**WRITTEN TESTIMONY OF**

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**HARMFUL ALGAL BLOOMS: IMPACTS ON OUR NATIONAL WATERS**
**BEFORE THE**
**SUBCOMMITTEE ON OCEANS, ATMOSPHERE, FISHERIES, AND COAST GUARD**
**COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION**
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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 over 40 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 Harmful Algal Blooms, a former co-Chair of the National HAB Committee, and have been actively involved in formulating the scientific and legislative framework and the agency partnerships that support and guide our national program on HABs. Today my testimony will summarize the national scale of the HABs problem in the U.S.—their distribution, impacts, and trends as well as the challenges that face those responsible for monitoring and managing these phenomena. I will also highlight recent research accomplishments as well as developments that are needed to improve the national response to HABs, and will provide my perspective on the programmatic, legislative, and funding needs of the national HAB program.

**A key take-away message is that HABs, in their various forms, are a national problem that requires a comprehensive national research, monitoring, and mitigation strategy**. Their increasing frequency and intensity are impacting the economics and environmental health of communities, states, tribes, and regions around the nation. Congress has responded by increasing HAB funding for some agencies, in particular for NOAA's base and competitive programs, which is essential if we are to improve our understanding of how these blooms develop and strategies to mitigate their impacts. These increases, however, do not fully restore major funding cuts made in previous years, and back then, the national HAB problem was much smaller than what we face now. **Clearly, sustained funding at a higher level is a critical need**. Enhanced support is also needed for HAB programs in the EPA, USGS, and multiple other agencies with mandates that include HAB issues. When major HAB events like the current Florida red tide, the drinking water crises that occurred in Toledo, OH in 2014 and Salem, OR in 2018 and the 2015 west coast HAB that stretched from Alaska to Mexico capture the attention of the public, the media, and Congress, the temptation to target funding to that one problem ignores the need for balanced, sustained national support that will allow other regions to respond to the inevitable outbreaks that will occur elsewhere in future years.

## BACKGROUND

**HABs and Their Impacts.** HABs are caused by simple aquatic plants called algae and cyanobacteria, the latter commonly referred to as blue-green algae. Many of them are microscopic and form the base of most aquatic food webs. The vast majority of algae are beneficial, but a number of species can cause harm to humans and ecosystems through "blooms" of cells that can result in one or more of the following: discolored water (hence the frequent use of the term "red tide"); illness and death of humans who have consumed contaminated shellfish or fish, drunk contaminated water, or come in contact with blooms through recreational activities; mass mortalities of fish, seabirds, and marine mammals; and respiratory problems caused by breathing aerosolized toxins. HAB impacts are serious and diverse, and include the following:

- Filter feeders like shellfish can accumulate algal toxins to levels that can be lethal or cause serious illness in humans, aquatic animals, and wildlife. The syndromes are referred to as paralytic, diarrhetic, neurotoxic, amnesic, or azaspiracid shellfish poisoning (PSP, DSP, NSP, ASP, and AZP respectively), depending on the causative organism(s) and the toxins they produce. Poisonings are also possible from the consumption of fish, seabirds or other animals that have accumulated HAB toxins through the food chain. This latter pathway is of particular concern in areas such as the Alaskan Arctic where these are critical food resources.
- A sixth human illness, ciguatera fish poisoning (CFP), is caused by biotoxins produced by certain HAB species 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.
- Some algal toxins become airborne in sea spray, causing respiratory irritation and more serious illness in those with respiratory diseases.
- Fish, seabirds, manatees, sea lions, turtles, whales, and dolphins are among the many animals commonly affected by HABs. These animals, as well as humans, can be exposed to algal toxins through the food they eat, the water they drink or swim in, or even the air they breathe. Oftentimes mortalities occur because of algal-produced compounds that are not toxic to humans, but nevertheless can kill fish, shellfish, and other aquatic animals.
- Negative impacts to ecosystems can occur when large and dense blooms form. These can degrade habitat through shading of aquatic vegetation on the ocean floor that serves as critically-important habitat for juvenile commercially important fish and shellfish. A related impact occurs when these high-biomass blooms terminate and the algae decay, removing oxygen from the water.
- High-biomass blooms can also be a nuisance to humans as they wash up on beaches, causing foul odors as they decay and providing a habitat for harmful bacteria to grow and produce toxins (e.g. avian botulism). These blooms can also threaten important infrastructure (e.g., power plants, desalination plants).

- 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 serious deterrent to tourism.
- Freshwater systems like lakes, ponds, rivers, and streams are also subject to HABs[1], primarily caused by cyanobacteria (blue-green algae) that can turn the water green and slimy, endangering humans through exposures from drinking water and recreational activities. Cyanobacteria are found in virtually all ecosystems, but are primarily a problem (termed cyanoHABs) in fresh and brackish waters. CyanoHABs are increasingly affecting waterbodies in all 50 states, making these events a national crisis. Recently, however, it is becoming clear that the toxins in these systems are also making their way to coastal marine waters, where shellfish and other marine animals can be exposed, adding yet another HAB threat to those areas.

CyanoHABs often consist of dense scums or aggregations of cells floating on the water surface, causing the water to become the consistency of paint. The most serious human health concern associated with these events is that cyanobacteria produce some of the most potent natural toxins known to man; these include the microcystins, formerly known as "fast-death factor" and anatoxins, formerly known as "very fast-death factor." Freshwater HABs thus pose serious risks for human and animal health, aquatic-ecosystem sustainability and economic vitality. One example of how blooms can be significant public health threats occurred in 2014 when a cyanoHAB near Toledo, Ohio's drinking water intake source in Lake Erie resulted in 500,000 water customers being advised not to drink their tap water for nearly three days. A similar event just occurred in Salem, Oregon, this year, affecting a similar number of people but for a longer interval. The scale of these blooms can be massive, evidenced by the largest bloom in recorded history in western Lake Erie in 2015—an event that produced a surface scum that covered nearly 300 square miles. A secondary problem that arises from cyanoHABS is that these huge masses of organic material create serious environmental problems by reducing water transparency, resulting in light limitation that can inhibit the growth of suspended and bottom-dwelling plants, and by depleting oxygen as the blooms collapse, killing fish and other organisms that are unable to escape to oxygenated waters**. Every single state has experienced CyanoHAB events**.

Another important freshwater HAB problem is caused by the "golden algae" *Prymnesium parvum* which blooms in reservoirs, rivers, and lakes, and causes large fish kills. These blooms have killed millions of fish in Texas year after year, and to date have impacted nearly half of the U.S. states (Figure 1)

**Causative mechanisms**. As noted above, HABs are highly diverse in the U.S. in terms of species, habitats, and impacts. While we know that the underlying causes leading to HAB development vary between species and locations, we do not have a full understanding of all the factors involved. In general, algal species grow best when environmental conditions (such as temperature, salinity, nutrients, and light) are optimal for cell growth. Other biological and physical processes (such as predation, disease, toxins and water currents) determine whether enhanced cell growth will result in bloom formation. The challenge for understanding the causes

[1] Hudnell, H.K. ed., 2008. *Cyanobacterial harmful algal blooms: state of the science and research needs* (Vol. 619). Springer Science & Business Media.

of HABs stem from the complexity and interrelationship of these processes for individual species and habitats. Knowledge of how these factors control the initiation, development, 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, but certainly not all HABs. Of considerable concern, particularly for coastal resource managers, is the relationship between the apparent increase in HABs and accelerated anthropogenic eutrophication of coastal marine and freshwaters, also known as human-influenced nutrient pollution[2]. Overall, there is a strong scientific consensus that links marine and freshwater HABs to human-influenced eutrophication[3,4]. Coastal marine and freshwaters are receiving massive and increasing quantities of industrial, agricultural and sewage effluents through a variety of pathways. Just as the application of fertilizer to lawns can enhance grass growth, algae and cyanobacteria 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 in marine systems.

Freshwater HABS are also frequently enhanced by excess nutrient inputs, often as a result of fertilizer applications on land. Recent assessments by the U.S. Environmental Protection Agency indicate that 44% of river and stream miles and 64% of lake and reservoir acres are impaired pursuant to section 303(d) of the U.S. Clean Water Act[4]. However, these numbers are likely to be conservative, as since that assessment, many other systems have been added to the 303d list including parts of the Great Lakes, our nation's largest and most important surface freshwaters. The open waters of western Lake Erie, where the large cyanoHABs generally occur, were not deemed impaired until 2016 when Michigan declared its portion of western Lake Erie to be impaired based on impacts of cyanoHABs to aquatic life and other wildlife. In 2018, Ohio also declared its portion of the open waters to be impaired for recreational use after consulting with a team of scientists to develop the nation's first standard methodology to designate a waterbody as impaired by cyanoHABs, per the Clean Water Act sections 305(b) and 303(d).

Climate change will almost certainly influence HABs since many critical processes governing HAB dynamics such as temperature, water column structure, upwelling and water circulation patterns, and nutrient inputs are influenced by climate. Freshwater cyanoHABs are expected to worsen as temperatures rise, as the causative species are strong competitors at high temperatures[5]. The interactive role of climate change with the other factors driving the frequency

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[2] Heisler, J., Glibert, P.M., Burkholder, J.M., Anderson, D.M., Cochlan, W., Dennison, W.c., Dortch, Q., Gobler, C.J., Heil, C.A., Humphries, E., Lewitus, A., Magnien, R., Marshall, H.G., Sellner, K., Stockwell, D.A., Stoecker, D.K., and Suddleson, M. 2008. Eutrophication and Harmful Algal Blooms: A Scientific Consensus. Harmful Algae 8(1): 3-13.

[3] Anderson, D.M., Burkholder, J.M., Cochlan, W.P., Glibert, P.M., Gobler, C.J., Heil, C.A., Kudela, R.M., Parsons, M.L., Rensel, J.J., Townsend, D.W. and Trainer, V.L., 2008. Harmful algal blooms and eutrophication: examining linkages from selected coastal regions of the United States. *Harmful Algae*, *8*(1), pp.39-53.

[4] EPA. 2009. National water quality inventory: report to Congress, 2004 reporting cycle. U.S. Environmental Protection Agency, EPA 841-R-08-001, Washington, D. C., pp. 37.

[5] O'Neil, J.M., Davis, T.W., Burford, M.A., Gobler, C.J., 2012. The rise of harmful cyanobacteria blooms (CHABs): The potential roles of eutrophication and climate change. *Harmful Algae* 14: 313-334.

and severity of HABs is in the early stages of research, but climate change is expected to exacerbate the HAB problem in some regions and shift species distributions geographically.

One area where this is of particular concern is in the Alaskan Arctic. With present-day warming leading toward major reductions in ice cover and changes in regional hydrography, biogeographic boundaries of a wide range of marine species at all trophic levels will be greatly impacted, particularly in summer ice-free shallow waters. Although many organisms may spread into Arctic waters or become more abundant there as a result of warming trends, few present such significant threats to human and ecosystem health as HAB species. If this occurs, human health and ecosystem impacts will be significant in a region where traditional monitoring programs for toxins in shellfish, fish, or other animals are not feasible, and where the ecosystems and human populations have no prior exposure to these toxins. There is now clear evidence that multiple HAB toxins are present in the Arctic food web at dangerous levels, and a strong likelihood that the problems will worsen. For example, recent surveys have found two different families of HAB toxins in many harvested or stranded marine mammals (Figure 1)[6]. Notably, all species tested contained the toxin domoic acid, in spite of different foraging strategies. Some


**Figure 1.** Locations where HAB toxins were detected in stranded (s) and harvested (h) marine mammals. Red represents species positive for domoic acid and purple represents species positive for saxitoxin. Marine mammal species are listed as follows: (A) humpback whales, (B) bowhead whales, (C) beluga whales, (D) harbor porpoises, (E) northern fur seals, (F) Steller sea lions, (G) harbor seals, (H) ringed seals, (I) bearded seals, (J) spotted seals, (K) ribbon seals, (L) Pacific walruses and (M) northern sea otters. (Source: Lefebvre et al., 2016).

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[6] Lefebvre, K.A., Quakenbush, L., Frame, E., Huntington, K.B., Sheffield, G., Stimmelmayr, R., Bryan, A., Kendrick, P., Ziel, H., Goldstein, T. and Snyder, J.A., 2016. Prevalence of algal toxins in Alaskan marine mammals foraging in a changing arctic and subarctic environment. *Harmful algae*, *55*, pp.13-24.

toxin levels were comparable to those found in marine mammals that were diagnosed with HAB poisoning during severe blooms along the U.S. West Coast. Impacts from these toxins have been devastating to regions elsewhere in the world, and now threaten the safety of the subsistence diet and the health of wildlife in Arctic waters.

**HAB distribution in the U.S**. All coastal and inland states experience HABs (Figure 2), including all five of the North American Great Lakes, but the specific organisms and thus the nature of the impacts differ dramatically from region to region. All of the human poisoning syndromes and other HAB impacts described above are known problems within the U.S. and its territories, affecting large expanses of coastline.

- **PSP** occurs on a near-annual basis in all coastal New England states as well as New York, extending to offshore areas in the Northeast such as Georges Bank, and along much of the West Coast from Alaska to Southern California. The current distribution of PSP in the U.S. has greatly expanded over the past several decades, with areas like Long Island, Puget Sound, and Florida (both coasts) now affected. Overall, PSP affects more U.S. coastline than any other marine algal bloom problem.
- **NSP** occurs along Gulf of Mexico coasts, with the most frequent outbreaks along western Florida and Texas. Outbreaks are near-annual, with some lasting for as long as a year. Louisiana, Mississippi, North Carolina and Alabama have also been affected in recent years, causing extensive losses to the oyster industry and killing birds and marine mammals.
- **ASP** has been a problem for all of the U.S. Pacific coast states since it was first discovered in 1987 in Canada[7]. Outbreaks are episodic, and some can be massive, as in 2015 when a bloom extended along the entire West Coast of the U.S., including Alaska, following a year of unusually warm offshore water temperatures[8]. The bloom resulted in enormous economic losses due to closure of recreational harvesting of shellfish in three states, as well as targeted closures for Dungeness crab, anchovy, and sardines. Toxin levels were the highest ever reported for anchovy, mussels and crabs—10 times the regulatory limits. Shortly thereafter in 2016, extensive shellfish closures were implemented in Maine, Massachusetts, and Rhode Island due to the first-ever recording of ASP toxins in that region. The ASP toxin, which can cause permanent brain damage and memory loss in affected consumers, has recently caused shellfish closures in Gulf of Mexico waters as well.
- Until recently, **DSP** was virtually unknown in the U.S., but a major outbreak was reported along the Texas coast in 2008, resulting in an extensive closure of shellfish beds in that area[9]. Since then, DSP toxins have been reported on both the East and West Coasts.

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[7] Trainer, V.L., Bates, S.S., Lundholm, N., Thessen, A.E., Cochlan, W.P., Adams, N.G. and Trick, C.G., 2012. Pseudo-nitzschia physiological ecology, phylogeny, toxicity, monitoring and impacts on ecosystem health. *Harmful Algae*, *14*, pp.271-300.

[8] Trainer, V., Moore, S., Mccabe, R., Hickey, B., Kudela, R., Marin, R., Mickett, J. and Mikulski, C., 2017. A massive harmful algal bloom on the US West Coast and the future of monitoring for early warning.

[9] Campbell, L., Olson, R.J., Sosik, H.M., Abraham, A., Henrichs, D.W., Hyatt, C.J. and Buskey, E.J., 2010. First harmful dinophysis (dinophyceae, dinophysiales) bloom in the US is revealed by automated imaging flow cytometry1. *Journal of Phycology*, *46*(1), pp.66-75.

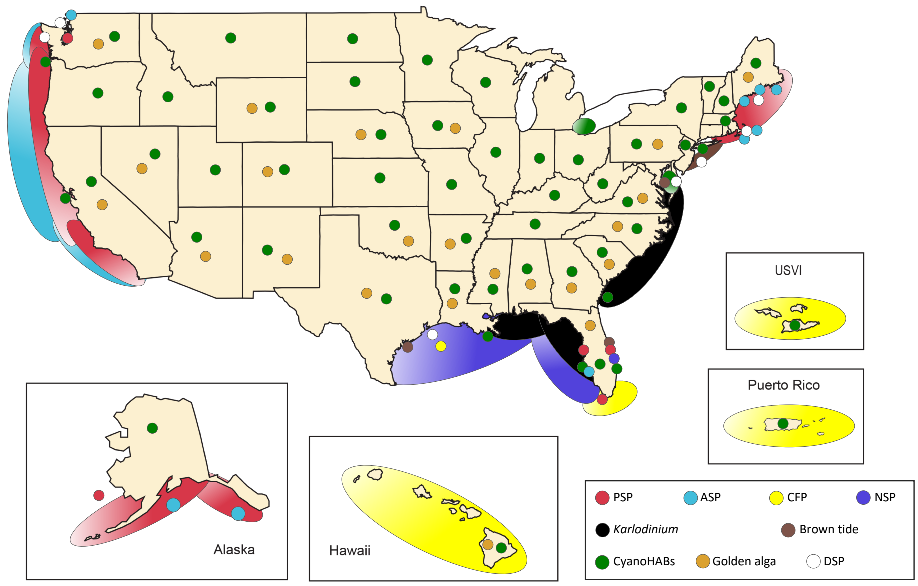


**Figure 2.** A generalized view of the U.S. showing the various HAB poisoning syndromes and other impacts that occur in specific areas. Colored dots or ovals indicate where a particular syndrome or impact has been reported. Ovals are used to depict regional phenomena that occur at multiple locations along a coastline. All 50 states are impacted by cyanobacterial HABs, in a variety of freshwater systems: rivers, streams, reservoirs, etc. The same is true for 23 states impacted by golden algal blooms caused by *Prymnesium parvum*. It is not practical to indicate the location of each cyanobacterial or golden algae bloom, so each state experiencing these blooms is indicated using a single green and/or gold dot. Larger green ovals denote widespread cyanoHABs in those areas. Source: NOAA U. S. National Office for Harmful Algal Blooms (http://www.whoi.edu/redtide/page.do?pid=14898), Woods Hole, MA.

- **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 since reporting is voluntary and there is no confirmatory laboratory test. In the U.S. 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 problem for consumers far from the tropics. For example, poisonings of restaurant patrons in the Washington DC area and elsewhere were linked to fish caught in the Flower Garden Banks National Marine Sanctuary in the Gulf of Mexico south of Texas[10].

[10] https://flowergarden.noaa.gov/visiting/ciguatera.html

- **<u>CyanoHABs</u>** occur in freshwater systems of all 50 states, including all five of the North American Great Lakes (Figure 3). The primary cyanotoxins of concern in many of these events are microcystins. There have been many examples of how microcystins impact human and animal health as mentioned previously. However, it should be noted that several other emerging toxins of concern are becoming more prevalent in freshwaters across the nation. These include anatoxins (neurotoxins), saxitoxins (PSP toxins) and cylindrospermopsins. Anatoxin-a has been the confirmed cause of deaths in dogs that have ingested toxic waters in California and elsewhere in North America. The 2007 National Lakes Assessment (NLA) revealed that 7% percent of U.S lakes were impacted by saxitoxins[11], consistent with a recent California survey that detected STX in 7% of wadeable streams[12]. Regionally though, the problem may be much worse. For example, in 2016 the Ohio EPA detected saxitoxins at 18 drinking water intake sites (15% of all sites sampled). Furthermore, low levels of saxitoxins were detected in the finished drinking water at eight Ohio public water systems, indicating a potential risk to human health.

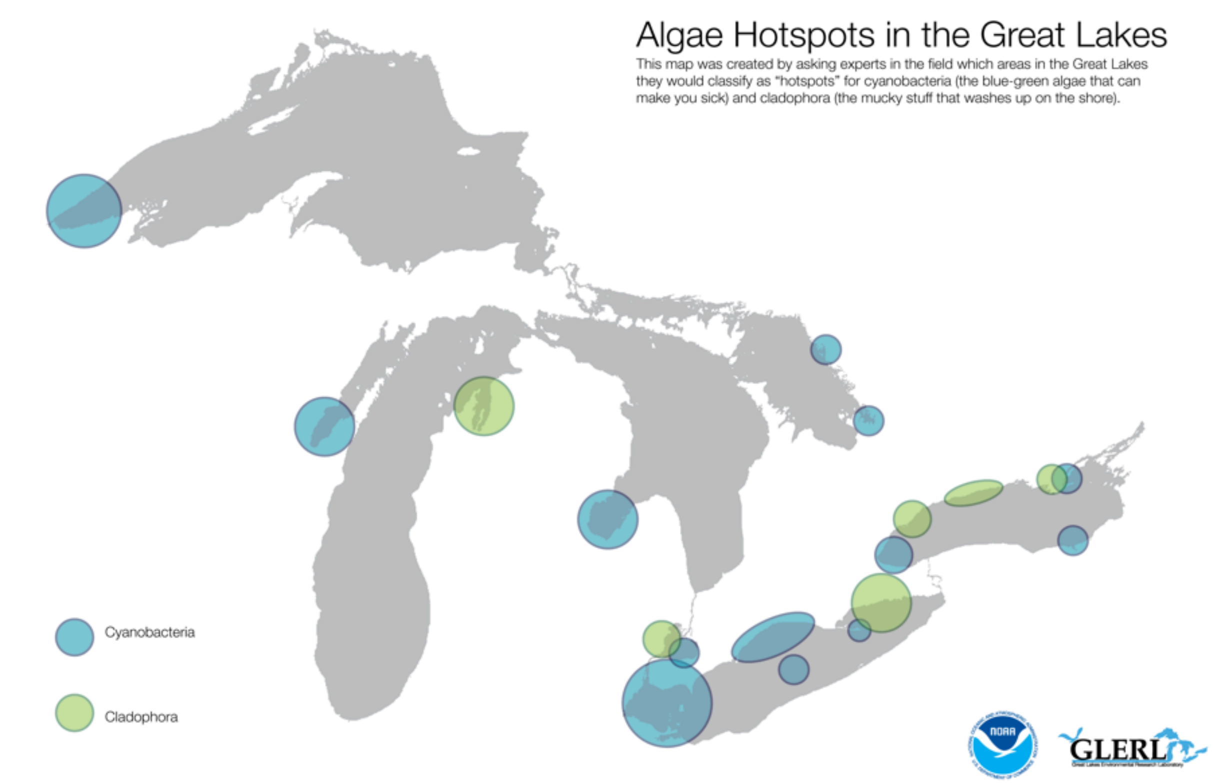


**Figure 3:** Current spatial distribution of HABs in the Great Lakes.

[11] Loftin, K. A., J. L. Graham; E. D. Hilborn, S. C. Lehmann, M. T. Meyer, J. E. Dietze, C. B. Griffith. 2016. Cyanotoxins in inland lakes of the United States: Occurrence and potential recreational health risks in the EPA National Lakes Assessment 2007. Harmful Algae. 56:77-90. DOI: 10.1016/j.hal.2016.04.001.

[12] Fetscher, A. E., M. D. A. Howard, R. Stancheva, R. M. Kudela, E. D. Stein, M. A. Sutula, L. B. Busse, and R. G. Sheath. 2015. Wadeable streams as widespread sources of benthic cyanotoxins in California, USA. Harmful Algae. 49:105-116. DOI: 101.1016/j.hal.2015.09.002.

**Recent Trends.** The nature of the HAB problem has changed considerably over the last 50 years in the U.S. **Virtually every coastal state is now threatened by harmful or toxic marine algal species, whereas 30 - 40 years ago, the problem was much more scattered and sporadic** (Figure 4). In inland states, HABs in rivers, lakes, reservoirs, and other water freshwater bodies have increased dramatically as well. Overall, the number of toxic blooms, the economic losses, 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[13] .

There are many reasons for this expansion, some of which involve human activities, such as

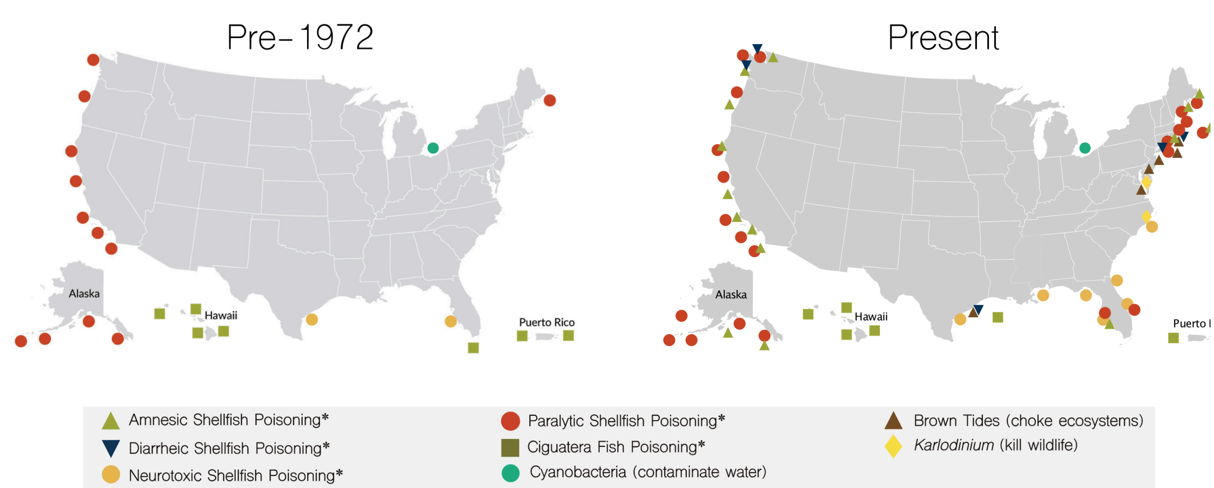


**Figure 4.** Expansion of the national U.S. HAB problem over the last 50 years. Note that freshwater cyanobacterial blooms are only indicated in Lake Erie, though similar problems occur in all inland states, many with problems only becoming apparent in recent years. These maps show both the spreading of HABs within regions, as well as the emergence of new HAB problems unknown to science until recently (e.g., ASP, DSP, brown tides, *Karlodinium*). Source: NOAA U. S. National Office for Harmful Algal Blooms. (http://www.whoi.edu/redtide/page.do?pid=14898), Woods Hole, MA.

nutrient pollution as noted above. Some new bloom events likely reflect newly discovered populations from better detection methods and more observers rather than new species introductions or dispersal events. 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 or in aquaculture species. 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 HAB species introductions worldwide.

**Economic and Societal Impacts**. HAB events 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

[13] HARNESS 2005. HARRNESS – a framework for HAB research and monitoring in the United States for the next decade. Ramsdell, J.S., D.M. Anderson, and P.M. Glibert (Eds.). Ecological Society of America, Washington D.C. 96 pp. .

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 marine HABs in the U.S. is approximately $82 million (Hoagland and Scatasta, 2006). However, single events can sometimes approach this annual average. For example, in 2005, a HAB event in New England resulted in a loss of $18 million in shellfish sales in Massachusetts alone.[14] Furthermore, harvesting closures in Maine (soft-shell clams, mahogany quahogs, and mussels) are estimated to cost $2.9 million each week, with typical closures ranging from 4 to 16 weeks, and occurring nearly every year[15]. Likewise, the direct economic impact from commercial closures due to the West Coast ASP outbreak in 2015 was estimated to be approximately $30 million for the Dungeness and rock crab fisheries in California alone, in addition to the substantial but unquantified impacts to other fisheries[16]. That same outbreak caused an estimated $23 million loss in the state of Washington[17].

The economic impacts from freshwater HABs is also substantial, with some estimates exceeding several billions of dollars per year when the decline in property values is included. One example is the closure of Grand Lake St. Marys in Ohio in 2011 due to toxic cyanoHAB blooms. That event cost the local community an estimated $200 million in lost tourism income. In addition, countless fish, waterfowl, and pets were sickened and killed by the lake's toxic conditions. The state of Ohio confirmed seven illnesses (and potentially 21 additional cases) were linked to exposure to toxins in lakes, including a case in which an individual was temporarily blinded. A recent report on the economic benefits of reducing HABs in Lake Erie[18] found that the annual economic impacts of the 2011 bloom (second largest in recorded history) and 2014 (the year of the Toledo water crisis) were $71 million and $65 million, respectively. Notably, 2014 data did not include the direct economic losses associated with the water crisis so that value is likely a gross underestimate. The study also estimated the 30-year economic impact to the region if blooms that range between the size of the 2011 and 2014 events continue to occur to be between $1.3 and $1.5 billion. Furthermore, another recent study from The Ohio State University found that people who wanted to use western Lake Erie for recreational purposes spent $800,000 - $1 million more in travel costs to avoid the bloom-impacted areas.[19] . *Cumulatively, the costs of HABs have exceeded 10-20 billion dollars over the last several decades, and t*hese 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.

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[14] 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.

[15] K. Ahearn. 2008. Economic losses from closure of shellfish harvesting areas in Maine. Prepared for the Maine Department of Marine Resources.

[16] http://www.oceansciencetrust.org/wp-content/uploads/2016/11/HABs-and-CA-Fisheries-Science-Guidance-10.25.16.pdf

[17] D. Ayres, personal communication.

[18] M. Bingham, S. K. Sinha and F. Lupi . 2015. Economic Benefits of Reducing Harmful Algal Blooms in Lake Erie", Environmental Consulting & Technology, Inc., Report, 66 pp,

[19] https://theconversation.com/whats-the-value-of-a-clean-beach-heres-how-economists-do-the-numbers-94805?utm_source=twitter&utm_medium=twitterbutton

In addition to impacting public health, ecosystems, and local economies, HABs can also have significant social and cultural consequences. For example, along the Washington and Oregon coasts, tens of thousands of people visit annually to participate in the recreational harvest of razor clams. However, a series of beach closures in recent years due to high levels of the ASP toxin domoic acid prevented access to this recreational fishery. These harvesting closures have not only caused economic losses, they have also resulted in an erosion of community identity, community recreation, and a traditional way of living for native coastal cultures.

## HAB PROGRAM DEVELOPMENT

**Marine HABs**. To better understand the nature of the national approach to researching and managing HABs, the following background is offered on the development of the suite of activities, facilities, and funding programs that constitute our national strategy for dealing with this significant problem.

The national HAB "program", or strategy, is viewed by many colleagues in other disciplines as a model program that has succeeded because of its organization, structure, and planning. As recently as 30 years ago, this was not the case, as there was very little research on HABs, and that being conducted in the academic community was scattered and unfocused. To rectify this problem, we formulated a *National Plan for Marine Biotoxins and Harmful Algae* (Anderson et al., 1993) that guided activities in this field for the next 10-15 years. The *National Plan* was broadly based, and encompassed ecology, physiology, toxicology, human health, economics, ecosystem health, and a variety of other issues. This breadth of topics exceeded the mandate and resources of any single agency or program, and therefore for implementation purposes, it was necessary to break the plan into a series of programs based on complementary topics. The first thematic area was the *Ecology and Oceanography of HABs*, which was addressed by the ECOHAB program. This was followed by MERHAB (*Monitoring and Event Response of HABs*), and then by *Prevention, Control and Mitigation of HABs* (PCMHAB) and then the *Ocean and Human Health* (OHH) programs. The latter began with a partnership between the National Institute of Environmental Health Sciences (NIEHS) and the National Science Foundation (NSF), who have supported multiple *Centers for Oceans and Human Health* (COHH) that conduct significant HAB research and outreach activities.

In 1998, Congress recognized the severity of these threats and authorized the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA 1998; embedded in Public Law 105-383). The Harmful Algal Bloom and Hypoxia Research and Control Amendments Act of 2004 (HABHRCA 2004, Public Law 108–456) and 2014 (HABHRCA 2014, Public Law 113–124) reaffirmed and expanded the mandate for NOAA to advance the scientific understanding and ability to detect, monitor, assess, and predict HAB and hypoxia events. Another HABHRCA reauthorization is currently moving through Congress, and I strongly support passage of this legislation. I do have comments on some sections of the draft legislation, and would be pleased to provide details if requested.

The 2014 reauthorization called for Federal agencies to provide integrated assessments on the causes and consequences of and approaches to reducing HABs and hypoxia nationally, with particular emphasis on the Great Lakes. This led to the creation of the Interagency Working Group on HABHRCA (IWG-HABHRCA), tasked with coordinating and convening Federal agencies and their stakeholders to discuss HAB and hypoxia events in the U.S., and to develop action plans and assessments of these situations. NOAA co-chairs the IWG-HABHRCA with

EPA. Other member agencies include FDA, USDA, CDC, USACE, NASA, NPS, USGS, BOEM, Navy, NIEHS, and NSF. A detailed report was recently issued[20], providing an assessment of the U.S. HAB problems and recommendations for action.

The 1993 *National Plan* provided the initial guidance and perspective that led to the creation of several multi-agency partnerships and individual agency initiatives, many of which continue to this day. Together, ECOHAB, MERHAB, and PCMHAB have funded nearly $140 million in marine and freshwater (Great Lakes) HAB research since the programs began in 1996, 2000, and 2010 respectively. Significant funding in excess of $45 million has also been provided by the NSF – NIEHS COHH program, with another $25 million anticipated over the next five years. Smaller contributions have been made by other programs and agencies, including Sea Grant, NASA, EPA and the NSF geoscience core programs.

After more than 10 years of strong program growth and diverse research activities, the 1993 National Plan became outdated, and was replaced by HARRNESS (*Harmful Algal Research and Response: A National Environmental Science Strategy 2005-2015*[21]). 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 was developed. HARRNESS is continuing to guide U.S. HAB research and monitoring, though updates to the program are now under consideration.

At the conceptual level, HARRNESS is a framework of initiatives and funding programs that identify and address current and evolving needs associated with HABs and their impacts. ECOHAB is a critical, core program that is needed to address the fundamental processes underlying the impacts and dynamics of HABs. ECOHAB's 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, as well as through PCMHAB, a program dedicated to HAB prevention, control and mitigation. All of these programs serve important topic areas, and collectively form a strong basis for progress.

The COHH initiative of NIEHS and NSF fills an important niche by creating linkages between members of the ocean sciences and biomedical communities to help both groups address public health aspects of HABs. The partnership between NIEHS and NSF clearly needs to be sustained and expanded in order to provide support to a large network 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.

### Freshwater HABs

**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 COHH programs.** This is because NOAA's mandate includes

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[20] National Science and Technology Council Subcommittee on Ocean Science and Technology. 2016. Harmful Algal Blooms and Hypoxia Comprehensive Research Plan and Action Strategy: An Interagency Report.

[21] HARNESS 2005. HARRNESS – a framework for HAB research and monitoring in the United States for the next decade. Ramsdell, J.S., D.M. Anderson, and P.M. Glibert (Eds.). Ecological Society of America, Washington D.C. 96 pp. .

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.

The reauthorization of HABHRCA in 2004 expanded the Act to include blooms in all U.S. freshwaters. The Act mandated an assessment of freshwater HABs[22], leading to an interagency monograph that described science and research needs[23]. This effort to address freshwater HABs at the national level was hampered because the Act did not contain a mandate or funding authorization for the EPA, which is the appropriate Agency to establish and maintain such a plan. All U.S. freshwaters are within the purview of the EPA, as defined in the Clean Water Act (2002) and the Safe Drinking Water Act (2002). The Agency acknowledges its mandate for safe and clean water in Goal 2 of the 2006-2011 EPA Strategic Plan (EPA, 2008), "Ensure drinking water is safe. Restore and maintain oceans, watersheds, and their aquatic ecosystems to protect human health, support economic and recreational activities, and provide healthy habitat for fish, plants, and wildlife." Because of this, many studies of inland HABs are funded through state programs such as the Ohio Department of Higher Education Harmful Algal Bloom Research Initiative as one example or by Sea Grant in states that have Sea Grant programs.

As detailed in the 2016 IWG-HABHRCA report, in 2010, the interagency Great Lakes Restoration Initiative (GLRI) was created to protect and restore Great Lakes natural resources, including HAB projects. After the 2014 Lake Erie HAB, $12 million in GLRI funding was provided to Federal and state programs to minimize HABs and hypoxia in the western basin of Lake Erie. Specific projects supported by this funding include upgrading controlled drainage systems, funding best management practices (BMPs) at livestock facilities, and planting cover crops. It also provides funding for the Environmental Quality Incentives Program, a voluntary program through USDA NRCS that provides financial and technical assistance to agricultural producers to plan and implement conservation practices that improve soil, water, plant, animal, air, and related natural resources on agricultural land and non-industrial private forestland.

In 2015, EPA announced the award of 14 GLRI grants totaling over $17 million, to fund projects that will improve Great Lakes water quality by preventing phosphorus runoff and solid erosion that contribute to algal blooms, and by reducing suspended sediments in Great Lakes tributaries. These projects focus on high-priority watersheds and receiving waters with high potential or known risk for HABs and hypoxia.

NOAA and EPA have shared responsibility under HABHRCA for the Great Lakes. HABHRCA gives EPA responsibility for inland freshwaters, but in reality, multiple agencies conduct intramural research in freshwater, however none are funded specifically for research on inland HABs.

## RECENT RESEARCH ACCOMPLISHMENTS

Given the challenges above, it is worth highlighting some of the recent accomplishments that show how properly administered and directed research funding can lead to big strides in our

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[22] Lopez, C.B., Jewett, E.B., Dortch, Q., Walton, B.T. Hudnell, H.K. 2008. Scientific Assessment of Freshwater Harmful Algal Blooms. Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology. Washington, D.C., 65 pp.

[23] Hudnell, H.K. (Ed.). 2008. *Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs*, Advances in Experimental Medicine and Biology, Vol. 619, Springer Press.

ability to understand and manage HAB phenomena. Progress has been rapid in many areas, and new approaches and technologies for research and management are now available, a few of which are listed here.

- DNA technology has led to the development of species- or strain-specific "molecular probes" that can label HAB cells of interest so they can rapidly be detected visually, electronically, or chemically. Progress has been significant and probes and assays of multiple types are available for many HAB species, with this technology now routinely employed in HAB research and monitoring programs[24]
- New optical- and DNA-based sensors are now available that can be moored in open waters or placed on docks and other structures where they can monitor the water for HAB cells and toxins continuously. These in situ sensors are dramatically changing the nature of research and monitoring as they open the door to an era where remote, subsurface, near real-time detection of HAB species and toxins can be envisioned. One example is an array of IFCBs (Imaging FlowCytobots, or underwater microscopes) that take hundreds of thousands of images of algal cells every day, identifying and counting HAB species autonomously, and sending that data to shore 24/7. IFCB sensors in the Gulf of Mexico have provided early warning of seven HABs in the Texas region in recent years[25][26], with text messages and e-mail alerts being sent to managers and scientists automatically when HAB species exceed specified cell concentration thresholds. Because they can be located in the water and thus in close proximity to the cells in a bloom, these instruments have also begun to reveal details of HAB dynamics that were not possible before. In one series of deployments in New England, IFCBs have revealed that the cells responsible for PSP outbreaks grow faster, swim faster, and are much more toxic than was previously thought on the basis of laboratory studies.[27]
- Technological advances have expanded our capabilities for research and monitoring of HABs, but the blooms will always be under sampled because of the large space and time scales over which they occur. As a result, numerical models are being used to help extrapolate and interpret these sparse observations. ECOHAB regional programs all developed large-scale models of the HABs in those study areas, and many of these are now adding greatly to our understanding and management of these phenomena. In

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[24] Anderson, D.M., Keafer, B.A., McGillicuddy Jr, D.J., Mickelson, M.J., Keay, K.E., Libby, P.S., Manning, J.P., Mayo, C.A., Whittaker, D.K., Hickey, J.M. and He, R., 2005. Initial observations of the 2005 Alexandrium fundyense bloom in southern New England: General patterns and mechanisms. *Deep Sea Research Part II: Topical Studies in Oceanography*, *52*(19-21), pp.2856-2876.

[25] Campbell, L., Olson, R.J., Sosik, H.M., Abraham, A., Henrichs, D.W., Hyatt, C.J. and Buskey, E.J., 2010. First harmful dinophysis (dinophyceae, dinophysiales) bloom in the US is revealed by automated imaging flow cytometry1. *Journal of Phycology*, *46*(1), pp.66-75.

[26] Jochens, A.E. and Watson, S.M., 2013. The Gulf of Mexico Coastal Ocean Observing System: An integrated approach to building an operational regional observing system. *Marine Technology Society Journal*, *47*(1), pp.118-133.

[27] Brosnahan, M.L., Velo-Suárez, L., Ralston, D.K., Fox, S.E., Sehein, T.R., Shalapyonok, A., Sosik, H.M., Olson, R.J. and Anderson, D.M., 2015. Rapid growth and concerted sexual transitions by a bloom of the harmful dinoflagellate *Alexandrium fundyense* (Dinophyceae). *Limnology and oceanography*, *60*(6), pp.2059-2078.

particular, some are the basis of operational HAB forecast systems that are providing information to managers and the public on daily, weakly, and seasonal scales.

- Sustained ecosystem studies of the causes and impacts of HABs is leading to the ability to predict when and where HABs will occur. Forecasts for *Karenia brevis* on the Gulf Coast and cyanobacterial blooms in Lake Erie have been operationalized in NOAA, so that forecasts are offered every few days during blooms seasons. Other forecasts are in pilot stages, including *Alexandrium* in the Gulf of Maine and *Pseudo-nitzschia* on the Washington-Oregon coast and California. In all cases the purpose is to provide early warning to protect human health and help businesses dependent on these fish/shellfish or tourism to be prepared.
- Combining the previous highlights, a realistic vision for the future would be that of arrays of moored instruments capable of detecting HAB cells and their toxins and transmitting this information to shore where the data can be assimilated into numerical models and forecasts, to be used by managers to make decisions for harvesting closures or other mitigation strategies to reduce HAB impacts. An exciting development in this regard is the advent of ocean observing systems (OOSs), arrays or networks of moored and mobile instruments that can collect and transmit data continuously from remote locations to shore-based scientists and managers. Just as networks of meteorological stations and numerical models of atmospheric dynamics greatly improved our ability to provide accurate forecasts of weather events, OOSs and their associated numerical models of ocean dynamics have the potential to document long-term patterns and changes in the sea, to detect infrequent events that previously went unobserved, and to make predictions or forecasts about these and other phenomena that directly affect human populations and marine ecosystems. The HAB sensors described above are viewed by many as an important component of the emerging ocean observing system infrastructure worldwide.
- One of the most frequent questions addressed to HAB scientists is "what can you do to stop these blooms?" To address this need, NOAA established the PCMHAB program in which all funding applications fall within the same topic area, ensuring that unfair comparisons between practical versus fundamental science are not made during the peer review process. The program is still young, but promising approaches are already emerging, including some that can directly lead to bloom prevention or even suppression. Some of the latter approaches include water clarification using dispersed clay solutions, and cell and toxin destruction using ozone. **Progress has been made, but this is a long-neglected area that can benefit from enhanced, targeted funding**.
- One significant outcome of a number of regional HAB research programs is the development of integrated research and response communities that include scientists, federal and state agencies, tribes, and industry. In the past, many of these individuals and groups worked independently and with little exchange of ideas and data. The networks that now exist in many parts of the country are active and productive, and should continue to be a major element in the growing capabilities of the national HAB program.
- In this context, outreach and communication by HAB research programs has led to greatly improved understanding of HAB phenomena by the general public and

stakeholders. HAB bulletins are now produced and widely distributed in multiple regions of the country.

- The new technologies developed to study and manage HABs and their impacts have had important commercial benefits. New companies or product lines have been established to build instruments, toxin test kits, and many other tools used in HAB management. Research has also led to increased exploitation of aquatic resources. One example is the opening of offshore hard clam resources on Georges Bank that had been closed for nearly two decades due to PSP toxins. An ECOHAB-funded regional project called GOMTOX provided background data and samples that helped in the development of an Onboard Screening, Dockside Testing Program that allows fishermen to use new toxin testing kits on board their vessels to determine if areas are safe for harvesting in the offshore waters of Georges Bank, an area with an estimated $10-15 million sustained fishery of surf clams and ocean quahogs[28].

## CHALLENGES IN HAB RESEARCH, MONITORING AND MANAGEMENT

As is evident from the diverse and large nature of the national HAB problem described above, **managers responsible for the protection of human health and coastal resources are facing a growing and daunting challenge. Many regions are now subject to multiple HAB species, with many blooming at different times of the year, affecting multiple resources. All states now have HAB problems which appear to be getting worse, in part due to human activities. Monitoring programs that used to focus on a single HAB poisoning syndrome are now struggling to cover two, three, and even four different concurrent threats, greatly stretching scarce personnel and financial resources**. In some cases, this has led to blanket harvesting closures in which entire coastlines are quarantined for months at a time on an annual basis, even though the affected resources may not be toxic across that entire expanse and time.

Some species need to be present in very high abundances before harmful effects occur, which makes it easier to detect and track those HABs. However, other species cause problems at very low concentrations, essentially being hidden among other benign algae, making them difficult to detect and track. The factors that cause and control HABs, from their initiation to their decline vary, not only by species, but also by region due to differences in local factors such as the shape of the coastline, runoff patterns, oceanography, nutrient regime, other organisms present in the water, etc**. This diversity in species, toxins, habitats, and impacts means that there is no "one size fits all" approach to HAB research and management - each type of HAB needs to be studied individually.** An important conclusion in this regard is that it is necessary to sustain multiple HAB research and monitoring capabilities throughout the country. If funds are directed predominantly to individual, high-visibility events such as the massive 2015 West Coast ASP event or the ongoing Florida red and green tides, personnel and capabilities in other regions of the country will diminish, making those areas less able to deal with the outbreaks that will surely occur in future years. **Consequently, a national approach to coordination and funding is needed, following the framework that has already been established through the programs described above.**

NOAA is the only agency with extramural funding programs devoted solely to research on

[28] https://www.whoi.edu/news-release/Georges_Bank_fisheries

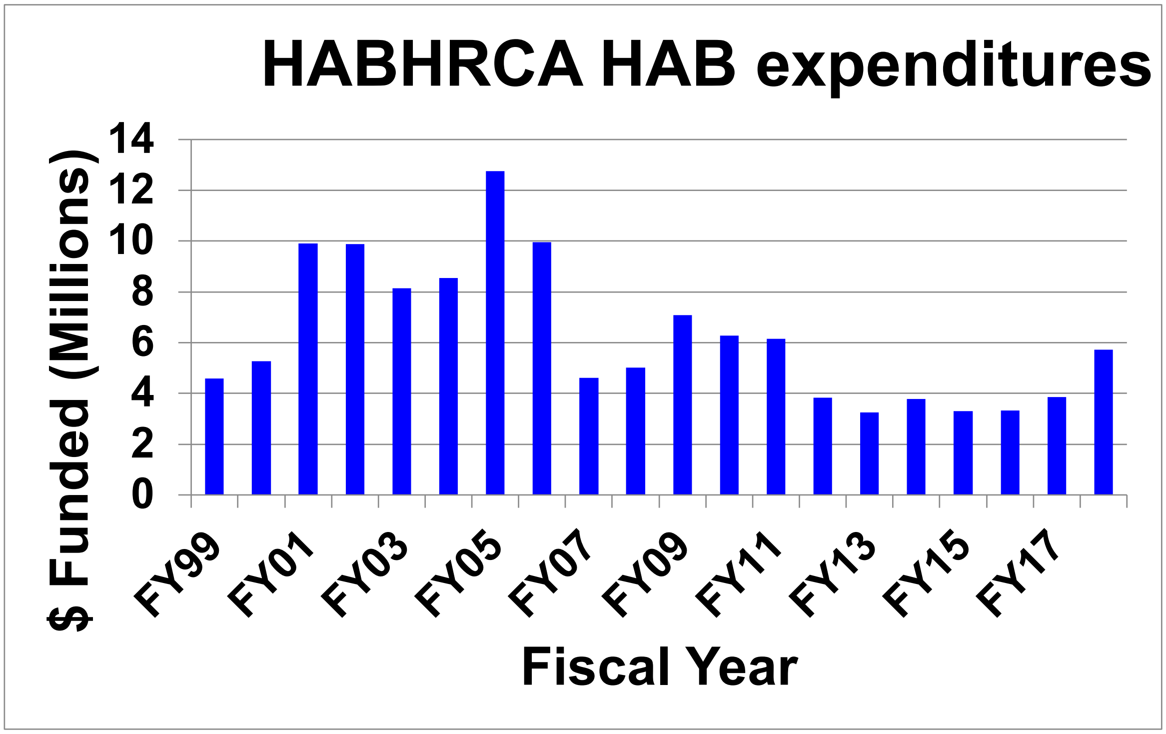


**Figure 5.** HAB HABHRCA expenditures from the NOAA CSCOR program. These values were determined under the assumption that HAB funding represents an average of 63% of the HABs plus hypoxia totals. 2018 data are preliminary.

HABs. Within that agency, one significant challenge has been that funding for HAB research has fluctuated widely, greatly impacting the pace and extent of progress. Since 1999, competitive funding for HAB research ranged from $3.3 to $12.8 million per year[29] (Figure 5). The number of research projects started varied from 0 to 25 per year, with significant intervals with no new starts (Figure 6**). Figures 5 and 6 demonstrate how funding has decreased dramatically since 2005-2006, even as the national HAB problem has expanded**. Recent increases are promising, but we are still far below the levels of prior years. Even if the prior years' maximum were re-established, however, the funding would not be enough to address all of the HAB problems in the US. For example, one five-year project to understand the causes of a single HAB in a single region costs $5 million in order to develop the appropriate model and a rudimentary HAB forecast, and more would be needed to refine the forecast and move it into an operational environment. The fluctuation in funding has meant that promising new technologies and approaches are lost or delayed, scientific capacity is lost as research teams disband, and new ideas do not get developed. As students and young professionals trained to work in the field move on to other pursuits, as has happened in recent low-funding years, our national response capabilities are greatly weakened. Scientists in our field talk about the "lost generation" of young HAB scientists who could not continue their training during the gap years seen in Figure 6. **Clearly, sustained funding at a higher level is a critical need.**

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[29] It was not possible to obtain a separate funding history for HABs since the competitive funding line within NOAA CSCOR is for HABs and hypoxia research and data are not available in early years for each program. Using the average percentage of the total that was used for HAB funding since 2007 (63%), these values in Figure 5 were calculated.

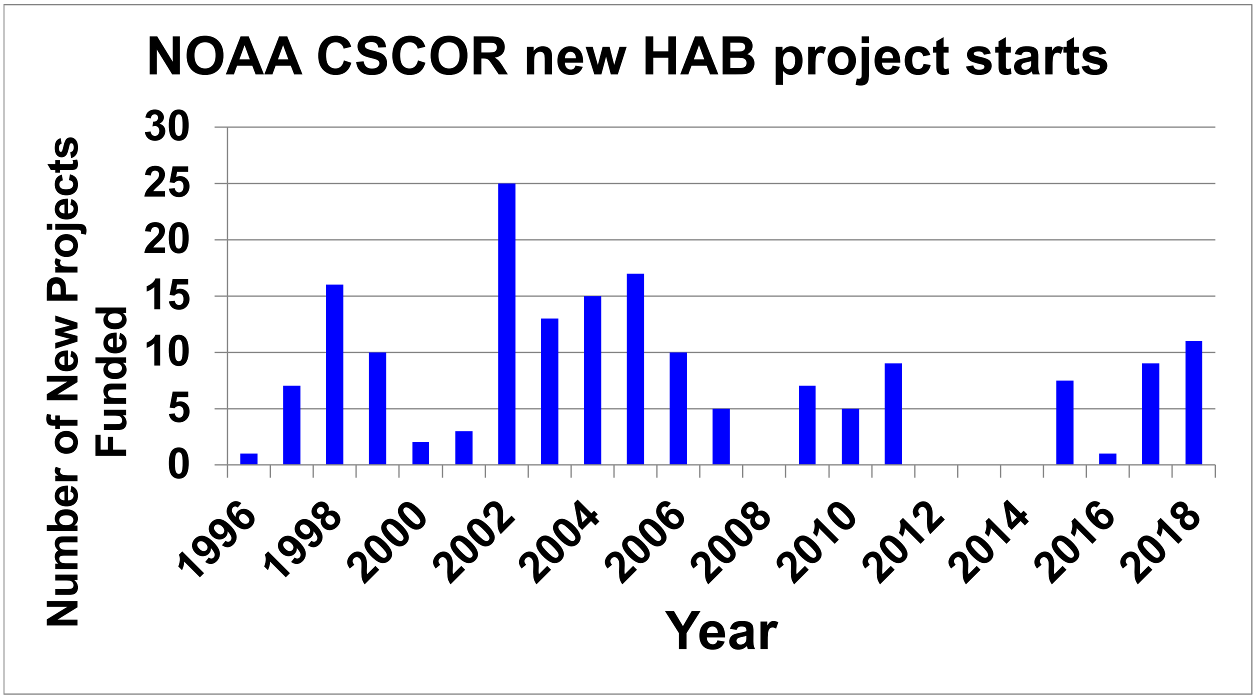


**Figure 6.** The number of HAB projects funded by NOAA CSCOR through the ECOHAB, MERHAB, and PCMHAB programs. Gaps indicate years when funding levels were only sufficient to support ongoing 3-5-year projects. These large gaps in new project starts and the low level of funding available in recent years (Figure 5) are in stark contrast to the rapidly expanding nature of the national HAB problem. 2018 data are preliminary.

Another challenge is that funding is needed for a wider diversity of activities. When HABHRCA was first passed in 1998, the only need was for research. That research has been highly successful and needs to continue, but now we are ready to move on to implementing the technology and approaches that have been developed, hence the creation of the MERHAB and PCMHAB programs. **Each time HABHRCA has been reauthorized there has been some wording about some of the other activities that are needed, besides research, but none of these have been explicitly authorized or funding provided.**

**Research**: The foregoing emphasizes that the need for research funding is greater than ever. There are emerging HAB species and toxins in every part of the U.S. While we understand the causes of some HABs in some regions, we do not understand why blooms terminate in any region, and the current situation in Florida, with a devastating bloom that has continued for over nine months, illustrates why this is critically important. The human health impacts and, as a corollary, the impacts on other animals, including endangered and threatened species, has barely been studied. We are now confronted, for example, with the possibility that shellfish may accumulate multiple diverse toxins, but all monitoring in the U.S. is focused on the health impacts of single toxins. This list could continue, but for those that ask, “Haven’t we done enough research?”, the answer is no, because we cannot manage what we do not understand and there is still very much that we do not understand.

**Operational HAB Forecasting**: Research has led to the development of HAB forecasts for specific HABs in specific regions[30]. Several are operational in NOAA and others are in various phases of transition to operations. However, making HAB forecasts operational, like weather forecasts, has taken funding away from research. **There is no clear mandate or funding for operational HAB forecasts,** although NOAA is implementing it slowly through its Ecological Forecasting Roadmap.

**Operational HAB Observing:** Research has led to the development of innovative and powerful HAB sensors that can be deployed autonomously at fixed locations and on a variety of mobile platforms. Some of these are highlighted in the testimony of Ivory Engstrom from McLane Laboratories for this hearing. These can provide states, tribes, and local management agencies and tourism, aquaculture and wild fisheries industries with HAB early warning and provide data for models that can forecast HABs, much as weather instruments provide data to improve the accuracy of weather forecasts. While the prices are likely to come down as more instruments are deployed, they are still too expensive for the agencies and industries that could most use them. There is a thus critical need for a National HAB Observing Network, perhaps under the auspices of the NOAA Integrated Ocean Observing System[31], and the Regional Observing Associations, which would deploy these sensors as part of the larger observing network. If states or industries wanted to add additional sensors to meet their specific needs, they could do it more cheaply and easily by becoming part of this larger network. **There is no clear mandate or funding for a national HAB observing system.**

**HAB Event Respon**se: As we have seen from the events in Florida this year, the West Coast in 2015, Lake Erie in multiple years, and many other outbreaks, extensive and damaging HABs can occur at any time and any place. There are immediate, short-term needs for predicting where the bloom will go and how severe it will be, assessing the impacts, and developing management responses, as well as longer-term needs for economic assistance and efforts to improve future response. NOAA has maintained a very small HAB Event Response Program[32], which is very effective, but much more is needed. We want to thank the Senate for passing S.1057, which includes an entire section on HAB and Hypoxia Events of National Significance. This highlights the importance of responding to events and is a great step forward. **However, some modification is required to make it effective for both short-term and long-term response, and a funding mechanism is required that will allow monies to be provided quickly.** I can provide additional suggestions at a later date, if requested, or recommend others who are more knowledgeable about the mechanics.

**Freshwater HABs**: The problem of inland freshwater HABs has exploded in the last five years and is only likely to get worse. While NOAA has purview over marine and coastal HABs including the Great Lakes, EPA has purview over inland freshwater HABs. **No HAB funding is authorized or appropriated for EPA** so that it can fulfill the requirements, similar to those of NOAA, for HAB programs.

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30 https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/hab-forecasts/

31 https://ioos.noaa.gov/

32 https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/rapid-response/

## SUMMARY AND RECOMMENDATIONS

- HABs are a serious and growing problem in the U.S., affecting every state. HAB problems will not go away and are currently increasing in severity and breadth nationwide.
- HABs have a wide array of economic and social 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 as well as community well-being, and medical treatment of exposed populations. Cumulatively, the costs of marine and freshwater HABs exceed $10-$20 billion over the last several decades.
- 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 program. Nevertheless, the combination of planning, coordination, and a highly compelling topic with great societal importance has led to integrated research and response communities that include scientists, federal and state agencies, tribes, and industry. In the past, many of these individuals and groups worked independently and with little exchange of ideas and data. The networks that now exist in many parts of the country are active and productive, and should be a major factor in the growing capabilities of the national HAB program.
- Progress thus far has been excellent, as the U.S. HAB program is seen as a model for other scientific disciplines in the U.S. and the world. The rate and extent of progress from here will depend upon how effectively the skills and expertise of government and academic scientists can be targeted on priority topics. The HAB community in the U.S. is fully capable of undertaking the new challenges inherent in an expanded national program. **This will be successful only if a coordinated national effort can be sustained to focus research personnel, facilities, and financial resources to the common goals of a comprehensive national strategy**

Additional recommendations are summarized as follows:

- As the lead federal agency for HABs, NOAA should retain the mandate to coordinate, conduct, and fund research and response efforts and levels of funding should reflect the importance of this responsibility.
- Funding needs to be sustained and enhanced for the existing NOAA HAB competitive programs—ECOHAB, MERHAB, and PCMHAB. These programs should be explicitly addressed in HABHRCA reauthorizations and appropriations.
- Given the breadth of environmental, economic, and human health impacts from HABs, funding is also required across a suite of federal agencies with different mandates, including NSF, NASA, EPA, NIEHS, and USGS.
- Specifically, freshwater HABs are an important focus but cannot be comprehensively addressed in NOAA programs other than in the great Lakes. HABHRCA authorizes EPA to address HABs, but does not provide a clear path and does not authorize funding. EPA should be authorized and appropriated funding to address freshwater HABs in a manner

to similar to NOAA. Clear direction should be provided so that EPA and NOAA move this program forward in a productive and efficient manner. One way to accomplish this is to require EPA to establish programs similar to the NOAA ECOHAB, MERHAB, PCMHAB and Event Response, perhaps in coordination with NOAA.

- Recognize that NOAA will require funds for operations in support of HAB management, such as HAB forecasting; authorize these activities with specific language, and specific funding allocations.
- Likewise, a clear mandate and funding for a National HAB Observing System are needed, possibly under NOAA's Integrated Ocean Observing System (IOOS).
- In the HABHRCA reauthorization that is moving through Congress, the Event Response program requires some modifications to make it effective for both short-term and long-term response, and a funding mechanism is required that will allow funding to be provided rapidly.

I would like to reiterate the importance of the national HAB program's role in helping understand and address the increasing frequency and intensity of bloom events. The extramural HAB science community also appreciates Congress's recent increases in funding for HAB work, and proposed increase in the FY'19 appropriation bills. We believe that a strengthened competitive research program working in coordination with enhanced agency core funding will ensure the best expertise, technology, and strategies are brought to bear on this growing problem.

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.

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