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Testimony of

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Mr. Chairman and members of the Subcommittee. I am Donald M. Anderson, a Senior Scientist in the Biology Department of the Woods Hole Oceanographic Institution, where I have been active in the study of red tides and harmful algal blooms (HABs) for 30 years. I am here to provide the perspective of an experienced scientist who has investigated many of the harmful algal bloom (HAB) phenomena that affect coastal waters of the United States and the world. I am also Director of the U.S. National Office for Marine Biotoxins and Harmful Algal Blooms, co-Chair of the National HAB Committee, and have been actively involved in formulating the scientific framework and agency partnerships that support and guide our national program on HABs. Thank you for the opportunity to acquaint you with the challenges posed to the U.S. and other countries by HABs, the present status of our research progress, options for prevention, control, and mitigation, and the future programmatic actions that are needed to maintain and expand this important national program. Other than a few general comments, I will restrict my comments to marine HABs, as testimony on freshwater HABs is being provided by my colleague Dr. Kenneth Hudnell.

BACKGROUND

Among the thousands of species of microscopic algae at the base of the marine food chain are a few dozen which produce potent toxins. These species make their presence known in many ways, sometimes as a massive "bloom" of cells that discolor the water, sometimes as dilute, inconspicuous concentrations of cells noticed only because they produce highly potent toxins which either kill marine organisms directly, or transfer through the food chain, causing harm at multiple levels. The impacts of these phenomena include mass mortalities of wild and farmed fish and shellfish, human intoxications or even death from contaminated shellfish or fish, alterations of marine trophic structure through adverse effects on larvae and other life history stages of commercial fisheries species, and death of marine mammals, seabirds, and other animals.

Blooms of toxic algae are commonly called "red tides," since the tiny plants sometimes increase in abundance until they dominate the planktonic community and sometimes make the water appear discolored. The term is misleading, however, since toxic blooms may be greenish or brownish, non-toxic species can bloom and harmlessly discolor the water, and, conversely, adverse effects can occur when some algal cell concentrations are low and the water is clear. Given the confusion, the scientific community now uses the term "harmful algal bloom" or HAB.

HAB phenomena take a variety of forms and have a variety of impacts. With regard to human health, the major category of impact occurs when toxic phytoplankton are filtered from the water as food by shellfish which then accumulate the algal toxins to levels that can be lethal to humans or other consumers. These poisoning syndromes have been given the names paralytic, diarrhetic, neurotoxic, azaspiracid, and amnesic shellfish poisoning (PSP, DSP, NSP, AZP, and ASP). All have serious effects, and some can be fatal. Except for ASP, all are caused by biotoxins synthesized by a class of marine algae called dinoflagellates. ASP is produced by diatoms that until recently were all thought to be free of toxins and generally harmless. A sixth human illness, ciguatera fish poisoning (CFP) is caused by biotoxins produced by dinoflagellates that grow on seaweeds and other surfaces in coral reef communities. Ciguatera toxins are transferred through the food chain from herbivorous reef fishes to larger carnivorous, commercially valuable finfish. Yet another human health impact from HABs occurs when a class of algal toxins called the brevetoxins becomes airborne in sea spray, causing respiratory irritation and asthma-like symptoms in beachgoers and coastal residents, typically along the Florida and Texas shores of the Gulf of Mexico. Macroalgal or seaweed blooms also fall under the HAB umbrella. Excessive seaweed growth, often linked to pollution inputs, can displace natural underwater vegetation, cover coral reefs, and wash up on beaches, where the odor of masses of decaying material is a serous deterrent to tourism. Finally, another poorly understood human illness linked to toxic algae is caused by the dinoflagellate *Pfiesteria piscicida* and related organisms (e.g., *Karlodinium*) that have been linked to symptoms such as deficiencies in learning and memory, skin lesions, and acute respiratory and eye irritation – all after exposure to estuarine waters where *Pfiesteria*-like organisms have been present (Burkholder and Glasgow, 1997).

Distribution of HAB Phenomena in the United States. With the exception of AZP, all of the poisoning syndromes described above are known problems within the U.S. and its territories, affecting large expanses of coastline (Fig. 1). PSP occurs in all coastal New England states as well as New York, extending to offshore areas in the northeast, and along much of the west coast from Alaska to northern California. Overall, PSP affects more U.S. coastline than any other algal bloom problem. NSP occurs annually along Gulf of Mexico coasts, with the most frequent outbreaks along western Florida and Texas. Louisiana, Mississippi, North Carolina and Alabama have also been affected intermittently, causing extensive losses to the oyster industry and killing

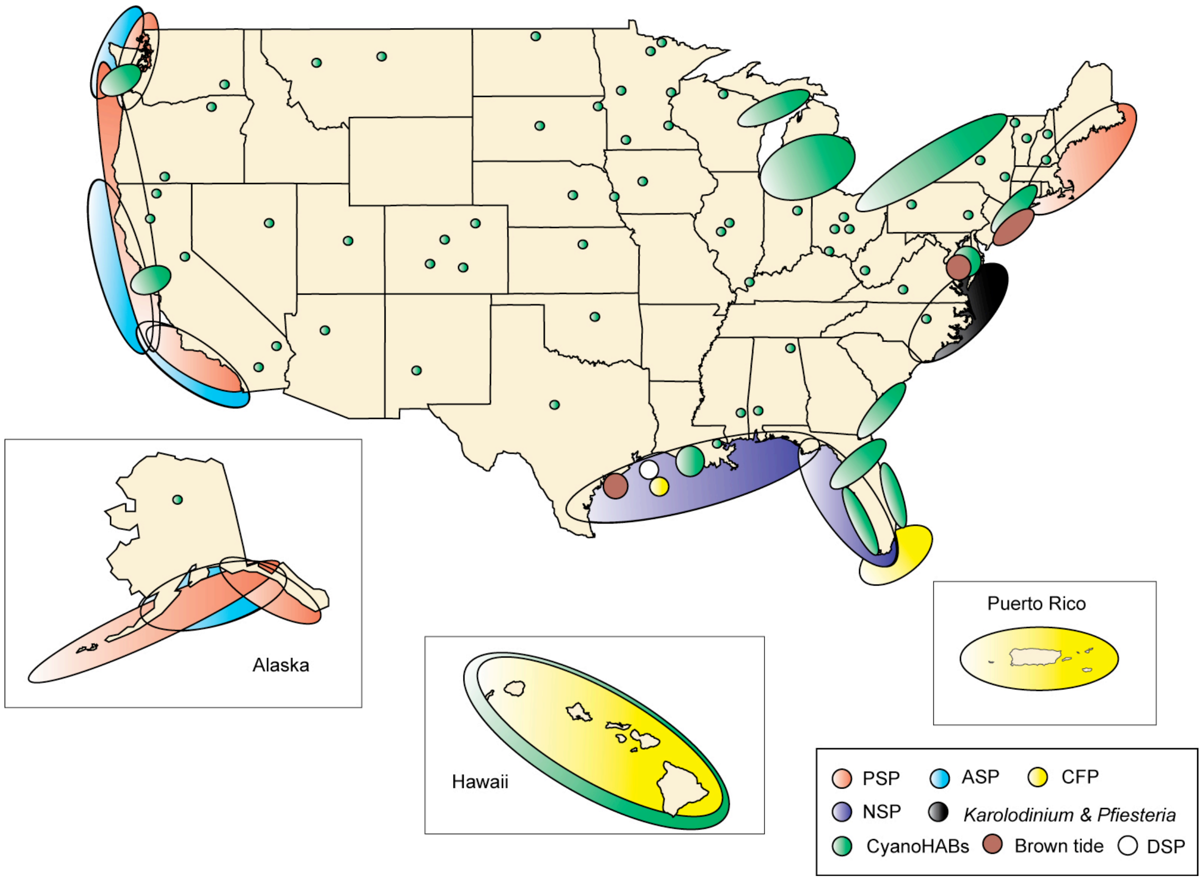

Figure 1. Distribution of HAB phenomena responsible for human illnesses in the U.S. (Source: U.S. National Office for Marine Biotoxins and Harmful Algal Blooms.)

birds and marine mammals. ASP has been a problem for all of the U.S. Pacific coast states. The ASP toxin has been detected in shellfish on the east coast as well, and in plankton from Gulf of Mexico waters. DSP is largely unknown in the U.S., but a major outbreak was recently reported along the Texas coast, resulting in an extensive closure of shellfish beds in that area. Human health problems from *Pfiesteria* and related species are thus far poorly documented, but some are thought to have affected laboratory workers, fishermen, and others working in or exposed to estuarine waters in several portions of the southeastern U.S. CFP is the most frequently reported non-bacterial illness associated with eating fish in the U.S. and its territories, but the number of cases is probably far higher, because reporting to the U.S. Center for Disease Control is voluntary and there is no confirmatory laboratory test. In the Virgin Islands, it is estimated that nearly 50% of the adults have been poisoned at least once, and some estimate that 20,000 – 40,000 individuals are poisoned by ciguatera annually in Puerto Rico and the U.S. Virgin Islands alone. CFP occurs in virtually all sub-tropical to tropical U.S. waters (i.e., Florida, Texas, Hawaii, Guam, Virgin Islands, Puerto Rico, and many Pacific Territories). As tropical fish are increasingly exported to distant markets, ciguatera has become a worldwide problem.

Economic and Societal Impacts. HABs have a wide array of economic impacts, including the costs of conducting routine monitoring programs for shellfish and other affected resources, short-term and permanent closure of harvestable shellfish and fish stocks, reductions in seafood sales (including the avoidance of "safe" seafoods as a result of over-reaction to health advisories), mortalities of wild and farmed fish, shellfish, submerged aquatic vegetation and coral reefs, impacts on tourism and tourism-related businesses, and medical treatment of exposed populations. A conservative estimate of the average annual economic impact resulting from HABs in the U.S. is approximately $82 million (Hoagland and Scatasta 2006). Cumulatively, the costs of HABs exceed a billion dollars over the last several decades. These estimates do not include the application of "multipliers" that are often used to account for the manner in which money transfers through a local economy. With multipliers, the estimate of HAB impacts in the United States would increase several fold. Furthermore, individual bloom events can approach the annual average, as occurred for example in 2005 when a massive bloom of *Alexandrium* species along the New England coast closed shellfish beds from Maine to southern Massachusetts. The impact to the Massachusetts shellfish industry alone was estimated by the state Division of Marine Fisheries to be $50M, with similar large impacts occurring in Maine. Additional unquantified losses were experienced by the tourist industry and by restaurants and seafood retailers, as consumers often avoided all seafood from the region, despite assurances that no toxins had been detected in many of these seafood products.

Recent Trends. The nature of the HAB problem has changed considerably over the last several decades in the U.S. Virtually every coastal state is now threatened by harmful or toxic algal species, whereas 30 - 40 years ago, the problem was much more scattered and sporadic (Fig. 2.). The number of toxic blooms, the economic losses from them, the types of resources affected, and the number of toxins and toxic species have all increased dramatically in recent years in the U.S. and around the world (Anderson, 1989; Hallegraeff, 1993).

The first thought of many is that pollution or other human activities are the main reason for this expansion, yet in the U.S. at least, many of the "new" or expanded HAB problems have occurred in waters where pollution is not an obvious factor. Some new bloom events likely reflect indigenous populations that have been discovered because of better detection methods and more observers rather than new species introductions or dispersal events (Anderson, 1989).

Other "spreading events" are most easily attributed to dispersal via natural currents, while it is also clear that man may have contributed to the global HAB expansion by transporting toxic species in ship ballast water (Hallegraeff and Bolch, 1992). The U.S. Coast Guard, EPA, and the International Maritime Organization are all working toward ballast water control and treatment regulations that will attempt to reduce the threat of species introductions worldwide.

Another factor underlying the global expansion of HABs is the dramatic increase in aquaculture activities. This leads to increased monitoring of product quality and safety, revealing indigenous toxic algae that were probably always present (Anderson, 1989). The construction of aquaculture facilities also places fish or shellfish resources in areas where toxic algal species occur but were previously unknown, leading to mortality events or toxicity outbreaks that would not have been noticed had the aquaculture facility not been placed there.

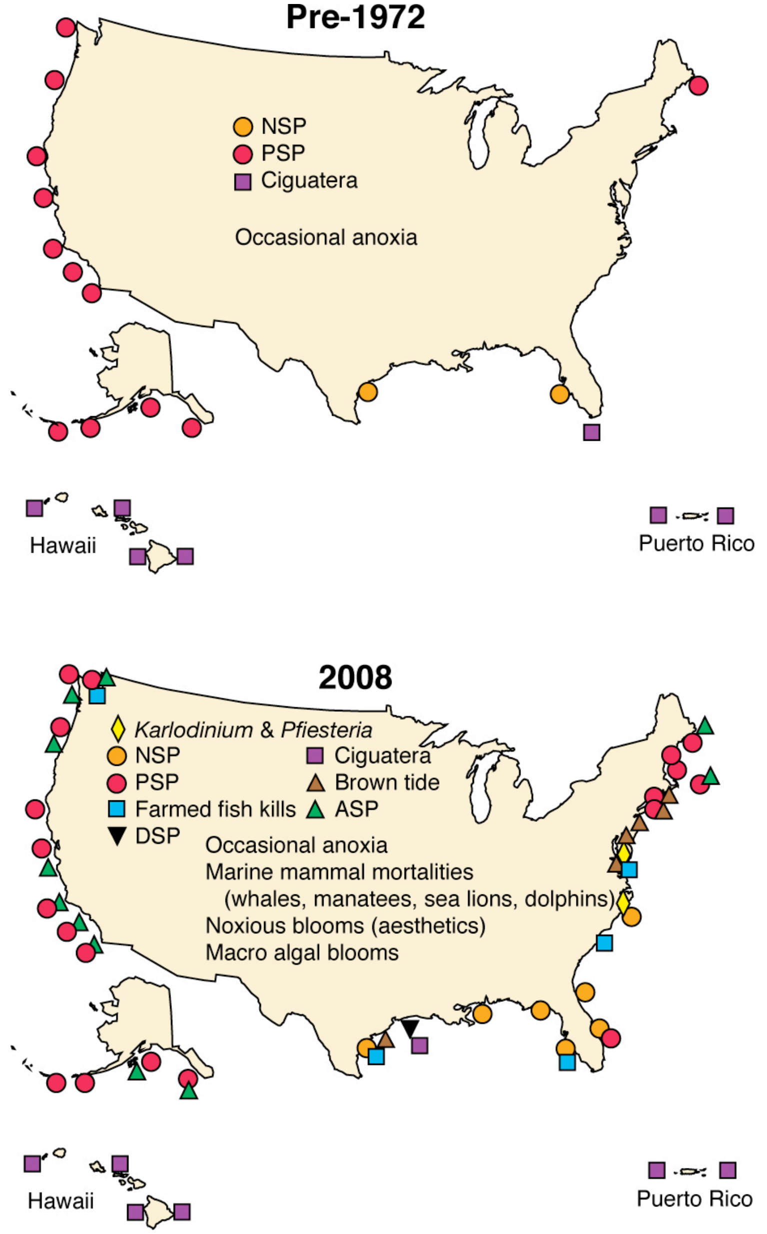

Figure 2. Expansion of HAB outbreaks over the past 36 years in the U.S. (Source: U.S. National Office for Marine Biotoxins and Harmful Algal Blooms.

Of considerable concern, particularly for coastal resource managers, is the potential relationship between the apparent increase in HABs and the accelerated eutrophication of coastal waters due to human activities (Anderson et al., 2002). As mentioned above, some HAB outbreaks occur in pristine waters with no influence from pollution or other anthropogenic effects, but linkages between HABs and eutrophication have been frequently noted within the past several decades (e.g., Smayda, 1990). Coastal waters are receiving massive and increasing quantities of industrial, agricultural and sewage effluents through a variety of pathways. In many urbanized coastal regions, these anthropogenic inputs have altered the size and composition of the nutrient pool which may, in turn, create a more favorable nutrient environment for certain HAB species. Just as the application of fertilizer to lawns can enhance grass growth, marine algae can grow in response to various types of nutrient inputs. Shallow and restricted coastal waters that are poorly flushed appear to be most susceptible to nutrient-related algal problems. Nutrient enrichment of such systems often leads to eutrophication and increased frequencies and magnitudes of phytoplankton blooms, including HABs. There is no doubt that this is true in certain areas of the world where pollution has increased dramatically. A prominent example is the area of the East China Sea near Qingdao – where sailing activities in the forthcoming Olympics are threatened by mass quantities of seaweed that are a direct result of unchecked coastal pollution. This problem is real, but less evident in areas where coastal pollution is more gradual and unobtrusive.

It is now clear that the worldwide expansion of HAB phenomena is in part a reflection of our ability to better define the boundaries of an existing problem. Those boundaries are also expanding, however, due to natural species dispersal via storms or currents, as well as to human-assisted species dispersal, and enhanced HAB population growth as a result of pollution or other anthropogenic influences. The fact that part of the expansion is a result of increased awareness should not temper our concern. The HAB problem in the U.S. is serious, large, and growing. It is a much larger problem than we thought it was several decades ago.

PROGRESS AND STATUS OF OUR NATIONAL PROGRAM ON HABS

More than a decade ago, the U.S. approach to research on marine HABS was uncoordinated and modest in scale. Research groups were few and their work was piecemeal and constrained by small budgets that fluctuated with the sporadic blooms that would occur. There were virtually no U.S. government laboratories involved in HAB research. Funding for academic scientists was largely available through competitions within the entire oceanographic community since there were no targeted funding programs for HABs. This situation changed dramatically with the formulation of a National Plan (*Marine Biotoxins and Harmful Algal Blooms; A National Plan*; Anderson et al., 1993). This plan, the result of a workshop involving academic and federal scientists, as well as agency officials, and industry representatives, identified major impediments to the goal of science-based management of resources affected by HABs, and made recommendations on the steps needed to remove those impediments. These impediments have been addressed to varying degrees with funding programs targeting specific topic areas within the broad field of HABs and their impacts. It is my belief that the *National Plan* has been a major success, leading to the creation of several multi-agency partnerships for HAB studies, and to many individual agency initiatives on this topic. Two national, extramural HAB funding programs, *Ecology of Harmful Algal Blooms* (ECOHAB) and *Monitoring and Event Response for Harmful Algal Blooms* (MERHAB), have together funded approximately $100 million in marine HAB research since the programs began in 1996 and 2000, respectively. Another partnership between the National Institute of Environmental Health Sciences (NIEHS) and the National Science Foundation (NSF) has supported four Centers for Oceans and Human Health that include significant HAB research and outreach activities. NOAA has also created an Oceans and Human Health Initiative (OHHI) that supports extramural research and focused activities at three federal OHHI centers. These are just a few of many programs and activities that were motivated by the 1993 *National Plan*.

Research And Management Progress

With the advent of ECOHAB, MERHAB, the OHH programs, and other national HAB programs, resources have been directed towards the goal of scientifically based management of coastal waters and fisheries that are potentially impacted by HABs. These activities have already made a significant contribution to HAB management capabilities in the U.S. Here I will highlight several advances in our understanding of HAB phenomena, as well as some of the program-derived technological developments that are providing new tools to coastal resource managers in regions impacted by HABs.

Enhanced understanding of HAB dynamics

In areas studied by the multi-investigator ECOHAB-funded regional research projects, HAB phenomena are now far better understood than was the case just 10 years ago when the program began. Knowledge is also increasing for HABs in other areas through smaller, targeted research projects. In the Gulf of Maine, the focus of the ECOHAB-GOM and GOMTOX regional programs, survey cruises, experimental and process studies, and numerical models have led to the development of a conceptual model of bloom dynamics that is consistent with observations of *Alexandrium* cell distributions, and with patterns of toxicity in shellfish along much of the New England coast (Anderson et al., 2005). A key feature of this model is the strong influence of dormant resting cysts in bottom sediments on bloom magnitude. Cysts in several large accumulation zones or "seedbeds" germinate in the spring and re-populate the water column with swimming *Alexandrium* cells, which then multiply and cause the annual PSP outbreaks. Major bloom transport pathways in the Maine Coastal Current system have also been identified, with delivery of the toxic algal cells to shore influenced by the patterns and strength of onshore- and offshore-oriented wind events.

In the Gulf of Mexico, the ECOHAB-Florida program identified transport and delivery mechanisms for the toxic *Karenia* cells that kill fish, cause shellfish to become toxic, and release an irritating aerosol that drives residents and tourists from beaches. In particular, the *Karenia* cells are now thought to be transported onshore in deeper waters through wind events that cause "upwelling". Special bathymetric features of the ocean bottom can facilitate this transport and focus cell delivery to areas known to be the sites of recurrent blooms. Studies of nutrient uptake by *Karenia* and surveys of nutrient concentrations in the region are addressing the sensitive and highly controversial issue of the potential link between red tide blooms and nutrient inputs from land, including those associated with agriculture and other human activities. This ongoing research has obvious implications to policy decisions concerning pollution and water quality in the region.

Consistent with the identification of "source regions" for Gulf of Maine and Gulf of Mexico HABs, researchers in the Pacific Northwest have identified an area west of Puget Sound that appears to accumulate toxic diatoms responsible for outbreaks of amnesic shellfish poisoning (ASP), a debilitating illness that includes permanent loss of short-term memory in some victims. Other programs have been equally productive in identifying underlying driving mechanisms for HAB blooms, such as the brown tide blooms in New York and New Jersey. These dense accumulations of tiny *Aureococcus anophagefferens* cells turn the water a deep brown, blocking sunlight to submerged vegetation, and altering the feeding behavior of shellfish. These blooms have been linked to certain types of nutrients that seem to favor the causative organism – in particular "organic" forms of nitrogen that are preferred by the brown tide cells, and give it a competitive advantage in certain locations.

Improved monitoring and detection of HAB cells and toxins

These are but a few of the advances in understanding that have accrued from ECOHAB regional funding. Equally important are the discoveries that provide management tools to reduce the impacts of HABs on coastal resources. Management options for dealing with the impacts of

HABs include reducing their incidence and extent (prevention), stopping or containing blooms (control), and minimizing impacts (mitigation). Where possible, it is preferable to prevent HABs rather than to treat their symptoms. Since increased pollution and nutrient loading may enhance the growth of some HAB species, these events may be prevented by reducing pollution inputs to coastal waters, particularly industrial, agricultural, and domestic effluents high in plant nutrients. This is especially important in shallow, poorly flushed coastal waters that are most susceptible to nutrient-related algal problems. As mentioned above, research on the links between certain HABs and nutrients has highlighted the importance of non-point sources of nutrients (e.g., from agricultural activities, fossil-fuel combustion, and animal feeding operations).

The most effective HAB management tools are monitoring programs that involve sampling and testing of wild or cultured seafood products directly from the natural environment, as this allows unequivocal tracking of toxins to their site of origin and targeted regulatory action. Numerous monitoring programs of this type have been established in U.S. coastal waters, typically by state agencies. This monitoring has become quite expensive, however, due to the proliferation of toxins and potentially affected resources. States are faced with flat or declining budgets and yet need to monitor for a growing list of HAB toxins and potentially affected fisheries resources. Technologies are thus urgently needed to facilitate the detection and characterization of HAB cells and blooms.

One very useful technology that has been developed through recent HAB research relies on species- or strain-specific "probes" that can be used to label only the HAB cells of interest so they can then be detected visually, electronically, or chemically. Progress has been rapid and probes of several different types are now available for many of the harmful algae, along with techniques for their application in the rapid and accurate identification, enumeration, and isolation of individual species. One example of the direct application of this technology in operational HAB monitoring is for the New York and New Jersey brown tide organism, *Aureococcus anophagefferens*. The causative organism is so small and non-descript that it is virtually impossible to identify and count cells using traditional microscopic techniques. Antibody probes were developed that bind only to *A. anophagefferens* cells, and these are now used routinely in monitoring programs run by state and local authorities, greatly improving counting time and accuracy.

These probes are being incorporated into a variety of different assay systems, including some that can be mounted on buoys and left unattended while they robotically sample the water and test for HAB cells. Clustered with other instruments that measure the physical, chemical, and optical characteristics of the water column, information can be collected and used to make "algal forecasts" of impending toxicity. These instruments are taking advantage of advances in ocean optics, as well as the new molecular and analytical methodologies that allow the toxic cells or chemicals (such as HAB toxins) to be detected with great sensitivity and specificity. A clear need has been identified for improved instrumentation for HAB cell and toxin detection, and additional resources are needed in this regard. This can be accomplished during development of the Integrated Ocean Observing System (IOOS) for U.S. coastal waters, and through a targeted research program on HAB prevention, control, and mitigation (see below). These are needed if we are to achieve our vision of future HAB monitoring and management programs – an integrated system that includes arrays of moored instruments as sentinels along the U.S.

coastline, detecting HABs as they develop and radioing the information to resource managers. Just as in weather forecasting, this information can be assimilated into numerical models to improve forecast accuracy

Prediction and forecasting of HABs

A long-term goal of HAB monitoring programs is to develop the ability to forecast or predict bloom development and movement. Prediction of HAB outbreaks requires physical/biological numerical models which account for both the growth and behavior of the toxic algal species, as well as the movement and dynamics of the surrounding water. Numerical models of coastal circulation are advancing rapidly in the U.S., and a number of these are beginning to incorporate HAB dynamics as well. A model developed to simulate the dynamics of the organism responsible for paralytic shellfish poisoning (PSP) outbreaks in the Gulf of Maine is relatively far advanced in this regard (McGillicuddy et al., 2005), and is now being transitioned from academic use towards an operational mode. Earlier this year, my colleagues and I were able to successfully predict a major regional PSP outbreak in the Gulf of Maine on the basis of our cyst mapping and modeling activities (www.whoi.edu/page.do?pid=24039&tid=282&cid=41211). This is the first time a major HAB event has been predicted several months in advance, and is strong testimony to the benefits of the ECOHAB program's regional research emphasis. Our numerical model for *Alexandrium* bloom dynamics is now being used to provide weekly nowcasts/forecasts to managers and other stakeholders affected by PSP outbreaks in the region, and is slated to be used by NOAA's National Ocean Service (NOS) as the basis of an operational HAB forecasting system for the Gulf of Maine.

In the Gulf of Mexico, satellite images of ocean color are now used to detect and track toxic red tides of *Karenia brevis*. Based on research results from the ECOHAB-Florida program, bloom forecast bulletins are now being provided to affected states in the Gulf of Mexico by the NOAA NOS Center for Coastal Monitoring and Assessment. The bulletins (see http://www.csc.noaa.gov/crs/habf/) are based on the integration of several data sources: satellite ocean color imagery; wind data from coastal meteorological stations; field observations of bloom location and intensity provided by the states of Florida and Texas; and weather forecasts from the National Weather Service. The combination of warning and rapid detection is a significant aid to the Gulf states in responding to these blooms.

Mitigation and control strategies

Other practical strategies to mitigate the impacts of HAB events include: regulating the siting of aquaculture facilities to avoid areas where HAB species are present, modifying water circulation for those locations where restricted water exchange is a factor in bloom development, and restricting species introductions (e.g., through regulations on ballast water discharges or shellfish and finfish transfers for aquaculture). Each of these strategies requires fundamental research such as that being conducted in our national HAB program. Potential approaches to directly control or suppress HABs are under development as well - similar to methods used to control pests on land – e.g., biological, physical, or chemical treatments that directly target the bloom cells. One example is work conducted in my own laboratory, again through ECOHAB support, using ordinary clay to control HABs. When certain clays are dispersed on the water surface, the tiny clay particles aggregate with each other and with other particles, including HAB cells. The aggregates then settle to the ocean bottom, carrying the unwanted HAB cells from the surface waters where they would otherwise grow and cause harm. As with many other new technologies for HABs, initial results are quite promising and small-scale field trials are underway, but continued support is needed to fully evaluate benefits, costs, and environmental impacts.

Another intriguing bloom control strategy is being evaluated for the brown tide problem. It has been suggested that one reason the brown tides appeared about 15-20 years ago was that hard clams and other shellfish stocks have been depleted by overfishing in certain areas. Removal of these resources altered the manner in which those waters were “grazed” - i.e., shellfish filter large quantities of water during feeding, and that removes many microscopic organisms from the water, including natural predators of the brown tide cells. If this hypothesis is valid, a logical bloom control strategy would be to re-seed shellfish in the affected areas, and to restrict harvesting. Pilot projects are now underway to explore this control strategy in Long Island.

In general, bloom control is an area where very little research effort has been directed in the U.S. (Anderson, 1997), and considerable research is needed before these means are used to control HABs in natural waters given the high sensitivity for possible damage to coastal ecosystem and water quality by the treatments. As discussed below, this could be accomplished as part of a separate national program on HAB prevention, control, and mitigation.

PROGRAMMATIC NEEDS

The 1993 *National Plan* is outdated. Some of its recommendations have been fulfilled, while others remain partially or completely unaddressed. Concurrently, the nature and extent of the U.S. HAB problem changed with the emergence of several new poisoning syndromes, the expansion of known problems into new areas, and the identification of a variety of new HAB impacts and affected resources. Furthermore, while new scientific understanding taught us that HABs and the toxins they produce are complex in their mode of action and that the ecosystems in which they proliferate are equally complex, decision-making and management systems did not change to reflect that complexity. Likewise, many new tools to detect HAB cells and their toxins have been developed, but are not fully tested or incorporated into existing research, management, and ocean observation programs. These and other considerations led to the decision to revise and update the *National Plan*. Several hundred scientists and managers, from a wide array of fields, contributed to the knowledge base on which this new national science and management strategy is based. Over a two-year period, an intensive collaborative effort was undertaken, including an open forum discussion among 200 participants at the U.S. National HAB Symposium, a detailed web-based questionnaire yielding more that 1,000 targeted responses, a workshop of 50 U.S. HAB experts, an Advisory Committee to guide, and a Steering Committee to assemble and review the most current information available for use in developing the new plan.

Our new national plan is called HARRNESS (*Harmful Algal Research and Response: A National Environmental Science Strategy 2005-2015*; Ramsdell et al., 2005). This is the framework that will guide U.S. HAB research and monitoring well into the future, and is one that I enthusiastically support.

At the conceptual level, HARRNESS is a framework of initiatives and programs that identify and address current and evolving needs associated with HABs and their impacts. Four major areas of research focus have been defined in HARRNESS: *Bloom Ecology and Dynamics, Toxins and Their Effects, Food Webs and Fisheries,* and *Public Health and Socioeconomic Impacts*. Each shares a need for a set of management and research activities directed at various scales of the HAB problem. These include highly focused or targeted research studies, regional and inter-regional scale investigations, and policy-making and resource management activities towards mitigation and control. Progress will be facilitated through the development of activities and services (Infrastructure) required by multiple program foci.

At the programmatic level, several of the existing national programs will continue to function, and new programs will need to be added. In the former category, ECOHAB will continue to address the fundamental processes underlying the impacts and population dynamics of HABs. This involves a recognition of the many factors at the organismal level that determine how HAB species respond to, and potentially alter their environment, the manner in which HAB species affect or are affected by food-web interactions, and how the distribution, abundance, and impact of HAB species are regulated by the environment. ECOHAB was established as a competitive, peer-reviewed research program supported by an interagency partnership involving NOAA, NSF, EPA, ONR, and NASA. Research results have been brought into practical applications through MERHAB, a program formulated to transfer technologies and foster innovative monitoring programs and rapid response by public agencies and health departments. MERHAB will also continue under the new HARRNESS framework.

Two relatively new programs (the Centers for Oceans and Human Health (COHH) initiative of NIEHS and NSF and NOAA's OHHI) are being enthusiastically received by the scientific, management and public health communities, and thus are expected to continue under HARRNESS. They fill an important niche by creating linkages between members of the ocean sciences and biomedical communities to help both groups address the public health aspects of HABs. The COHH focus on HABs, infectious diseases, and marine natural products, whereas the NOAA OHHI Centers and extramural funding include these subjects in addition to chemical pollutants, coastal water quality and beach safety, seafood quality, sentinel species as indicators of both potential human health risks and human impact on marine systems. The partnership between NIEHS, NSF, and NOAA clearly needs to be sustained and expanded in order to provide support to a network of sufficient size to address the significant problems under the OHH umbrella. This is best accomplished through additional funds to these agencies, as well as through the involvement of other agencies with interests in oceans and human health, including, for example, EPA, NASA, FDA, and CDC.

A number of the recommendations of HARRNESS are not adequately addressed by existing programs, however. As a result, the HAB community needs to work with Congressional staff and agency program managers to create new programs, as well as to modify existing ones, where appropriate. For example, a separate program on HABs and food web impacts could focus resources on this important topic area in a way that is not presently possible through ECOHAB. Chemistry and toxicology of HABs, the underlying basis to the adverse consequences of HABs, receives only piecemeal funding through support of other HAB efforts and requires focused attention and a targeted funding initiative. Likewise the practical aspects of HAB prevention, control and mitigation are also presently, but inadequately included in ECOHAB. This program is discussed in more detail below.

With the exception of the Great Lakes, which fall under NOAA's jurisdiction, freshwater systems that are impacted by HABs have not been comprehensively addressed in ECOHAB, MERHAB, or the OHH HAB programs. This is because NOAA's mandate includes the great Lakes and estuaries up to the freshwater interface, but does not include the many rivers, ponds, lakes, and reservoirs that are subject to freshwater HAB problems. Freshwater HABs are an important focus within HARRNESS, and therefore targeted (and separate) legislation and funding initiatives on freshwater HABs are needed.

The support provided to HAB research through ECOHAB, MERHAB, Sea Grant, and other national programs has had a tremendous impact on our understanding of HAB phenomena, and on the development of management tools and strategies. Funding for ECOHAB is modest, but it is administered in a scientifically rigorous manner that maximizes research progress. Several 5-year ECOHAB regional research projects have ended, and new ones are beginning. HAB phenomena are complex oceanographic phenomena, and a decade or more of targeted research are needed for each of the major poisoning syndromes or regions. ECOHAB support for regional studies must be sustained and expanded, and this will require a commitment of resources well in excess of those currently available. Underlying this recommendation is the recognition that we need to form multiple skilled research teams with the equipment and facilities required to attack the complex scientific issues involved in HAB phenomena. Since HAB problems facing the U.S. are diverse with respect to the causative species, the affected resources, the toxins involved, and the oceanographic systems and habitats in which the blooms occur, we need multiple teams of skilled researchers and managers distributed throughout the country. This argues against funding that ebbs and floods with the sporadic pattern of HAB outbreaks or that focuses resources in one region while others go begging. **I cannot emphasize too strongly the need for an equitable distribution of resources that is consistent with the scale and extent of the national problem, and that is sustained through time.** This is the only way to keep research teams intact, forming the core of expertise and knowledge that leads to scientific progress. To achieve this balance, we need a scientifically based allocation of resources, not one based on political jurisdictions. This is possible if we work within the guidelines of HARRNESS and with the inter-agency effort that has been guiding its implementation.

A National Program on Prevention, Control, and Mitigation of HABs

Congress mandated a program for HAB Prevention, Control and Management in the legislation reauthorizing the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 (HABHRCA). The strong Congressional support behind this program element is further seen in a section of HABHRCA that directs NOAA to "identify innovative response measures for the prevention, control, and mitigation of harmful algal blooms and identify steps needed for their development and implementation." Further rationale for this program is that much of the focus of past HAB research has been on fundamental aspects of organism physiology, ecology, and toxicology, so less effort has been directed towards practical issues such as resource management strategies, or even direct bloom suppression or control (Anderson, 1997). To meet this Congressional directive, a workshop was held, and a science agenda prepared for *Harmful Algal Bloom Research, Development, Demonstration, and Technology Transfer* (RDDTT). The Executive Summary of this report is appended here as Annex 1. Another common name for this program is MACHAB (Mitigation and Control of Harmful Algal Blooms).

The proposed RDDTT program has three essential components. These are 1) an extramural funding program focused on development, demonstration, and technology transfer of methods for **prevention, control, and mitigation (PCM)** of HABs; 2) a comprehensive national HAB **Event Response** program: and 3) a **Core Infrastructure** program. These components are interdependent and critical for improving future HAB response

The PCM component of the RDDTT Program focuses on moving promising technologies and strategies arising from HAB research from development through demonstration to technology transfer and field application by end users. The Event Response component improves access to existing resources through better information sharing, communication, and coordination and provides essential new resources. Researching and implementing new PCM strategies and improving event response will not be possible without enhancing 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.

The need and community readiness for the three RDDTT program elements varies with the status of existing research and the planning required for each activity. The RDDTT program can, therefore, be implemented in stages, with projected funding needs increasing as the components mature. Implementation requires both changes in authorizing legislation and increases in appropriations. Although RDDTT will be the program that the public will most readily perceive as 'progress' in the management of HABs, the program 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 element within the national HAB program (HARRNESS), with the expectation that related HAB research and response programs will provide the new technologies and approaches as well as the ecological and oceanographic context to guide its practical and applied activities.** Since many agencies are involved in HAB research and response, it will be necessary to specify that the RDDTT Program is an interagency program and to provide funding to agencies with major roles. In addition to NOAA and NSF, other agencies, such as FDA, CDC, NSF, NIEHS, and USGS also contribute substantially and should be named as partners in the national HAB program.

SUMMARY AND RECOMMENDATIONS

The diverse nature of HAB phenomena and the hydrodynamic and geographic variability associated with different outbreaks throughout the U.S. pose a significant constraint to the development of a coordinated national HAB program. Nevertheless, the combination of planning, coordination, and a highly compelling topic with great societal importance has initiated close cooperation between officials, government scientists and academics in a sustained attack on the HAB problem. The rate and extent of progress from here will depend upon how well the different federal agencies continue to work together, and on how effectively the skills and expertise of government and academic scientists can be targeted on priority topics that have not been well represented in the national HAB program. The opportunity for cooperation is clear, since as stated in the ECOHAB science plan (Anderson, 1995), "*Nowhere else do the missions and goals of so many government agencies intersect and interact as in the coastal zone where HAB phenomena are prominent*." The HAB community in the U.S. has matured scientifically and politically, and is fully capable of undertaking the new challenges inherent in an expanded national program, exemplified in HARRNESS. This will be successful only if a coordinated interagency effort can be implemented to focus research personnel, facilities, and financial resources to the common goals of a comprehensive national strategy.

In summary:

- Marine HABs are a serious and growing problem in the U.S., affecting every coastal state; freshwater HABS are an equally significant problem in inland states. HABs impact public health, fisheries, aquaculture, tourism, and coastal aesthetics. HAB problems will not go away and will likely increase in severity.
- HABs are just one of many problems in the coastal zone that are affected by nutrient inputs and over-enrichment from land. They represent a highly visible indicator of the health of our coastal ocean. More subtle impacts to fisheries and ecosystems are likely occurring that are far more difficult to discern.
- A coordinated national HAB Program was created over 15 years ago and partially implemented. That *National Plan* is now outdated, and as a result, a new plan called HARRNESS has been formulated to guide the next decade or more of activities in HAB research and management.
- At the programmatic level, several of the existing national partnerships (e.g., ECOHAB, MERHAB, COHH, OHHI) should be sustained and expanded within HARRNESS, and new programs will need to be added. In the latter context, a separate program on HABs and food web impacts could focus resources on this important topic area in a way that is not presently possible through ECOHAB. The chemistry and toxicology of HABs requires focused attention and a targeted funding initiative. Likewise the practical aspects of HAB prevention, control and mitigation need to be implemented through a targeted program.
- State agencies are doing an excellent job protecting public health and fisheries, but those monitoring programs are facing growing challenges. Needs for the future include new technologies for HAB monitoring and forecasting and incorporation of these tools into regional Ocean Observing Systems.

Recommendations:

- Sustain and enhance support for the national HAB program HARRNESS.
- Sustain and enhance support for the ECOHAB, MERHAB and OHH programs, and implement new programs, such as Prevention, Control and Mitigation of HABs (RDDTT or MACHAB) that include Event Response and Infrastructure elements.
- Encourage interagency partnerships, as the HAB problem transcends the resources or mandate of any single agency

- Identify and authorize freshwater programs that would fall under the purview of relevant agencies, such as EPA, in addition to the marine and coastal programs authorized in NOAA. Separate funding lines are needed since NOAA has a geographic mandate that includes marine coastal waters and the upper reaches of estuaries, and the Great Lakes. Many freshwater HAB problems fall outside these boundaries, however, and therefore will need to be supported through separate appropriations.
- Support methods and instrument development for land- and mooring-based cell and toxin detection, and for bloom forecasting through instrument development support for the Integrated Ocean Observing System.
- Support appropriations that are commensurate with the scale of the HAB problem. The national HAB program is well established and productive, but it needs additional resources if new topics, responsibilities and tasks are added through new legislation. Research should be peer-reviewed and competitive, and should take full advantage of the extensive capabilities of the extramural research community.

Mr. Chairman, that concludes my testimony. Thank you for the opportunity to offer information that is based on my own research and policy activities, as well as on the collective wisdom and creativity of numerous colleagues in the HAB field. I would be pleased to answer any questions that you or other members may have.

Respectfully submitted,

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Literature citations:

Anderson, D.M. 1997. Turning back the harmful red tide. Nature 388:513-514.

Anderson, D.M. (Ed.). 1995. ECOHAB: The ecology and oceanography of harmful algal blooms - A research agenda. Woods Hole Oceanographic Institution. 66 pp.

Anderson, D. M. 1989. Toxic algal blooms and red tides: a global perspective. pp. 11-16, in: T. Okaichi, D. M. Anderson, and T. Nemoto (eds.), *Red Tides: Biology, Environmental Science and Toxicology*, Elsevier: New York, Amsterdam, London.

Anderson, D.M., S.B. Galloway, and J.D. Joseph. 1993. Marine Biotoxins and Harmful Algae: A National Plan. Woods Hole Oceanographic Institution Tech. Report, WHOI 93-02. Woods Hole, MA. 59pp.

Anderson, D.M., P.M. Glibert, and J.M. Burkholder. 2002. Harmful algal blooms and eutrophication: Nutrient sources, composition, and consequences. Estuaries 25(4b): 704-726.

Anderson, D.M., C.A. Stock, B.A. Keafer, A. Bronzino Nelson, B. Thompson, D.J. McGillicuddy, M. Keller, P.A. Matrai, and J. Martin. 2005. *Alexandrium fundyense* cyst dynamics in the Gulf of Maine. Deep-Sea Res. II 52(19-21): 2522-2542.

Boesch, D. F., D. M. Anderson, R. A. Horner, S. E. Shumway, P. A. Tester, T. E. Whitledge. 1997. *Harmful Algal Blooms in Coastal Waters: Options for Prevention, Control and Mitigation.* Science for Solutions. NOAA Coastal Ocean Program, Decision Analysis Series No. 10, Special Joint Report with the National Fish and Wildlife Foundation.

Burkholder, J. M. and H. B. Glasgow, Jr. 1997. The ichthyotoxic dinoflagellate *Pfiesteria piscicida*: Behavior, impacts and environmental controls. Limnology and Oceanography 42:1052-1075.

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

Hallegraeff, G. M. and C. J. Bolch. 1992. Transport of diatom and dinoflagellate resting spores via ship's ballast water: implications for plankton biogeography and aquaculture. Journal of Plankton Research 14:1067-1084.

Hoagland, P. and S. Scatasta. 2006. The economic effects of harmful algal blooms. *In* E. Graneli and J. Turner, eds., *Ecology of Harmful Algae*. Ecology Studies Series. Dordrecht, The Netherlands: Springer-Verlag.

McGillicuddy, D.J., Jr., D.M. Anderson, D.R. Lynch, and D.W. Townsend. 2005. Mechanisms regulating large-scale seasonal fluctuations in *Alexandrium fundyense* populations in the Gulf of Maine: Results from a physical-biological model. Deep-Sea Res. II 52(19-21): 2698-2714.

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

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

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Associate Scientist, Woods Hole Oceanographic Institution, 1983-1991; tenure 1987
Assistant Scientist, Woods Hole Oceanographic Institution, 1979-1983
Postdoctoral Investigator, Woods Hole Oceanographic Institution, 1978-1979
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Phycological Society of America
International Society for the Study of Harmful Algae (Member, ISSHA Council)
The Oceanography Society

SELECTED COMMITTEES AND DISTINCTIONS

Recipient, Stanley W. Watson Chair for Excellence in Oceanography (1993)
Recipient, NOAA Environmental Hero Award (1999)
Recipient, Yasumoto Lifetime Achievement Award, International Society for the Study of Harmful Algae (2006)
Bruun Memorial Medal, Bruun Memorial Lecture. IOC Assembly, Paris, France, 2005
Director, NATO ASI: The Physiological Ecology of Harmful Algal Blooms (1996)
Director, U.S. National Office on Marine Biotoxins and Harmful Algal Blooms
Member, Scientific Steering Committee, GEOHAB (1998-2003)
Scientific Advisor, U.S. Delegation to the IOC/FAO Intergovernmental Panel on Harmful Algal Blooms (1992-present)
Testimony before the Subcommittee on Oceans and Fisheries of the Committee on Commerce, Science, and Transportation, United States Senate 105th Congress, Second Session, May 20, 1998
Testimony for US Commission on Ocean Policy, 2002; prepared White Paper on Harmful Algal Blooms for inclusion in the Commission's report "Oceans and Human Health"
Testimony before the Committee on Science, Subcommittee on Environment, Technology and Standards, U.S. House of Representatives Hearing on the "Harmful Algal Bloom and Hypoxia Research Amendments Act of 2003", March 13, 2003
Briefing before the House Science Committee, "Coastal Nutrient Pollution and Harmful Algal Blooms", September 24, 2003
Briefing before New England congressional staffers, The 2005 New England red tide", June 14, 2005

Congressional briefings, “Harmful Algal Blooms (Red Tides) and Ocean Health”, House of Representatives, and U.S. Senate, June 23, 2005

Testimony before the Subcommittee on Fisheries Conservation, Wildlife and Oceans, U.S. House of Representatives Hearing on H.R. 1856, the Harmful Algal Bloom and Hypoxia Research Amendments Act of 2003, February 26, 2004.

SELECTED PUBLICATIONS

(Publications selected from over 230 authored or co-authored publications)

2005 Anderson, D.M., B.A. Keafer, D.J. McGillicuddy, M.J. Mickelson, K.E. Keay, P.S. Libby, J.P. Manning, C.A. Mayo, D.K. Whittaker, J.M. Hickey, R. He, D.R. Lynch, and K.W. Smith. Initial observations of the 2005 *Alexandrium fundyense* bloom in southern New England: General patterns and mechanisms. Deep-Sea Res. II 52(19-21): 2856-2876.

2005 Anderson, D.M., C.A. Stock, B.A. Keafer, A. Bronzino Nelson, B. Thompson, D.J. McGillicuddy, M. Keller, P.A. Matrai, and J. Martin. *Alexandrium fundyense* cyst dynamics in the Gulf of Maine. Deep-Sea Res. II 52(19-21): 2522-2542.

2005 Anderson, D.M., B.A. Keafer, W.R. Geyer, R.P. Signell, and T.C. Loder. Toxic *Alexandrium* blooms in the western Gulf of Maine: The plume advection hypothesis revisited. Limnol. Oceanogr. 50(1): 328-345.

2005 Anderson, D.M., D.M. Kulis, B.A. Keafer, K.E. Gribble, R. Marin, and C.A. Scholin. Identification and enumeration of *Alexandrium* spp. from the Gulf of Maine using molecular probes. Deep-Sea Res. II 52(19-21): 2467-2490.

2005 Keafer, B.A., J.H. Churchill, D.J. McGillicuddy, and D.M. Anderson. Bloom development and transport of toxic *Alexandrium fundyense* populations within a coastal plume in the Gulf of Maine. Deep-Sea Res. II 52(19-21): 2674-2697.

2003 McGillicuddy, D.J., Jr., R.P. Signell, C.A. Stock, B.A. Keafer, M.D. Keller, R.D. Hetland, and D.M. Anderson. A mechanism for offshore initiation of harmful algal blooms in the coastal Gulf of Maine. J. Plankt. Res. 25(9): 1131-1138.

2005 McGillicuddy, D.J., Jr., D.M. Anderson, D.R. Lynch, and D.W. Townsend. Mechanisms regulating large-scale seasonal fluctuations in *Alexandrium fundyense* populations in the Gulf of Maine: Results from a physical-biological model. Deep-Sea Res. II 52(19-21): 2698-2714.

2005 Stock, C.A., D.J. McGillicuddy, A.R. Solow, D. M. Anderson. Evaluating hypotheses for the initiation and development of *Alexandrium fundyense* blooms in the western Gulf of Maine using a coupled physical-biological model. Deep-Sea Res. II 52(19-21): 2715-2744.

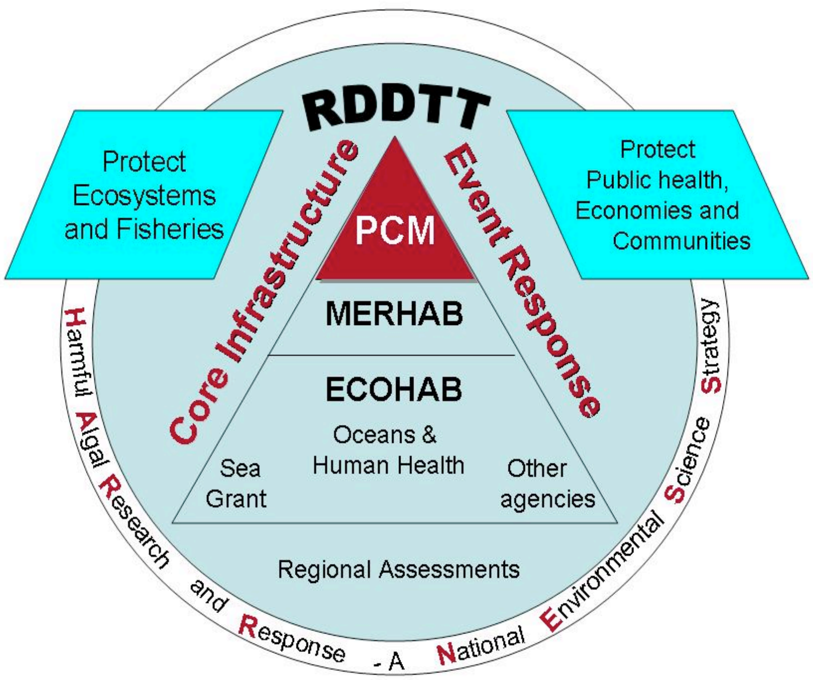
1997 Anderson, D. M. Bloom dynamics of toxic *Alexandrium* species in the northeastern United States. Limnol. & Oceanogr. 42:1009-1022.

1994 Anderson, D. M., D. M. Kulis, G. J. Doucette, J. C. Gallager and E. Balech. Biogeography of toxic dinoflagellates in the genus *Alexandrium* from the northeast United States and Canada as determined by morphology, bioluminescence, toxin composition, and mating compatibility. Mar. Biol. 120: 467-478.

Annex 1. Executive Summary – The Harmful Algal Bloom Research, Development, Demonstration and Technology Transfer Program.

DRAFT

Harmful Algal Bloom Research, Development, Demonstration and Technology Transfer Workshop Report



Editors: Q. Dortch, D. Anderson, D. Ayres, P. Glibert

October, 2007

Workshop held June 22-24, 2007 Woods Hole, MA

EXECUTIVE SUMMARY

Background

The marine and freshwaters of many countries are increasingly impacted by the growing 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 such blooms may also be green, yellow, brown, or even without visible color, depending on the type of organisms present. HABs is a more appropriate descriptor.

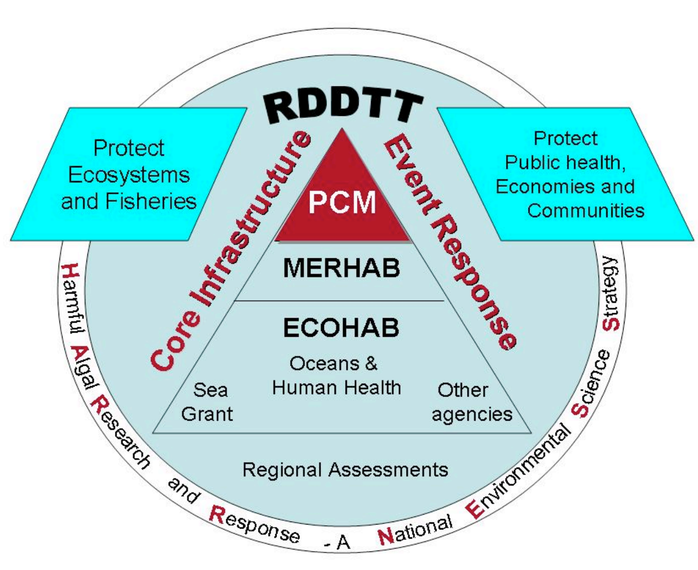
In U.S. waters HABs are found in expanding numbers of locations and are also increasing in duration and severity. Further, new HAB species or impacts have emerged to pose additional threats to human and ecosystem health in particular regions. The expansion in HABs has led to increased awareness of impacts 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 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, the *National Assessment of Efforts to Predict and Respond to Harmful Algal Blooms in U.S. Water (Prediction and Response Report 2007)*, assesses the extent of the HAB problem in the U.S., 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. A strategy to address these needs for both marine and fresh waters will be included in the follow up *HABHRCA* 2004 report, the *National Scientific Research, Development, Demonstration, and Technology Transfer Plan (RDDTT Plan) on Reducing Impacts from Harmful Algal Blooms*, which will be derived in part from this Workshop Report. Besides addressing the needs identified in the *Prediction and Response Report*, the *RDDTT Plan* will also address issues raised in three recent reports developed by the HAB management and research community, *Harmful Algal Research and Response, A National Environmental Science Strategy* (HARRNESS, 2005), *Harmful Algal Research and Response: A Human Dimensions Strategy* (HARR-HD 2006), and the *Proceedings of the Interagency, International Symposium on Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs* (*ISOCHAB* 2007).

Process for Developing the RDDTT Program

Input for the *RDDTT Plan* was solicited from both the marine and freshwater HAB research and management communities during a workshop in Woods Hole, MA June 22-25, 2007. This *RDDTT Workshop Report* summarizes the current status of the field, recommends a program to improve HAB prediction and response (Box 1), and suggests an implementation process. The

RDDTT Plan, which will be written by the Joint Committee on Ocean Science and Technology Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health and submitted to Congress, will draw from these recommendations.



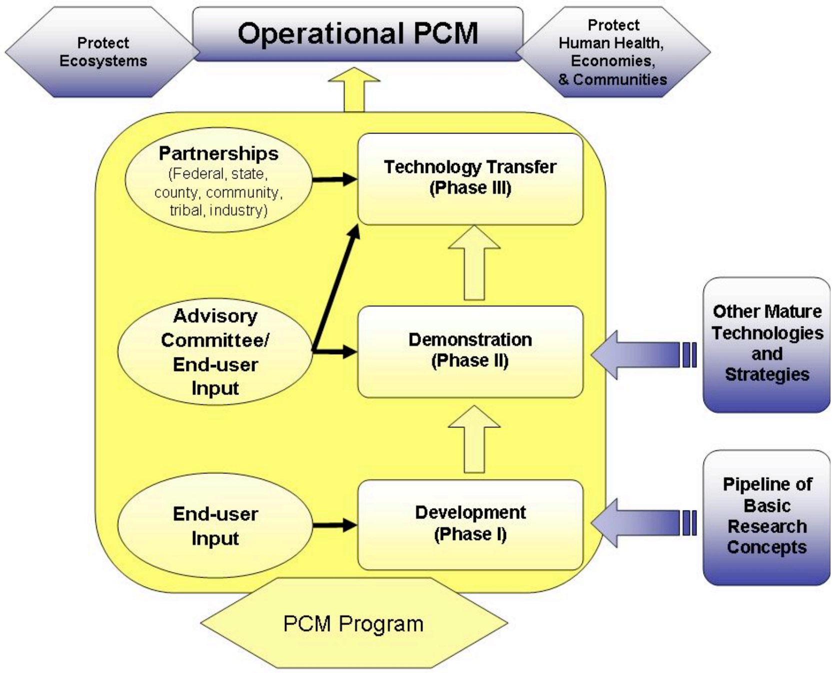
Box 1. Diagram showing the relationship of the three elements of the RDDTT Program with other HAB research and response programs.

The workshop attendees proposed approaches for an RDDTT Program with three essential components, based on the opportunities for advancement identified in the reports cited above. These are 1) an extramural funding program focused on development, demonstration, and technology transfer of methods for prevention, control, and mitigation (**PCM**) of HABs; 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 related to "human dimensions" and call for the meaningful engagement of at risk and affected communities. These components are interdependent and critical for improving future HAB response (Box 1).

Prevention, Control, and Mitigation (PCM) Development, Demonstration, and Technology Transfer

The PCM component or sub-program of the RDDTT Program focuses on moving promising technologies and strategies, arising from HAB research from development through demonstration to technology transfer and field application by end users. Programs that would feed technologies to the PCM component would include programs such as the Ecology of Harmful Algal Blooms (ECOHAB), Monitoring and Event Response (MERHAB), Sea Grant, and Oceans and Human Health (OHH), As shown in Box 2, the program work would flow 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 technologies in the field across a broad temporal and spatial scale. 3) The Technology Transfer phase (Phase 3) facilitates the transition of proven technologies and strategies to end users. End users, including local, state, and federal resource and public health managers, non-profit 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 are already available to feed into the PCM sub-program. Example focal areas within the prevention category include modifications of hydrodynamic conditions in areas



Box 2. Diagrammatic representation of the PCM program component showing the pipeline for PCM technologies leading to full-scale technology transfer and field applications. .

subject to HABs, or methods to avoid introducing HABs cells and cysts as invasive species. Although nutrient reduction is also a very promising strategy for HAB prevention, many nutrient management programs already exist and are motivated by issues other than HABs. Methods of control or bloom suppression through the removal of HAB cells or toxins by biological, chemical, or mechanical means are ready for further investigation. For example, mechanical removal of cells and toxins by clay flocculation is one approach that has already been tested in pilot field studies, so it is ready for further Phase 2 evaluation. A number of biological control methods are ready for Phase 1 development studies in the field, with concomitant research needed in risk communication to foster public understanding and participation in decision making about potentially controversial strategies. Many opportunities exist to improve mitigation activities that 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, preventing and treating human and animal disease syndromes, assessing the socioeconomic impacts of HABs and the effectiveness of PCM strategies, and advancing education and outreach.

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. Involvement of 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.

Event Response

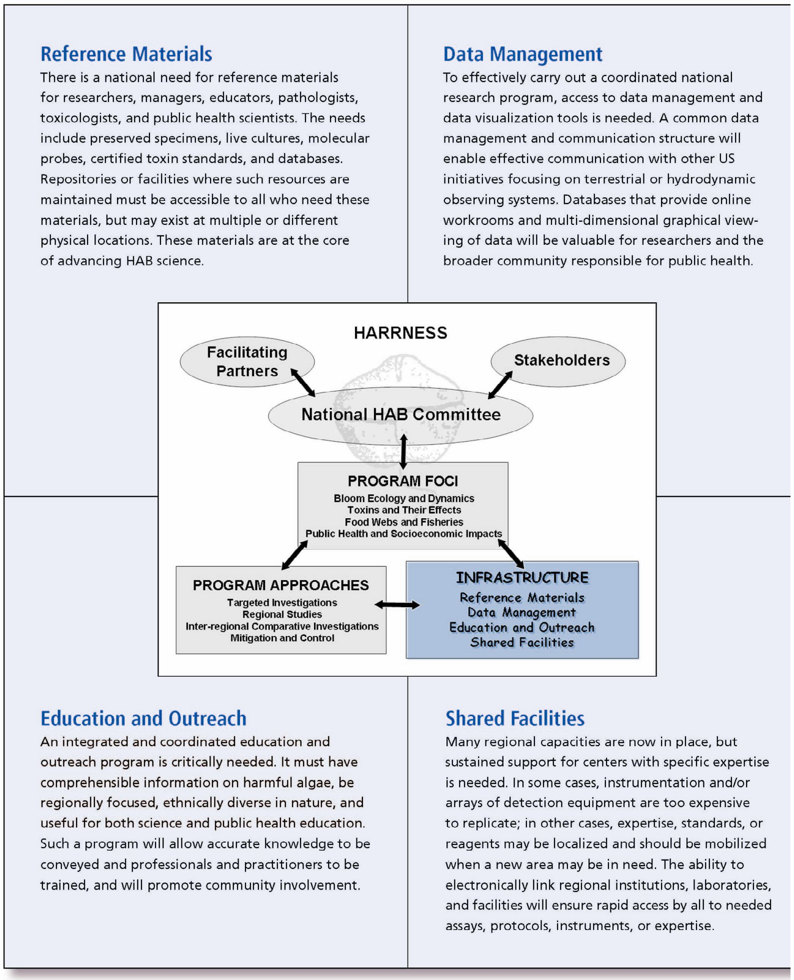
In order to mitigate the impacts of HABs, there is an urgent need to further develop the capacity for anticipating events and responding rapidly. The range of stakeholders involved in event response depends upon the nature of the HAB, the geographic area affected and the implications for human, fish, 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. 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 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 carefully timed and positioned shellfish closures. Many other states also have successful programs in place to manage shellfish closures.

As HABs are occurring at larger scales, greater frequency and scope of impact than in the past, 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. Toxic freshwater blooms can threaten public water supplies and lead to widespread recreational impacts.

The insufficient capacity for adequate responses to new or large-scale HAB events is in part a product of inexperience, lack of resources, and the unpredictable nature of such events. It is costly and time-consuming to develop a response capacity for events that are sporadic or rare, or for those that have increased in frequency and scale, and for which damages are uncertain. These characteristics argue strongly for a national and regional approaches to event response. In effect, such a program helps a region or the nation insure itself against the public health effects, ecological impacts, and economic damages that could arise from unusual, unpredictable, and devastating HAB events.

It is clear that HAB event response capacities need to be expanded at a national level. Existing program will not be able to address anticipated increases in HAB frequency and intensity.

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 Coordinators, possibly residing in NOAA and EPA, potentially linked to a network of Regional 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, but inadequately funded NOAA Event Response Program (http://www.cop.noaa.gov/stressors/extremeevents/hab/current/fact-ev_resp.html). 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 3. Summary of Infrastructure needs from HARRNESS

CORE Infrastructure

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. These needs cross-cut science and management and bridge individual agency interests. While in some cases they may intersect with the goals of other US programs already in place, existing programs are inadequate to meet these requirements. The needs for critical infrastructure were identified in the first National HAB plan in 1993 and strongly reiterated in the revised national plan for 2005-2015 (HARRNESS 2005). Critical infrastructural needs can now be identified and efforts made to obtain the financial and administrative support needed to make them a reality, with an ultimate goal of growing a greater community through collaboration.

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 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

The proposed RDDTT Program (Box 1) is comprised of three components: 1) a component for HAB prevention, control, and mitigation (PCM), 2) an Event Response component, and 3) a Core Infrastructure component. The need and community readiness for each 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 reauthorizations of HABHRCA every five years, with projected funding needs increasing as the components mature (Box 4). The PCM component forms the core 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 not fully implemented until the next five year reauthorization (FY 14-FY 18).

Implementation requires both changes in authorizing legislation and increases in appropriations. Although the RDDTT will be the program that the public will most readily perceive as 'progress' in the management of HABs, the program 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 element within the national HAB program (HARRNESS 2005), with the expectation that related HAB 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. When HABHRCA is reauthorized, the RDDTT program should therefore be hihglighted along with the existing ECOHAB and MERHAB programs, with the three components of the RDDTT Program specifically listed.

Since many agencies are involved in HAB research and response, it will be necessary to specify that the RDDTT Program is an interagency program and to provide funding to agencies with major roles. In particular the HABHRCA reauthorization should identify and authorize freshwater programs that would fall under the purview of relevant agencies, such as EPA, in addition to the marine and coastal programs authorized in NOAA. Separate funding lines are needed since NOAA has a geographic mandate that includes marine coastal waters and the upper reaches of estuaries, and the Great Lakes. Many freshwater HAB problems fall outside these boundaries, however, and therefore will need to be supported through separate appropriations to the EPA. Other agencies, such as FDA, CDC, NSF, NIEHS, and USGS, also contribute substantially and should be named as partners in the national HAB program.

Funding to implement the freshwater and marine components of the RDDTT program over the next five years (FY09-FY13) is roughly projected to be equivalent to that of the ECOHAB and

MERHAB programs. Full implementation will thus require additional funding of \$6.5M (FY 08) to \$10.5M (FY 13).

Box 4. **Outline of HAB RDDTT Program Components**

1. Prevention, Control, and Mitigation Development, Demonstration, and Technology Transfer
   a. Move promising technologies and strategies 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 extramural funding*
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, improving 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

**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.

***Requests for assistance would most likely come from state, local or tribal governments.

Benefits of RDDTT Implementation

Full implementation of all the components of an RDDTT Program will yield many benefits for the public health and management communities and for residents, resource users, businesses and other stakeholders in at-risk and affected communities. It will also address many of the frustrations people living in HAB impacted communities experience and provide them with new strategies to address the problems. These benefits include:

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

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