Chesapeake Bay monitoring and assessment of HABs and environmental conditions.

Maryland Department of Natural Resources (MD DNR) is responsible for the long-term comprehensive Chesapeake Bay Water Quality and Habitat Monitoring Program. In 1997 a toxic outbreak of *Pfiesteria piscicida* occurred on Maryland's lower Eastern shore with estimated economic losses of over $40 million dollars to the seafood, fishing and tourist industries. In response to the outbreak, NOAA awarded MD DNR a MERHAB grant over a 5-year period to implement a HAB monitoring program.

In 2005, Maryland legislated and implemented a Targeted Watershed Restoration Program to restore the Corsica River, a tributary of the Chester River on Maryland's upper Eastern shore that is highly eutrophic with persistent algal blooms, low D.O. and in the fall of 2005 and 2006, fish kills of over 30,000 dead fish. Through DNR's HAB monitoring program, the fish kills were attributed to *Karlodinium veneficum* and low D.O.

MD DNR, in an effort to conduct a highly focused study of the Corsica River and its water quality problems and with the integration of various partnerships including coordination with the University of Maryland's Horn Point Laboratory, is conducting intensive water quality, habitat and plankton monitoring using new innovative technologies, developed through State, federal (NOAA MERHAB and ECOHAB) and local partnerships. These new technologies for spatially intensive water quality mapping and temporally intensive real-time monitoring of nutrients and physical parameters provide the data required by the research community and state agencies to ensure a coordinated response, understand bloom ecology and dynamics and to determine potential causes of the *Karlodinium* bloom and related fish kill. These new monitoring technologies have provided key nutrient results on a scale previously unattainable through traditional monitoring efforts and that address the immediate nutrient and water quality dynamics preceding bloom conditions.

Although much has been learned over the previous 2-year study, restoration strategies are not fully implemented and the nutrient inputs and water quality conditions have changed little over the time period. Furthermore, due to resource limitations, MD DNR will not have sufficient resources to continue the level of algal bloom assessments developed and conducted by the research community, limiting the capability to address potential bloom prevention strategies.

Much of this network will be part of the newly emerging observing systems such as the IOOS, Ocean Observations Initiative (OOI), and the Global Ocean Observing System (GOOS) which list HABs as a priority area of concern. This suite of observations can provide information on the environmental conditions favoring, accompanying, or inhibiting harmful algal species and their toxin expression. Monitoring for HABs and their adverse effects on humans and wildlife provides the foundation for operational modeling and forecasting and, when appropriately condensed and interpreted, can then be used to improve predictions of HAB events, promote mitigation efforts, and reduce public health risks.

4.C.1. Current Status

Many local "observatories" now exist that focus on routine water quality measurements of conductivity, salinity, temperature, dissolved oxygen (DO), currents, incident light, fluorescence, and in some cases, nutrients. These can be associated with mobile platforms, such as standard monitoring programs with ship-board horizontal and vertical sampling (e.g., Chesapeake Bay monitoring program, Box 22), but an expanding mobile autonomous system is currently being developed at specific sites along the U.S. coast. Several of IOOS' stated goals including mitigation of the effects of natural hazards are to reduce public health risks, to sustain and restore living resources, and to preserve and restore healthy ecosystems.

The IOOS system is divided into nine regional associations that span all the major coastal zones including the Great Lakes. These regional observing systems often form the basis of both operational monitoring and forecasting models. For example, there are well established, routine water quality (Maryland, Virginia, Texas, California, New York, and Michigan), plankton (Maryland, Virginia, Texas, Florida, New England States, Vermont, and Washington), shellfish (New England States, Florida, California, Oregon, and Washington), and marine mammal monitoring programs (California and Florida) along the U.S. coast and the Great Lakes. Several states have established human HAB-related disease surveillance and reporting protocols. Results from monitoring programs are often used locally

and/or regionally for describing recent HA events and, less frequently, for forecasting future blooms or exposures. In the Gulf of Mexico, chlorophyll anomalies (deviation from monthly mean conditions) are used to assist Florida field teams in locating focused monitoring for *Karenia* along the coast and using regional wind fields, projecting landfall from Florida to Texas (Box 10). In Maryland, nowcasts of *Karlodinium* distributions are now in place, derived from temperature and salinity ranges for the Bay's population, and summer cyanobacteria bloom forecasts are distributed throughout the regional community. In the Gulf of Maine, a biophysical model of the region has been excellent in hindcasting past blooms of *Alexandrium*; forecasting, the next step, has been in demonstration mode since 2005 and is also proving successful. Indeed, a successful prediction of a major regional bloom of *Alexandrium* was made in 2008. In the Pacific Northwest, landfall predictions of domoic acid-rich *Pseudo-nitzschia* appear more promising with continued field data collection and modeling studies. In addition to these large observing systems, numerous smaller freshwater observatory systems exist in states such as Nebraska, New York, and California. These multiple smaller systems need to be integrated into larger networks, perhaps through developing observatories such as National Observatory Network (NEON), Consortium of Universities for Advance of Hydrologic Services (CUAHSI), or the regional IOOS associations.

4.C.2. Proposed Approach

4.C.2.a. Observing Systems

A fundamental component of observing systems are the in-water data collection resources (platforms and instruments). Development and maintenance of these networked observing platforms and instruments are costly and such capabilities are currently being developed by various groups, agencies, and organizations. HAB observing efforts should be integrated with these existing and developing state (e.g., continuous monitoring), regional (e.g., Great Lakes Observatory System), and national (e.g., IOOS, Ocean Observatories Initiative (OOI), NEON, CUAHSI, Long Term Ecological Research (LTER) networks, and NERRS environmental efforts. In fact, many such efforts such as the NOAA-led IOOS and NSF's OOI currently list ocean and human health issues, specifically HABs, as a priority focus for their observing systems (Box 23). Key to the successful integration of HAB-

Box 23. Developing observing systems have identified HAB monitoring and prediction as a significant benefit.

"Identify decision processes and critical information gaps experienced by coastal public health officials that could be filled by the Integrated Ocean Observing System, with a specific focus on reducing the risk of illness or injury from direct human exposure to coastal waters from:
a. Microbial pathogens
b. Marine biotoxins and harmful algal blooms (HABs)
c. Emerging coastal public health threats"

Ocean.US 2006[61]

"*Enhancements to coastal observing systems could improve our response to episodic, deleterious events, such as harmful algal blooms of Florida red tide, toxic diatoms in California, and* Pfiesteria *in the Mid-Atlantic region. These events can pose risks to humans and marine life, and public concerns regarding recreation and seafood consumption can cause substantive economic impacts even if the risks are not realized. A robust, integrated observing system would allow advance preparation where the risks are real and reduce costly overreaction where they are not.*"

Ocean.US 2006[62]

"*Monitoring technologies that can be stationed in aquatic environments and continually measure for HABs are urgently needed.*"

US Commission on Ocean Policy[63], p. 345

"*While these lists provide a starting point for further discussion, many of the items included are actually broad categories rather than specific variables to be measured. The lists do not specify which variables can be measured with current technologies, which particular contaminants and pathogens should be observed, or which sets of observations can be assimilated to predict potentially hazardous environmental conditions, such as harmful algal blooms.*"

US Commission on Ocean Policy[63], p. 400

targeted observing systems into this network is for the HAB community to provide greater input into the location and decision-making process for these existing/developing systems, both at the national organization level (e.g., National Federation of Regional Associations and Ocean. US) and at the regional level (e.g., individual LTER sites and IOOS Regional Associations).

An effective HAB observing system will include the transfer or incorporation of novel HAB-specific sensing technologies into operational use. Laboratory-based protocols for species and toxin detection are now routine and efforts to shift these technologies to in-water platforms are in progress. While there are several existing programs focused on this technology development and transfer process (e.g., ECOHAB, MERHAB, Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET), NSF, Small Business Innovation Research), a clear need for facilitating the final step of technology adoption and movement through the high capital-demanding commercialization phase ('Valley of Death"; see Chapter 2) into operational use still remains. Specific mechanisms need to be identified to facilitate the inclusion of emerging sensors into HAB observing systems. In particular, partnerships with organizations such as the Alliance for Coastal Technologies to foster the further development, user training, and third-party evaluation of HAB-specific sensors, and participation in national testing activities such as the EPA Environmental Technology Verification testing program, are appropriate. Once effective and reliable sensors are identified, funds must be designated for their purchase, operation, and maintenance as part of routine infrastructure so that they can be incorporated as routine tools in our nationwide observing system.

***Requested Infrastructure*:** The Core Infrastructure Program must foster active collaboration with existing and developing observatory programs at the local, state, regional, and national scale.

***Requested Infrastructure*:** The Core Infrastructure Program must identify mechanisms for a competitive, peer reviewed sensor development program designed to provide HAB sensors for platform deployment across freshwater and marine systems (see Phase 1, Chapter 2).

***Requested Infrastructure*:** The Core Infrastructure Program must foster methods for the development, testing, and deployment of in-water sensor techniques for routine operational use in most monitoring and observatory programs (see Phase 2, Chapter 2).

***Requested Infrastructure*:** The Core Infrastructure Program must identify and encourage commercial production and subsequent routine deployment and maintenance of validated algal/toxin sensors (see Phase 3, Chapter 2).

4.C.2.b. Operational Monitoring and Forecasting Systems

Water quality monitoring networks are now well established throughout many states and regions. The next step is to use this information to develop regional operational forecasts. These forecasts represent a new and highly valued product combining basic HAB research and operational monitoring, with the expansion of HAB forecasting to include health and socio-economic impacts as a desired outcome.

New data inputs to these operational monitoring and forecasting systems are continually being developed, both through expansion of some existing routine monitoring programs such as the NERRS, the developing observatories in IOOS, CUAHSI, NEON, and LTERs, as well as through basic research programs funded by ECOHAB and MERHAB. Initial development and deployment is largely through partnerships among state resource managers, academic researchers, NOAA operational buoy managers, and some industrial partners. In the future, however, long-term maintenance of the platforms and sensors as well as continuous distribution of data and associated derived products may need to be shifted from academic institutions to state, Federal, or private entities to ensure continuous support for maintenance and data management.

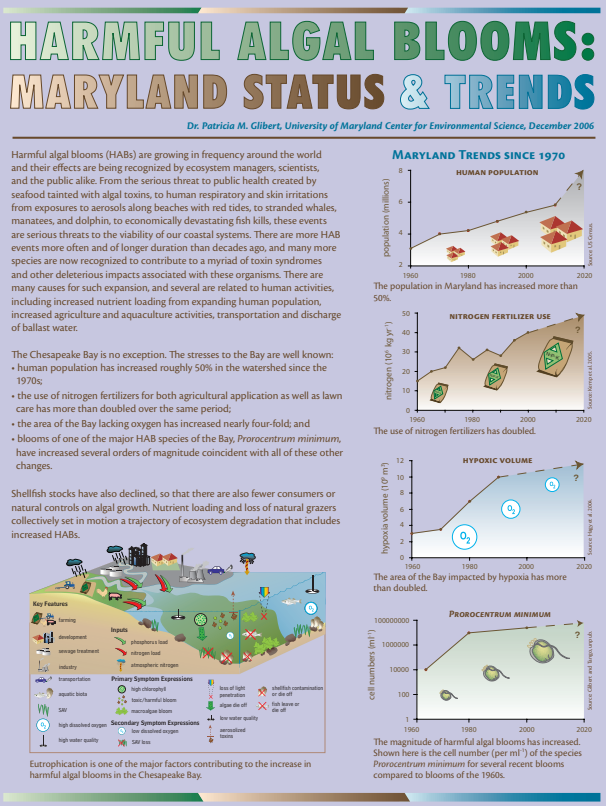
Finally, once in place, long-term support should be guaranteed for routine production of the user-identified and, therefore, valued forecast products. Routine delivery of these products assures local acceptance and use, thereby potentially focusing monitoring in spatially explicit areas and reducing unnecessary costs for monitoring over large numbers of lakes or coastline. As forecasts and models are developed and/or enhanced, public frustration with HAB events may decrease as stakeholders are able to make informed decisions. These new tools will connect the HAB science community, resource managers, the healthcare community, and the general public in providing the information needed to make informed decisions at all levels.

***Requested Infrastructure*:** The Core Infrastructure Program should identify existing and planned monitoring and observatory programs and data sets for potential use in developing HA forecasts. This may be best addressed at the regional level where watershed to coastal ocean linkages and associated models are generally in place/ available.

***Requested Infrastructure*:** The Core Infrastructure Program should strongly encourage adoption and use of standard data management formats, such as the IOOS Data Management and Communwications (DMAC), to assure compatibility across developing national and international programs. Design of data streams and model development compatible with future operational forecasts must be encouraged.

***Requested Infrastructure*:** The Core Infrastructure Program, in collaboration with the PCM program (Chapter 2), must identify mechanisms for long-term support for assuring technical transfer of developed models and forecasts to states and regions for their operational use in managing coasts and lakes to minimize the health and ecosystem risks associated with HAB events.

Box 24. Newsletters such as this one on Maryland HAB trends are useful in conveying information to general audiences.



http://ian.umces.edu/pdfs/iannewsletter16.pdf

4.D. Communication and Networking

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

pretest studies, and field surveys) to develop effective messages and delivery mechanisms integral to education and outreach efforts.

4.D.1. Current Status

Communication between agencies, investigators, regulators, and stakeholders is essential not only for a coordinated and well managed response to HAB events, but also for an increased general awareness of HABs. This communication can be developed and fostered through newsletters (Box 24), websites, working groups, as well as other forums. The HAB community is fortunate in that some of this basic infrastructure is already in place. HARRNESS[2] specifically called for the establishment of a National HAB Committee to encourage and foster communication between researchers and end-users. With support from NOAA's CSCOR, the U.S. National Office for Harmful Algal Blooms maintains a basic website (http://www.whoi.edu/redtide/) that provides information and a national focal point for HAB communication. This site is supplemented by a number of excellent local and state sites that focus more on particular issues or regions. In addition, most of the Federal programs such as ECOHAB and MERHAB also maintain websites to disseminate information and findings about their individual programs.

4.D.2. Proposed Approach

4.D.2.a. Communication

Communication efforts must address four main user groups: the public, the HAB community, public health and natural resource health managers, and the media. Coordinated and informative delivery of easily understood scientific information to the public, local government, commercial, and medical communities is essential to effective, smoothly run HAB response policies along our coasts. Implementation of social science methods promotes effective information transfer mechanisms to alter local behaviors. Engagement of local leaders and community members through multi-ethnic broadcasts, local government assurances, hotel and restaurant distribution of alternative tourist activities for short-term beach closures, the development of clinical information (e.g., case definitions, treatment regimens) will assure communication coverage to groups in greatest need. The emphasis of communication will be to utilize and build upon existing regional websites for access and distribution of information while also providing a coordinated effort for HAB event response. The sharing of accurate, understandable, and useful information will help avoid duplication and conflicting messages. Evaluation and design of regional websites need to take advantage of current knowledge of effective and successful models of electronic-based outreach.

***Requested Infrastructure*:** The Core Infrastructure Program should coordinate with the event response program in working with states to assist in establishing communication lines and links for conveying information on HABs and specific HAB events within and among regions. This coordination should take advantage of existing conduits through state and various extension agencies (e.g., Sea Grant and Land Grant Colleges).

4.D.2.b. Cyberinfrastructure

"Cyberinfrastructures" are networks, generally via the internet, of advanced data acquisition, data storage, data management, data integration, data mining, and data visualization tools and capabilities. They can be conceived of as comprehensive digital capabilities for advanced levels of computational, storage, and data transfer capacity. HAB cyberinfrastructure should be designed to minimize institutional and user infrastructure tensions and to optimize existing regional associations and communities. The cyberinfrastructure network would incorporate the operational regional associations (e.g., Great Lakes, Northeast, Mid-Atlantic, South Atlantic/Caribbean, Gulf of Mexico, Midwest, California Pacific Northwest, Hawaii, and territories) while also eliminating geographic constraints through direct connection of their distributed resources (e.g., culture facilities, repositories, analytical facilities, operational monitoring plateforms, observatories, education, and outreach efforts).

Requested Infrastructure: The Core Infrastructure Program should develop a program following the model of the NSF Office of Cyberinfrastructure to provide guidance for a HAB-related cyberinfrastructure.

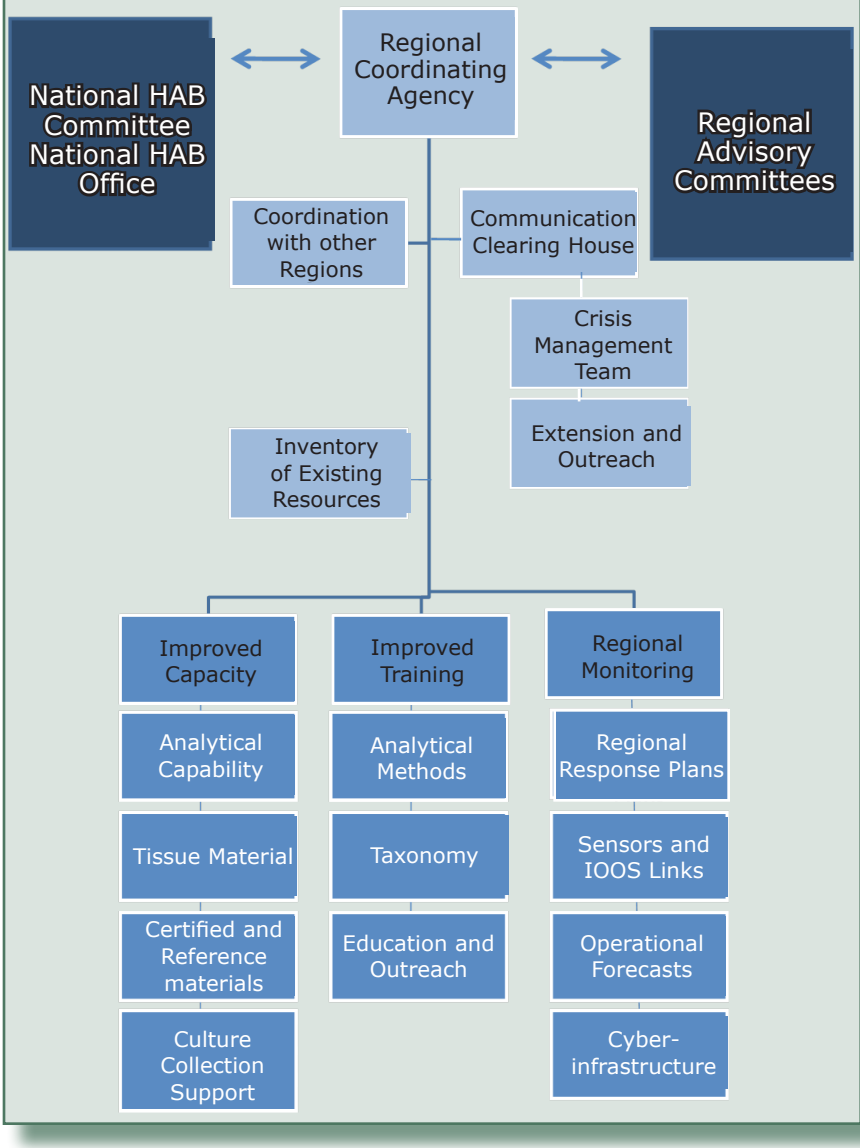
4.E. Developing the Core Infrastructure Program

The numerous specific needs detailed above can be addressed through two specific implementation actions. These are:

- **Action**: Develop an inter-agency funding mechanism that will support the Core Infrastructure needs outlined above, including, but not limited to:
  - Purchase of analytical equipment
  - Development and validation of standard operating procedures and intercalibration exercises
  - Support for maintenance and expansion of the national culture collections
  - Preparation of certified and general reference materials
  - Preparation of bulk certified toxins
  - Long term storage of tissue collections
  - Training workshops and higher education.
- **Action**: Develop regional networks to leverage existing resources, encourage coordination and foster active communication with users and stakeholders within the region and between regions. The regional networks will be linked through National Coordinators for freshwater and marine HAB infrastructure. Funding will need to be provided to support national and regional coordinations and the development and maintenance of these regional entities.

Regionally coordinated networks for marine and freshwater HAB infrastructure, such as illustrated in Box 25, require National Coordinators in appropriate agencies (such as NOAA and EPA) who will work within both new and existing regional resources and communication capacities to provide inventories, updates, and contact information to users in the region (see Chapter 3). This lead will maintain an active link to, and coordination with, other regional programs such as Sea Grant extension and outreach. He/she will

Box 25. Diagram of Core Infrastructure Program.



also interact with the National Coordinator for the regional Event Response Program to ensure access to, and familiarity with, resources and capacities of the region that can be mobilized for a HAB event. Regional Coordinators and a Regional Advisory Team of scientists, managers and industry representatives will regularly interact with the National Coordinator to further guarantee focused regional resource recognition. At the national level, the National and Regional Coordinators will interface with the NHC to continue to identify needs for the community as well as new partnerships enabling leveraging of all resources. Because of the similarity in structure and function between the national and regional networks for infrastructure and event response, the functions of the National and Regional Coordinators can initially be combined for the two programs, and if the programs expand as the need arises the functions can be separated.

In sum, the national capacity for harmful algal research, development, demonstration and technology transfer will be greatly advanced with additional resources for core infrastructure and through enhanced networking and leveraging of existing resources through regional associations.

Chapter 5

Implementation Plan

By D.M. Anderson

5.A. Steps for Implementing the RDDTT Program

The proposed RDDTT Program is comprised of three components: 1) a component for HAB PCM, 2) an Event Response component, and 3) a Core Infrastructure component. The need and community readiness for each of these components varies with the status of currently existing research and the planning required for each activity. The RDDTT program can, therefore, be implemented in stages corresponding to the reauthorization of HABHRCA every five years, with projected funding needs increasing as the different components mature (Box 26.). The prevention, control, and mitigation (PCM) component is the central element of the RDDTT Program because it is only through PCM that the grave risks posed by HAB expansion can be successfully confronted in the long term. Thus, in the first stage (FY 09-FY 13), the greatest emphasis is on developing the PCM component because many promising technologies, developed through other HAB research programs, are ready to be transitioned to operational use. Since Core Infrastructure and Event Response are integral to developing HAB response, these programs should be initiated in the first five years, but full implementation can develop over the next five year reauthorization (FY 14-FY 18) based on the experience and plans developed during the first five years.

Implementing an RDDTT program will be more likely to be accomplished if the program is formalized through authorizations and appropriations. Wording changes are needed in the next HABHRCA reauthorization that specifically identify an RDDTT program in NOAA with the above three components and projected funding targets, as described in Box 26. Since many agencies, such as EPA, NSF, FDA, NASA, ONR, CDC, NIH, USFWS, USDA, and USGS, are also involved in HAB research and response[1], it will be necessary to specify that the RDDTT Program is an interagency program and funds be appropriated to facilitate the participation of other agencies.

The Freshwater HAB Report[13] notes that most freshwater HAB research and response is conducted as part of other programs, and there are no programs dedicated to improving response to freshwater HABs. NOAA has a geographic mandate that only includes marine coastal waters and the upper reaches of estuaries, and the Great Lakes. Many freshwater HAB problems fall outside these boundaries and, therefore, parallel programs will need to be authorized and funded in an agency with an appropriate mandate, such as the EPA. Separate authorizing legislation is required to establish freshwater HAB programs because NOAA and EPA are under the purview of different Congressional committees, and separate appropriations are also required. Because freshwater HABs are a problem in nearly every state in the United States[13], a freshwater RDDTT program needs to be funded at the same levels as the marine RDDTT program (Box 26).

Although the RDDTT will be the program that the public will most readily perceive as 'progress' in the management of HABs, it is part of an integrated approach to HAB risk management that includes other research and response programs. Thus, it is essential that the RDDTT program be established as a separate program, with the expectation that other research and response programs will provide the innovative new technologies and approaches as well as the ecological and oceanographic context to guide its practical and applied activities. Funding to implement the entire RDDTT program over the next five years (FY09-FY13) is roughly projected

to be equivalent to that of the ECOHAB and MERHAB Programs (Box 26).

5.B. Prevention, Control and Mitigation

The PCM component is designed to bring technologies for HAB prevention, control, and mitigation from initial, conceptual stages to full operational use through a three-phase program. The first phase, that of development and proof of concept, will require significant funding early in the program that is sustained through time to keep the flow of ideas and technologies moving into the other phases of the PCM program. Initial funding for Phase 2 and 3 projects (i.e., pilot-scale studies and major demonstration projects respectively) will be low in the early stages of the program but will grow significantly through time. It is likely that more projects will enter Phase 1 than Phases 2 and 3, but individual projects in the later phases will be more expensive. Projects will be selected by competitive peer review and the transition from one phase to the next will be guided by a panel of experts.

Funding to implement the PCM component is projected to be approximately equivalent to funding authorized in HABHRCA 2004 for the PCM program at the outset ($4 million each for marine and freshwater PCM in FY 09) and rising over time ($6.5 million each in FY 13) due to the increasing numbers of projects entering the expensive demonstration and technology transfer phases, while maintaining a flow of new projects entering the development phase. Separate funding lines are needed to support equivalent marine and freshwater HAB activities. Funding needs for the subsequent 5 years (FY 14-FY 18) would be determined based on experience with the costs of implementing the Phase 2 and 3 programs, which

Box 26. Funding levels for RDDTT and other national HAB programs, authorized by HABHRCA 2004 and proposed to address future needs.

Funding ($ million)	Program	Federal Facilities[c]	ECOHAB	RDDTT				MERHAB	Regional Assessments[d]	Total
				Total RDDTT	*PCM*	*Event Response*	*Core Infrastructre*			
HABHRCA 2004	Marine and Great Lakes[a]	2.5	6.5	3	*3*			6	1.5	19.5
Proposed FY09	Marine and Great Lakes[a]	3	6	6.5	*4*	*0.5*	*2*	5	1	21.5
	Freshwater[b]	3	6	6.5	*4*	*0.5*	*2*	5	1	21.5
Proposed FY10	Marine and Great Lakes[a]	3	6	7	*4.5*	*0.5*	*2*	5	1	22
	Freshwater[b]	3	6	7	*4.5*	*0.5*	*2*	5	1	22
Proposed FY11	Marine and Great Lakes[a]	3.5	6.5	8.5	*5*	*1*	*2.5*	6	1	25.5
	Freshwater[b]	3.5	6.5	8.5	*5*	*1*	*2.5*	6	1	25.5
Proposed FY12	Marine and Great Lakes[a]	3.5	6.5	9	*5.5*	*1*	*2.5*	6	1	26
	Freshwater[b]	3.5	6.5	9	*5.5*	*1*	*2.5*	6	1	26
Proposed FY13	Marine and Great Lakes[a]	4	7	10.5	*6.5*	*1*	*3*	6.5	1	29
	Freshwater[b]	4	7	10.5	*6.5*	*1*	*3*	6.5	1	29

a NOAA
b Not NOAA mandate
c Research, assessment, and operational activities for HABs and hypoxia at Federal facilities
d HABs and Hypoxia

are presently not well known. Since the intent is to fully fund the PCM component in the first phase, large increases are not anticipated in the second phase.

5.C. Event Response

Funds are needed for program coordinators at the Federal level who will initially compile an inventory of the many different monitoring and event response capabilities at the Federal and state levels that might relate to HABs, and subsequently help to administer and coordinate the program. Two full time equivalents (FTEs) are recommended for this activity, one in NOAA and one in an appropriate agency for fresh water event response, such as EPA.

A Contingency Fund has been proposed that will support the immediate response to unexpected or unusual HABs. It is, of course, impossible to predict the frequency at which these events occur, or their magnitude, but significant funds are needed, given the scale of past events. For example, the emergency response to the massive 2005 New England red tide required many days of ship time and other activities that resulted in an allocation of approximately $540,000 for that single event.

An additional need for the Event Response program is a Technical Assistance Fund to be used in a competitive program for instrumentation, training, and other activities that lead to an enhancement of event response capabilities in states, localities, or regions. To maximize cost efficiency such a program would need to be coordinated with the Core Infrastructure Program (see next section) and the existing MERHAB Program.

The total sum requested at the outset of the RDDTT program for event response activities is $0.5 million per year for freshwater systems and the same amount for marine systems with increases later to $1 million each (see Box 26). In the second phase, the Event Response Program would be fully implemented with incorporation of the regional coordinators and fully developed regional programs. Costs would be approximately double the funding of the first phase.

5.D. Core Infrastructure

The Core Infrastructure Program can be implemented in phases. In the initial phase program coordinators at the Federal level should catalog available infrastructure resources and make this information available on the web. Since this activity overlaps with the activities of the Event Response Coordinators (see previous section), in the first phase the functions of the Core Infrastructure Coordinators could be combined with the Event Response Coordinators. Two programs should also be established, one for one-time only purchases of equipment or set up of facilities and another for providing sustained funding for certain activities that are recurrent in nature. Both could be modeled after existing peer reviewed NSF programs as described in Chapter 4.

Funding of approximately $1 million per year is needed initially for the equipment and instrumentation purchases and development. This amount would gradually increase as the RDDTT program moves through its 5-year life span (Box 26). As with other program elements, this same amount is needed for instrumentation and equipment for freshwater and for marine HABs. Another $2 million per year ($1 million each for marine and freshwater HABs) is needed for recurring costs associated with training, culture collection maintenance, equipment maintenance, preparation of standards, and other facilities needs. It is anticipated that many of the analytical facilities and some other Core Infrastructure activities will become self-supporting by charging fees to cover costs. This will take time, however, and thus initial investments are needed. At the outset of the program, a total of $2 million dollars per year is needed for Core Infrastructure activities and equipment for each of the freshwater and marine HAB programs. This would be scaled up through time to a total of $3 million each by the end of the 5-year program. Additional funds will be needed in the next 5-year phase to fully implement the Core Infrastructure Program, and by then, it will probably be necessary to have separate Event Response and Core Infrastructure Coordinators.

5.E. Overview

Overall, the RDDTT program would provide a substantial infusion of funds to activities that lie at the center of the national HAB program. All program elements are expected to grow in sophistication and capabilities through time and thus the funding requirements should increase as well. Given the restricted nature of NOAA's focus on marine coastal waters and the Great Lakes, parallel authorization and funding is needed for other agencies such as EPA that can support freshwater HAB studies. As in all other aspects of HAB research and response, strong interagency partnerships are needed for full program implementation. Every effort must be made to engage Federal and state agencies in these new activities and to convince Congress to provide the funding support for the many RDDTT needs identified herein.

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Appendix III. RDDTT Workshop Agenda

*RDDTT** HAB Workshop Agenda

Page 1

Dates: June 25 – 28, 2007
Location: WHOI, Jonsson Center

Sunday, June 24

7 pm SC Meeting at Landfall Restaurant (near Hotel)

Monday, June 25

7 - 8 Breakfast at Jonsson Center (Main House)
8 – 12 Background talks (Carriage House)

8 – 8:30 Overview of HABHRCA and RDDTT Process– Quay Dortch
8:30 – 9 Overview of HARRNESS – Pat Glibert
9 – 9:30 Human Dimensions –Marybeth Bauer
9:30 – 10 Infrastructure – John Ramsdell and Kevin Sellner
10 – 10:30 Break
10:30 – 11 Event Response – Libby Jewett
11 – 11:30 PCM – Mario Sengco
11:30 – 12 Charges to Work Groups (10 min each) – Work group leads

12 – 1	LUNCH at Jonsson Center (Main House)
1 – 3	Work Groups Break Out
3 – 3:15	Break
3:15-4:45	Work Groups Break Out
4:45-5:00	Plenary – Opportunity for questions, announcements, etc.
5 – 6	Workgroup Chairs, Rapporteurs, Co-chairs Convene
	Dinner on our own

Tuesday, June 26

7 - 8 Breakfast at Jonsson Center (Carriage House)
8 – 9:30 Plenary.
Each Work Group presents progress/discussion
8 – 8:30 Dan Ayres – Event Response
8:30 – 9 Don Anderson – PCM
9 – 9:30 Pat Glibert - Infrastructure

9:30 – 10	Break
10 -12	Work Groups Break Out
12 – 1	LUNCH (Human Dimensions Reps meet)
1 - 3	Work Groups Break Out

* National Scientific Research, Development, Demonstration, and Technology Transfer Plan on Reducing Impacts from HABs (RDDTT Plan)

*RDDTT** HAB Workshop Agenda

Page 2

Tuesday, June 26 (Cont.)

3 – 3:15	Break
3:15-4:45	Work Groups Break Out
4:45-5:00	Plenary – Opportunity for questions, announcements, etc
5 – 6	Workgroup leads, rapporteurs and steering committee co chairs meet
6:30—7:30	Reception at Jonsson Center (Main House)
7:30 – 9	Group Dinner (also in Main House)

Wednesday, June 27

7 – 8 Breakfast at Jonsson Center (Main House)
8 – 10 Plenary (Carriage House)
Each Work Group presents progress/discussion
8 – 8:30 Don Anderson – PCM
8:30 – 9 Pat Glibert - Infrastructure
9 – 9:30 Dan Ayres – Event Response
9:30 – 10 Marybeth Bauer – Human Dimensions

10 – 10:15	Break
10:15 -12	Work Groups outline reports
12 – 1	LUNCH (Main House)
1 - 3	Work Groups outline/ write reports
3 – 3:15	Break
3:15-4:30	Work Groups write reports
4:30 - 5	Final Plenary

Thursday, June 28

8 – 9	Breakfast (Main House)
12 – 1	Lunch (Main House)

Some Steering Committee, session chairs, rapporteurs remain.
Rest of participants depart.
All day writing of reports (until 5 pm)

* National Scientific Research, Development, Demonstration, and Technology Transfer Plan on Reducing Impacts from HABs (RDDTT Plan)