TESTIMONY OF
ROBERT E. MAGNIEN, Ph.D.
DIRECTOR
CENTER FOR SPONSORED COASTAL OCEAN SCIENCE
NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINSTRATION

BEFORE THE
COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
U.S. HOUSE OF REPRESENTATIVES

July 10, 2008

Introduction

Good morning, Mr. Chairman and members of the Subcommittee. My name is Robert E. Magnien, Director of the National Oceanic and Atmospheric Administration's (NOAA's) Center for Sponsored Coastal Ocean Research (CSCOR). CSCOR provides extramural funding for multi-disciplinary research focused on understanding and predicting the impacts of natural and anthropogenic influences on coastal ecosystems, communities, and economies. In this capacity, I administer the only two national programs solely focused on harmful algal blooms (HABs): the interagency Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) Program and NOAA's Monitoring and Event Response for Harmful Algal Blooms (MERHAB) Program, which are authorized by the *Harmful Algal Bloom and Hypoxia Research and Control Act of 1998* (*HABHRCA*). I also serve on the Interagency Working Group on HABs, Hypoxia, and Human Health (IWG-4H), which, among other responsibilities, implements the reporting requirements of *HABHRCA* 2004. I appreciate the opportunity to discuss NOAA's role in addressing HABs in our coastal waters and the Great Lakes. I will highlight the advances NOAA's efforts have made in improving HAB management and discuss how we plan to build on our early successes.

HAB Problem

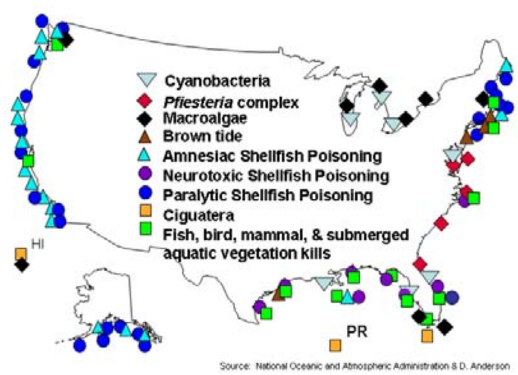
Algae are simple plants that, in general, are beneficial because they provide the main source of energy that sustains marine and aquatic life. However, a small percentage of algae cause harm to humans, animals, and the environment by producing toxins or by growing in excessively large numbers. When this occurs they are referred to as "harmful algal blooms" or HABs. When these algae are present in such high numbers that they discolor the water, HABs are sometimes called "red tides," "brown tides," etc., but not all HABs cause water discoloration. Table 1 lists some of the major HAB organisms in the United States.

Some harmful algae produce potent toxins that cause illness or death in humans and other organisms — fish, seabirds, manatees, sea lions, turtles, and dolphins are some commonly affected animals. Humans and other animals can be exposed to algal toxins through the food they eat, the water they drink or swim in, or the air that they breathe. Other harmful algae are nontoxic to humans and wildlife but form such large blooms that they degrade habitat quality through massive overgrowth, shading, or oxygen depletion (hypoxia). These high biomass blooms can also be a nuisance to humans when masses of algae accumulate along beaches and subsequently decay.

HABs can have major negative impacts on local economies when, for example, shellfish harvesting is restricted to protect human health or when tourism declines due to degradation of recreational resources. HABs can also result in significant public health costs when humans become ill. A recent conservative assessment estimates that HABs occurring in marine waters alone have an average annual impact of $82 million dollars in the United States[1]. We know that local impacts of single events can be large, sometimes larger than the average annual impact. For example, in 2005, we saw $18 million in lost shellfish sales in Massachusetts alone[2]. Economic impacts can be difficult to calculate as they vary from region to region and event to event, but they are a primary concern of coastal communities that experience HAB events.

The public health, ecosystem, and economic impacts can all have social and cultural consequences. For example, along the Washington and Oregon coasts, tens of thousands of people visit annually to harvest razor clams recreationally whenever the beaches are opened but, due to high levels of the HAB toxin domoic acid, there have been a number of closures to the recreational fishery in recent years. These closures have not only resulted in economic losses, but also in an erosion of community identity, community recreation, and a traditional way of living for native coastal cultures.

The geographic distribution of HAB events in the United States is broad. For example, all coastal states have experienced HAB events over the last decade (see map of HAB events). Moreover, the problem is not limited to the marine coasts of the United States, as freshwater HABs occur in the Great Lakes and in many inland waters. Evidence indicates that the frequency and distribution of these events and their impacts have increased considerably in recent years in the United States and globally[3].



Although all coastal states experience HABs, the specific organisms responsible for the HABs

[1] Hoagland, P., and Scatasta, S. 2006. The economic effects of harmful algal blooms. In E Graneli and J Turner, eds., Ecology of Harmful Algae. Ecology Studies Series. Dordrecht, The Netherlands: Springer-Verlag, Chap. 29.
[2] Jin, D., Thunberg, E., and Hoagland, P. 2008. Economic impact of the 2005 red tide event on commercial shellfish fisheries in New England. Ocean and Coastal Management. 51(5): 420-429.
[3] GEOHAB, 2006. Global Ecology and Oceanography of Harmful Algal Blooms, Harmful Algal Blooms in Eutrophic Systems. P. Glibert (ed.). IOC and SCOR, Paris and Baltimore, 74, pp.
* Heisler, J., P. Glibert, J. Burkholder, D. Anderson, W. Cochlan, W. Dennison, C. Gobler, Q. Dortch, C. Heil, E. Humphries, A. Lewitus, R. Magnien, H. Marshall, K. Sellner, D. Stockwell, D. Stoecker, and M. Suddleson. 2008 Eutrophication and Harmful Algal Blooms: A Scientific Consensus. *Harmful Algae*. In press.

differ among regions of the country (see HAB map). As a result the harmful impacts vary in their scope and severity, which leads to the need for specific management approaches for each region and problem. Some species need to be present in very high abundance before harmful effects occur making them easy to detect and track. Others cause problems at very low concentrations and can in essence be hidden among other benign algae, so they are difficult to detect and track. The factors that cause and control blooms from initiation to decline vary not only by species, but also by region due to differences in coastlines, runoff, oceanography, nutrient regime, other organisms present in the water, etc. Consequently, developing strategies for HAB management requires a regional approach.

The causes of HABs are complex. Not only do they vary between species and locations but they are not all well understood. In general, algal species grow best when environmental conditions (such as temperature, salinity, and availability of nutrients and light) are optimal for cell growth. Other biological and physical processes determine if enhanced cell growth will result in biomass accumulation (or what we call a "bloom"). The challenge for understanding the causes of HABs stems from the complexity of these biological, chemical, and physical interactions and their variable influence on growth and bloom development among different HAB species. The complexity of interactions between HABs, the environment, and other plankton complicate the predictions of when and where HAB events will occur. Knowledge of how all these factors control the initiation, sustainment, and decline of a bloom is a critical precursor for advancing HAB management.

Human activities are thought to contribute to the increased frequency of some HABs[3]. For example, increased nutrient pollution has been acknowledged as a likely factor contributing to increased occurrence of several high biomass HABs. Other human-induced environmental changes that may foster development of certain HABs include changes in the types of nutrients entering coastal waters, alteration of food webs by overfishing, introductions of non-indigenous species that change food web structure, introduction of HAB cells to new areas via ballast water or other mechanisms, and modifications to water flow. It should also be noted that climate change will almost certainly influence HAB dynamics in some way since many critical processes governing HAB dynamics—such as temperature, water column stratification, upwelling and ocean circulation patterns, and freshwater and land-derived nutrient inputs—are influenced by climate. The interactive role of climate change with the other factors driving the frequency and severity of HABs is an important topic in the early stages of research, but climate change is expected to exacerbate the HAB problem in some regions[4].

NOAA HAB Programs

The long-term goal of NOAA's HAB programs is to prevent, control, and mitigate HABs and their impacts in U.S. coastal waters, including the Great Lakes. Since most HAB impacts are managed at the state and local level, achieving this goal is mainly accomplished by providing state and local coastal and public health managers and local communities with the information

[4] Edwards, M., Johns, D.G,, Leterme, S.C., Svendsen, E., and Richardson, A.J. 2006. Regional climate change and harmful algal blooms in thenortheast Atlantic. Limnol. Oceanogr. 52(2): 820-829.
* Dale, B., Edwards, M., and Reid, P.C. 2006. Climate change and harmful algal blooms. In Granéli, E., and Turner, J.T. (eds.), Ecology of Harmful Algae. Ecological Studies. 189: 367-378.

and tools they need to protect human health, ecosystem health, and coastal economies. NOAA, through its HAB research and partnerships with academic institutions as well as other efforts in coordination with multiple agencies, is developing tools and applications to assist local decision-makers. A few examples include:

- more accurate methodologies for detecting and tracking HAB cells and toxins that allow managers to assess more quickly, and cost-effectively, the magnitude of a HAB event;
- models for forecasting when and where HABs will occur and testing prevention strategies;
- methods of diagnosing and treating toxin exposure in animals and humans;
- risk communication and prevention strategies based on economic analyses and risk assessments for human, animal, and ecosystem health; and
- public education and awareness resources and materials.

These efforts are guided in part by two strategic plans: (1) *HARRNESS: National Plan for Algal Toxins and Harmful Algal Blooms* and (2) *Harmful Algal Research and Response: A Human Dimensions Strategy*, which have both provided direction for NOAA's HAB research and management strategies. Developing useful products for HAB management is a multi-step process that requires a variety of approaches, all of which require a strong scientific understanding of the causes and impacts of HABs.

NOAA leads two programs solely focused on HABs: the interagency Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) Program and the NOAA Monitoring and Event Response for Harmful Algal Blooms (MERHAB) Program, both of which were authorized by *HABHRCA*. ECOHAB is a competitive research program focused on determining the causes and impacts of HABs. The information and tools ECOHAB provides are necessary for developing technologies for, and approaches to, predicting, preventing, monitoring and controlling HABs. MERHAB is a competitive research program that focuses on incorporating tools, approaches, and technologies from HAB research programs into existing HAB monitoring programs. MERHAB also establishes partnerships to enhance existing and initiate new HAB monitoring capabilities to provide managers with timely information needed to mitigate HAB impacts on coastal communities.

Numerous other programs within NOAA also address HAB problems as part of their specific legislative mandate. These include the Oceans and Human Health Initiative, Sea Grant, the Office of Protected Resources, fisheries management programs, the Integrated Ocean Observing System Program, and numerous NOAA labs and centers that conduct intramural research. There is close collaboration between all of these programs. Many of NOAA's research accomplishments have resulted from the efforts of more than one NOAA program.

Other agencies also contribute substantially to improving HAB research and response. These include the Food and Drug Administration, the Environmental Protection Agency (EPA), the National Science Foundation, the National Institute of Environmental Health Sciences, the National Aeronautics and Space Administration, the Centers for Disease Control, and the U.S. Geological Survey. Interagency coordination is provided by the IWG-4H, which has taken on the functions of the HAB Task Force, designated in *HABHRCA*. Interagency coordination has improved considerably since the IWG-4H was established under the direction of the *U.S. Ocean*

Action Plan governance structure, through the Joint Subcommittee on Ocean Science and Technology.

Accomplishments Since 1998

The passage of *HABHRCA* in 1998 marked the formal beginning of NOAA's HAB programs, although some efforts were already underway. In the following 10 years there have been many accomplishments that have improved HAB management and response in virtually every coastal state. Below are just a few examples that highlight the benefits of NOAA's HAB research.

In April 2008, NOAA-funded researchers predicted a severe outbreak of *Alexandrium fundyense* off the New England coast. This organism produces potent neurotoxins that are filtered by shellfish. When humans consume contaminated shellfish they become extremely ill and can die without immediate medical treatment. To prevent human health illness and death, states in the region have extensive, rigorous shellfish toxin monitoring programs. When toxins in shellfish reach regulatory limits in a particular region, both commercial and recreational harvests are closed.

The 2008 prediction was derived from a model, based on 10 years of ecosystem research in the Gulf of Maine. The prediction was remarkably accurate, but the severity of the event cannot be fully assessed until the end of the HAB season. The prediction allows state managers and the shellfish aquaculture industry to plan for a difficult season. By showing the news media and the public that the event was expected and state managers were prepared, the prediction may have also reduced the "halo" effect in which shellfish harvesting closures in one area reduce shellfish and fish sales from areas unaffected by toxicity. Subsequent weekly predictions and survey cruises have provided managers with information about the location of high numbers of toxic cells and where they are likely to be transported by currents in the next few days, helping them to monitor more efficiently and effectively. A simple listserv for state and federal managers and researchers keeps everyone from the Bay of Fundy to the southern New England states informed about the progress of the event.

Florida's harmful algal blooms are typically red tides caused by an organism called *Karenia brevis*, which produces a very different neurotoxin than that found in the species that causes the New England blooms. Blooms occur most often along the west Florida coast, but also in the Panhandle and occasionally on the east coast of Florida. Besides contaminating shellfish, resulting in harvest closures to protect public health, *Karenia* blooms also cause massive fish, bird, turtle, and marine mammal mortalities. In addition, the toxin can be suspended in the air as an aerosol along beaches and in near-shore areas, causing irritation of the throats and eyes of beachgoers. In extreme cases severe respiratory problems can result and require hospitalization. Recent research shows that instead of one species, *Karenia brevis*, there are multiple *Karenia* species that produce HABs, and which differ in types of toxins and conditions favoring growth. Research is underway to develop quick methods and sensors that can be deployed on moorings to identify these species.

A Florida HAB Bulletin is issued twice a week by NOAA, providing the location of current blooms, as determined by satellites, and forecasting transport and impacts over the next few days. A pilot project, funded by the State of Florida, is currently linking lifeguard observations to the HAB Bulletin, to provide beach goers with real time information about beach conditions.

Many methods for detecting *Karenia brevis* and its toxins have been developed with NOAA funding, for use in different applications. A quick test for the toxins has been developed and is now undergoing approval for use as an official monitoring method for public health. This test has also been instrumental in investigating dolphin and manatee mortality events, leading to the discovery of unusual toxin exposure pathways in both organisms. Additionally, an autonomous underwater glider has been developed that can optically map the distribution of *Karenia* below the surface and send the data back to shore-based labs.

Several large regional studies have produced a model that, along with observations, is being used to determine the environmental factors that contribute to blooms. In particular there is a debate currently about the source of nutrients fueling these recurring blooms. If land-based nutrient pollution is an important cause, it may be possible to reduce or prevent blooms by reducing nutrient inputs.

NOAA and other agencies have also funded studies to investigate both physical and biological methods of controlling *Karenia* blooms. A pilot project in the field has shown that spraying a clay suspension on a bloom is highly effective in causing a bloom to sink to the bottom. The control of blooms by both naturally occurring bacteria and viruses has also been investigated. No suitable viruses were found, but several algicidal bacteria were found that killed *Karenia* in laboratory cultures. These studies hold great promise for future HAB control strategies, and follow up research would be a priority topic in NOAA competitions.

Karenia brevis blooms also occur in Texas coastal waters, although much less frequently than in Florida. A Texas HAB Bulletin has been provided by NOAA weekly since 2006 in a demonstration/testing mode, as we reevaluate our models to incorporate the specific oceanographic conditions off Texas. Because *Karenia* blooms are much more sporadic along the Texas coast, routine monitoring is not conducted unless an outbreak is occurring so early warning is especially important for protecting public health.

Several NOAA projects have investigated the use of instruments moored offshore that are capable of taking pictures, recognizing images of *Karenia* and sending the pictures back to shore-based labs to provide early warning. During a recent experimental deployment a HAB organism was observed in very high numbers that had never caused problems in the U.S. before, *Dinophysis*. State public health managers were immediately notified and oysters were found to be toxic. Shellfish harvesting was closed and shellfish recalled just days before the Fulton Oysterfest, a major event in the region, attended by thousands of people. Early detection and quick warning prevented human illness which would have been a devastating blow to the local shellfish industry.

The entire west coast of the U.S. has problems with two HAB groups, *Alexandrium* and *Pseudo-nitzschia*. The *Alexandrium* on the west coast is a different species, but similar in many ways to the *Alexandrium* in the Gulf of Maine. Much less is known about the factors that cause the west coast blooms or their impacts. *Pseudo-nitzschia* are a group of species, some of whom produce a potent neurotoxin and others do not. The toxin accumulates in both shellfish and fish and has caused bird and marine mammal mortality events. Particularly hard hit are sea lions, in which the neurotoxin causes seizures. The effected sea lions are often permanently impaired if they survive. In pregnant females, the seizures have caused them to go into labor prematurely.

State and tribal public health monitoring is focused on shellfish and Dungeness crabs. Through a variety of programs, NOAA has been very active in developing and evaluating quick tests for detecting the toxins from *Alexandrium* and *Pseudo-nitzschia*. These are being incorporated into both state and tribal monitoring in order to better protect human health. Monitoring partnerships between state and tribal agencies and researchers have been fostered by NOAA projects in Washington, Oregon, and several locations in California to incorporate these new monitoring technologies and to develop new, more effective strategies. One of these, the Olympic Region Harmful Algal Bloom Partnership, is now funded by the State of Washington.

NOAA has jointly funded with NSF a large regional study along the Washington coast to determine the off-shore source of toxic *Pseudo-nitzschia*, which are occasionally transported into shore and make shellfish, particularly razor clams, toxic. This study is developing a predictive model and is the basis of a HAB Forecast that will be released this summer on an experimental basis.

Some of the Great Lakes have experienced a resurgence of algal blooms in the last few years, especially Lake Erie and parts of Lake Huron. These blooms, comprised of a mixture of cyanobacteria (blue-green algae), but usually dominated by *Microcystis*, can produce hepatotoxins and neurotoxins that can cause animal and human illness and death. The organisms also produce compounds which make the water taste and smell foul and can impart a bad taste to fish. In addition, the high biomass levels can lead to bottom water oxygen depletion (hypoxia), which kills other organisms. Several NOAA projects have led to development of capacity for measuring most of the common cyanobacterial toxins and then determining when and where these toxins occur. These projects have shown that all major groups of cyanobacterial toxins occur in the Great Lakes at some times and that concentrations can at times be very high. NOAA is developing a Great Lakes HAB forecast, based on satellite remote sensing, in order to provide early warning of blooms and bloom tracking.

Cyanobacterial hepatotoxins are structurally very different from any of the other HAB toxins and little is known about their ability to accumulate up the food chain and impact higher trophic levels, including humans. Several NOAA studies are investigating accumulation and impacts of these toxins in organisms that consume cyanobacteria and could transfer the toxins through food chains that might lead to humans. The link between the zebra and quagga mussel invasion, alterations in nutrient cycling, and cyanobacterial blooms is being investigated by both NOAA and EPA, as a jointly funded project under the interagency ECOHAB program, to explain why these blooms have recurred and, perhaps, lead to an effective prevention strategy.

In general NOAA-funded research has made the greatest improvements in developing new methods of detecting HABs and HAB toxins: improving monitoring capabilities; understanding the causes and impacts of blooms; and predicting some of the most devastating blooms. Progress towards prevention and control of HABs and their impacts is also moving forward as a result of this advanced understanding and capability. Development of prevention strategies and control technologies requires a comprehensive understanding of HAB causes, adequate technology development, and programs that foster the transition from research to operations. The President's FY 2009 Budget Request will allow NOAA to continue its efforts to advance the nation's capabilities in HAB prevention, control, and mitigation.

Future Directions and Challenges

The 2004 *HABHRCA* reauthorization mandated four HAB reports be produced, which summarize the accomplishments of federal research and response efforts and provide guidance on future directions for HAB research and response. These reports, developed by the IWG-4H, include the *National Assessment of Efforts to Predict and Respond to Harmful Algal Blooms in U.S. Waters* and the *National Scientific Research, Development, Demonstration, and Technology Transfer Plan on Reducing Impacts from Harmful Algal Blooms (RDDTT Plan)*. These two reports will be combined and published under the name *Harmful Algal Bloom Management and Response: Assessment and Plan*. The other two reports are the *Scientific Assessment of Marine Harmful Algal Blooms (Marine HAB Report)*, and the *Scientific Assessment of Freshwater Harmful Algal Blooms*. The *National Assessment of Efforts to Predict and Respond to Harmful Algal Blooms in U.S. Waters* was transmitted to Congress in September 2007; all of the remaining reports are undergoing review and will be transmitted to Congress as soon as possible.

The *RDDTT Plan* lays out a comprehensive approach for improving HAB prevention, mitigation, control, event response, and HAB research and response infrastructure. As a result, NOAA is establishing an RDDTT Program, which will be an extramural, competitive research program to support the development, demonstration and transfer of tools, technologies, and strategies to help resource managers, public health managers, and researchers detect, monitor, investigate, control, and reduce HABs and their impacts. Both the original *HABHRCA* and the 2004 reauthorization authorize a prevention, control, and mitigation program, which the *RDDTT Plan* now defines. The purpose of the RDDTT Program will be to transition new technology and information into tools that can easily be used by managers and local communities.

Recent events and the increasing intensity and frequency of HAB events have highlighted the need for enhancing event response capabilities. The *RDDTT Plan* also gives a high priority to enhancing event response capabilities. NOAA is considering approaches to addressing this emerging issue.

The *Marine HAB Report* shows that most HAB problems occur regionally. Consequently, most research is conducted and accomplishments are achieved on a regional basis. In response to the conclusions outlined in the *Marine HAB Report* and priorities within NOAA, we plan to increase the regional emphasis of our programs. Research in each region would be guided by a series of plans developed through workshops attended by researchers, state and local resource and public health managers, and other interested stake holders. These workshops would assess the state of the problem, the tools that are currently available to address the problem, and propose priorities for future research and actions to improve management and response in that region. NOAA has already sponsored workshops on specific HABs in the Gulf of Mexico, southern California, and Gulf of Maine and has workshops in the planning stages for the entire West Coast Region and Hawaii.

One of the long term goals of NOAA's research is the development of operational HAB forecasts, similar in many ways to weather forecasts. The purpose is to give advance warning that a HAB is or will be present and predict where it will go. Depending on the region, the early warning could be an annual prediction or a forecast for the next few days. State public health and resource managers unanimously say that the longer the warning lead time the more useful it is to them. These managers primarily use warnings to guide state monitoring programs both in the short and long term.

In summary, operational forecasts are provided in Florida. While initially these forecasts were focused on the southwest coast, they are now available for the Panhandle and the east coast of Florida as well. NOAA is testing forecast models in Texas and the Gulf of Maine, and plans to test forecast models for the Washington coast and in Lake Erie later this summer. In the next few years, the plan is to transition the forecast models we are testing into an operational mode. This will require close collaboration with the developing U.S. Integrated Ocean Observing System because HAB forecasts are dependent on real-time data about ocean conditions. In addition, the development and deployment of HAB sensors are critical for providing models with data about HAB incidence and abundance.

Conclusion

Thank you for this opportunity to update you on NOAA's HAB programs. Over the last ten years we have made enormous progress in understanding the causes and consequences of HABs, which has led to the development of many tools and information products that improve HAB management, particularly in the area of mitigation. We anticipate that in the next ten years this progress will continue and our ability to prevent and control as well as mitigate will be greatly enhanced.

Table 1. Major HAB organisms causing problems in U.S. marine systems, their major toxins (if characterized), their direct acute impacts to humans and ecosystem health, and regions of the U.S. that have been impacted by these HAB organisms. 'Not characterized' indicates that toxins have been implicated but not characterized.

Table 1. Major HAB organisms causing problems in U.S. marine systems, their major toxins (if characterized), their direct acute impacts to humans and ecosystem health, and regions of the U.S. that have been impacted by these HAB organisms. 'Not characterized' indicates that toxins have been implicated but not characterized.

Organisms	Toxins	Acute Human Illness*	Direct Ecosystem Impacts	Impacted Regions
Alexandrium spp.	Saxitoxins	Paralytic Shellfish Poisoning	Marine mammal mortalities	Northeast, Pacific Coast, Alaska
Aureococcus anophagefferens (Long Island Brown Tide)	Not characterized	--	Shellfish mortality, seagrass die-off	Northeast, Mid-Atlantic Coast
Aureoumbra lagunensis (Texas Brown Tide)	Not characterized	--	Seagrass die-off	Gulf of Mexico (Texas)
Dinophysis	Okadaic Acid	Diarrhetic Shellfish Poisoning	--	Gulf of Mexico, possibly New England and Pacific Coast
Gambierdiscus spp., *Prorocentrum* spp., *Ostreopsis* spp.	Ciguatoxin, Gambiertoxin, and Maitotoxin	Ciguatera Fish Poisoning	--	Gulf of Mexico (Florida, Texas), Hawaii, Pacific Islands, Puerto Rico and U.S. Virgin Islands
High biomass bloom formers	†	--	Low dissolved oxygen, Food web disruption	All regions
Karenia spp.	Brevetoxins	Neurotoxic Shellfish Poisoning, Acute respiratory illness	Fish kills, mortalities of other marine animals	Gulf of Mexico, South-Atlantic Coast
Karlodinium spp.	Karlotoxins	--	Fish kills	Mid- and South-Atlantic Coast, Gulf of Mexico (Alabama, Florida)
Macroalgae	‡	--	Low dissolved oxygen, seagrass and coral overgrowth and die-off, beach fouling	All regions
Marine Cyanobacteria (CyanoHABs) (*Lyngbya* spp)	Lyngbyatoxins	Dermatitis	Seagrass and coral overgrowth and die-off, beach fouling	Gulf of Mexico and South-Atlantic Coast (FL), Hawaii and Pacific Territories
Pfiesteria spp.	Free radical toxin, others not characterized	--	Fish kills	Mid- and South-Atlantic Coast
Pseudo-nitzschia spp.	Domoic Acid	Amnesic Shellfish Poisoning	Mortality of seabirds and marine mammals	Pacific Coast, Alaska, Gulf of Mexico, Northeast, Mid-Atlantic Coast
Pyrodinium bahamense	Saxitoxins	Puffer Fish Poisoning	--	South-Atlantic Coast (Florida)
Some raphidophytes (e.g., *Heterosigma akashiwo, Chattonella spp.*)	Brevetoxins (*Chattonella*), other icthyotoxins not characterized	--	Fish kills	Pacific Coast (Washington), Mid-Atlantic Coast

*This table only captures the major acute human illnesses associated with these HAB species. Other, less severe acute health effects, such as skin irritation, may occur with some of these HAB groups. Chronic effects, such as tumor promotion, can also occur. A table of short- and long-term health effects is given in HARRNESS 2005 and Jewett et al. 2007.

†Some high biomass bloom formers may produce toxins.

‡Some macroalgae have been shown to produce bioactive compounds, such as dopamine and dimethylsulfoniopropionate (DMSP), which may have direct ecosystem effects (Van Alstyne et al. 2001)