Testimony of

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Mr. Chairman and members of the Subcommittee. I am Donald M. Anderson, a Senior Scientist in the Biology Department of the Woods Hole Oceanographic Institution, where I have been active in the study of red tides and harmful algal blooms (HABs) for 30 years. I am here to provide the perspective of an experienced scientist who has investigated many of the harmful algal bloom (HAB) phenomena that affect coastal waters of the United States and the world. I am also Director of the U.S. National Office for Harmful Algal Blooms, co-Chair of the National HAB Committee, and have been actively involved in formulating the scientific framework and agency partnerships that support and guide our national program on HABs. Today my testimony will briefly summarize HABs and their impacts and provide some examples of the nature of our national HAB program and the technologies that have been developed to help mitigate and control these outbreaks. I will also provide my perspective on the research, programmatic, and legislative needs to move towards a National HAB action plan, and will offer some comments about the Committee's draft legislation for the reauthorization of HABHRCA (Harmful Algal Bloom and Hypoxia Research and Control Act). Other than a few general comments, I will restrict my comments to marine HABs, as testimony on freshwater HABs is being provided by my colleague Dr. Greg Boyer.

Background

HABs are caused by algae – many of them microscopic. These species sometimes make their presence known through massive "blooms" of cells that discolor the water (hence the common use of the term "red tide"), sometimes through illness and death of humans who have consumed contaminated shellfish or fish, sometimes through mass mortalities of fish, seabirds, and marine mammals, and sometimes through irritating aerosolized toxins that drive tourists and coastal residents from beaches. 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. As you will hear from Dr. Boyer, there are also HABs in freshwater systems that pose threats to human, animals, and ecosystems as a result of toxins present in drinking and recreational waters.

With regard to human health, one major category of HAB impact occurs when toxic phytoplankton are filtered from the water as food by shellfish which then accumulate the algal toxins to levels that can be lethal to humans or other consumers. These poisoning syndromes have been given the names paralytic, diarrhetic, neurotoxic, azaspiracid, and amnesic shellfish poisoning (PSP, DSP, NSP, AZP, and ASP). All have serious effects, and some can be fatal. A sixth human illness, ciguatera fish poisoning (CFP) is caused by biotoxins produced by dinoflagellates that grow on seaweeds and other surfaces in coral reef communities. Ciguatera toxins are transferred through the food chain from herbivorous reef fishes to larger carnivorous, commercially valuable finfish. Yet another human health impact from HABs occurs when a class of algal toxins called the brevetoxins becomes airborne in sea spray, causing respiratory irritation and asthma-like symptoms in beachgoers and coastal residents, typically along the Florida and Texas shores of the Gulf of Mexico.

Distribution of HAB Phenomena in the United States. With the exception of AZP, all of the poisoning syndromes described above are known problems within the U.S. and its territories, affecting large expanses of coastline (Fig. 1). PSP occurs in all coastal New England states as well as New York, extending to offshore areas in the northeast, and along much of the west coast from Alaska to northern California. Overall, PSP affects more U.S. coastline than any other algal bloom problem. NSP occurs annually along Gulf of Mexico coasts, with the most frequent outbreaks along western Florida and Texas. Louisiana, Mississippi, North Carolina and Alabama have also been affected intermittently, causing extensive losses to the oyster industry and killing birds and marine mammals. ASP has been a problem for all of the U.S. Pacific coast states. The ASP toxin has been detected in shellfish on the east coast as well, and in plankton from Gulf of Mexico waters. Until recently, DSP was virtually unknown in the U.S., but a major outbreak was recently reported along the Texas coast, resulting in an extensive closure of shellfish beds in that area. CFP is the most frequently reported non-bacterial illness associated with eating fish in the U.S. and its territories, but the number of cases is probably far higher, because reporting to the U.S. Center for Disease Control is voluntary and there is no confirmatory laboratory test. In the Virgin Islands, it is estimated that nearly 50% of the adults have been poisoned at least once, and some estimate that 20,000 – 40,000 individuals are poisoned by ciguatera annually in Puerto Rico and the U.S. Virgin Islands alone. CFP occurs in virtually all sub-tropical to tropical U.S. waters (i.e., Florida, Texas, Hawaii, Guam, Virgin Islands, Puerto Rico, and many Pacific Territories). As tropical fish are increasingly exported to distant markets, ciguatera has become a problem for consumers far from the tropics. For example, recent 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. The FDA subsequently issued a letter of guidance to seafood processors that recommends that certain fish species caught around that sanctuary should be avoided.

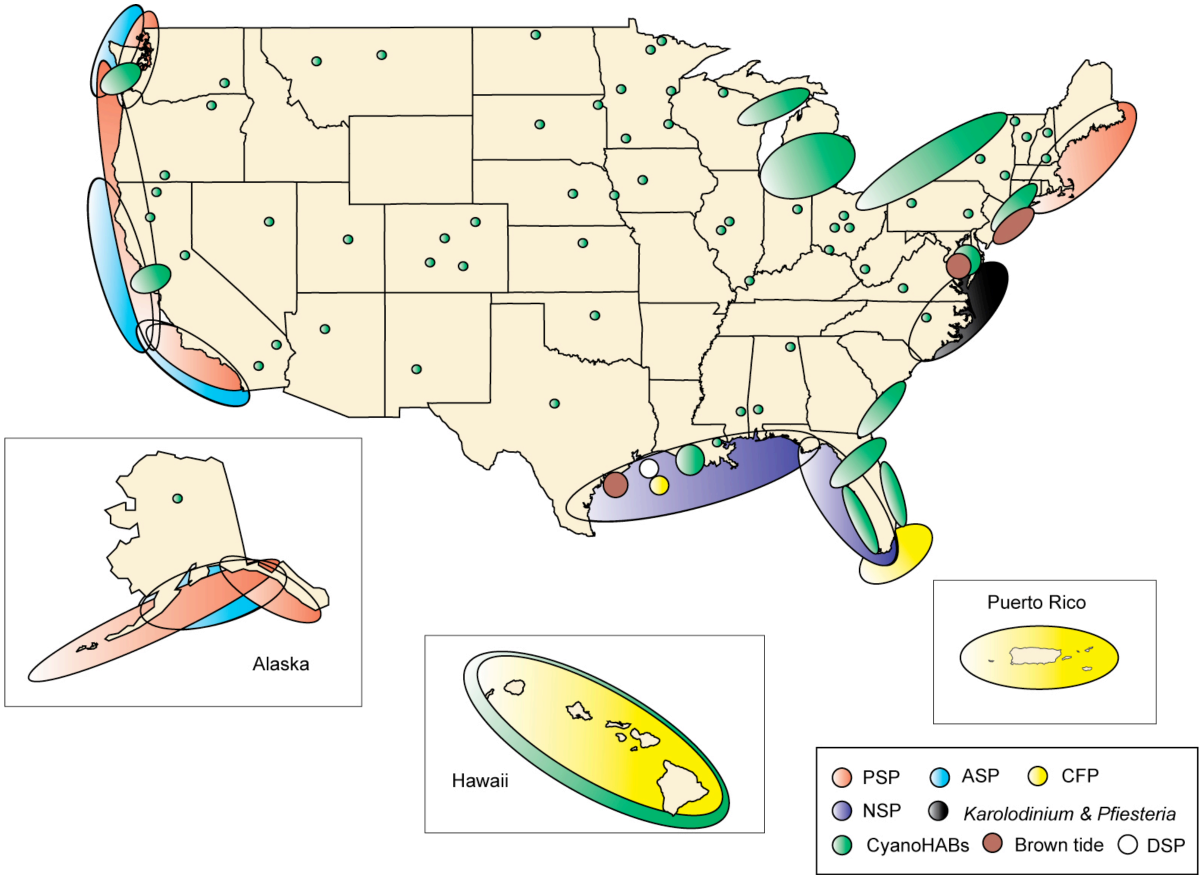

Figure 1. Distribution of HAB phenomena responsible for human illnesses in the U.S. (Source: U.S. National Office for Harmful Algal Blooms.)

Recent Trends. The nature of the HAB problem has changed considerably over the last three decades 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. In inland states, HABs in rivers, lakes, reservoirs, and other water bodies have increased as well. Overall, the number of toxic blooms, the economic losses from them, the types of resources affected, and the number of toxins and toxic species have all increased dramatically in recent years in the U.S. and around the world (Ramsdell et al., 2005).

There are many reasons for this expansion, some of which involve human activities. Some new bloom events likely reflect indigenous populations that have been discovered because of better detection methods and more observers rather than new species introductions or dispersal events. 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. The U.S. Coast Guard, EPA, and the International Maritime Organization are all working toward ballast water control and treatment regulations that will attempt to reduce the threat of species introductions worldwide.

Of considerable concern, particularly for coastal resource managers, is the potential relationship between the apparent increase in HABs and the accelerated eutrophication of coastal waters due to human activities (Anderson et al., 2002). Some HAB outbreaks occur in pristine U.S. waters with no influence from pollution or other anthropogenic effects, but in other areas, linkages between HABs and eutrophication have been noted (Anderson et al., 2008). Coastal waters 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, marine algae can grow in response to various types of nutrient inputs. Shallow and restricted coastal waters that are poorly flushed appear to be most susceptible to nutrient-related algal problems. Nutrient enrichment of such systems often leads to eutrophication and increased frequencies and magnitudes of phytoplankton blooms, including HABs.

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

HAB Program Development

In addition to providing background information on HABs, I was asked to comment on the technologies that are used for the mitigation and control of HABs. I was also asked to comment on the draft HABHRCA legislation and the need for action plans and research strategies, including those at the regional level. Below I will highlight some of the technologies that have been developed under past funding initiatives. This will demonstrate some of the extraordinary progress that has been made in our ability to monitor and manage HABs, but it will also help to demonstrate where there are gaps in our national program that need to be filled through specific, thematic funding programs that I believe should be specified in the draft legislation.

Our national HAB program is viewed by many colleagues in other disciplines as a model program that has succeeded because of its organization and planning. As recently as 20 years ago, this was not the case, however, as there was very little research on HABs, and that being conducted in the academic community was scattered and unfocused. To help rectify this problem, we formulated a *National Plan* (Anderson et al., 1993) that guided activities in this field for the next 10-15 years, identifying major impediments to progress and identifying the steps that were needed to overcome those impediments. The *National Plan* was broadly based, however, encompassing ecology, physiology, toxicology, human health, economics, ecosystem health, and many other topics. This breadth exceeded the mandate and resources of any single agency or program, and thus for implementation purposes, it was necessary to break the plan into a series of programs on complementary topics that together would meet all needs. 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 *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 four *Centers for Oceans and Human Health* that include significant HAB research and outreach activities. This program is in transition at the moment, due to the decision of NIEHS not to participate in the renewal process for the Centers due to budgetary issues. NSF has provided interim support, and efforts are underway to encourage NIEHS to re-join the program. NOAA has also created an *Oceans and Human Health Initiative* (OHHI) that supports extramural research and focused activities at three federal OHHI centers. As discussed below, several other programs are needed to complete the national program.

Research progress and technological advances

ECOHAB projects have been highly successful in unraveling the fundamental mechanisms behind the blooms or outbreaks of toxic and harmful algae throughout the U.S. In some cases, the advances represent the accumulation of knowledge that leads to a conceptual understanding of the dynamics of blooms that can stretch for 1000 km or more. Imagine the complexity of the biological, chemical, and physical phenomena that underlie blooms that occur on that scale. Yet as a result of the ECOHAB program's sustained investment in regional survey cruises and multi-disciplinary research teams, we now have what I believe is the best fundamental understanding of several regional HABs anywhere in the world. In the Northeastern US, for example, this has led to our ability to forecast toxic PSP outbreaks on an annual basis, which we have done quite successfully for the last two years, and which we will continue to do in the future. (See www.whoi.edu/page.do?pid=24039&tid=282&cid=41211). We also provide weekly numerical model predictions of bloom status that are posted on the Internet and widely used by resource managers within the region. The value of these long and short-term forecasts is seen in the actions of three states (Maine, Massachusetts, and New Hampshire) who contributed nearly $500,000 of emergency ("failed fishery") funds for the collection of data needed to initialize the models that will be used to forecast the regional blooms for 2010 and 2011.

In a similar manner, a regional ECOHAB program on the west coast of the U.S. has identified an eddy or circulating water mass off Puget Sound that serves as a reservoir or incubator for the toxic cells that cause ASP poisonings on that coast. (ASP is a debilitating illness that includes permanent loss of short-term memory in some victims). As water spins off of that eddy, it carries the cells to shore, causing sudden and significant outbreaks that are now easier to manage given this understanding of the source. I expect that Dan Ayres will provide more information on the value of this type of information in his accompanying testimony.

In the Gulf of Mexico, a second phase of the ECOHAB-Florida program is investigating nutrient uptake by the toxic red tide organism *Karenia brevis,* and is conducting surveys of nutrient concentrations in the region that are addressing the sensitive and highly controversial issue of the potential link between red tide blooms and nutrient inputs from land, including those associated with agriculture and other human activities. This ongoing research has obvious implications to policy decisions concerning pollution and water quality in the region.

These are but a few of the advances in understanding that have accrued from ECOHAB regional funding. Equally important are the discoveries from smaller, targeted research projects, as well as those that provide management tools to reduce the impacts of HABs on coastal resources. The most effective HAB management strategies are monitoring programs that involve sampling and testing of wild or cultured seafood products directly from the natural environment, as this allows unequivocal tracking of toxins to their site of origin and targeted regulatory action. Numerous monitoring programs of this type have been established in U.S. coastal waters, typically by state agencies. This monitoring has become quite expensive, however, due to the proliferation of toxins and potentially affected resources. States are faced with flat or declining budgets and yet need to monitor for a growing list of HAB toxins and potentially affected fisheries resources. Technologies are thus urgently needed to facilitate the detection and characterization of HAB cells and blooms. This need is being addressed through the MERHAB program. MERHAB projects have contributed valuable technologies to these ongoing monitoring programs, such as the application of species- or strain-specific DNA “probes” that can be used to label only the HAB cells of interest so they can then be detected visually, electronically, or chemically. With technological advances that often started with ECOHAB projects and moved to MERHAB applications, progress has been rapid and probes of several different types are now available for many of the harmful algae, along with techniques for their application in the rapid and accurate identification, enumeration, and isolation of individual species. One example of the direct application of this technology in operational HAB monitoring is for the New York and New Jersey brown tide organism, *Aureococcus anophagefferens*. The causative organism is so small and non-descript that it is virtually impossible to identify and count cells using traditional microscopic techniques. Antibody probes were developed that bind only to *A. anophagefferens* cells, and these are now used routinely in monitoring programs run by state and local authorities, greatly improving counting time and accuracy.

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

This capability is consistent with ECOHAB and MERHAB goals to develop and incorporate forecasts or predictions of bloom development and movement into management and mitigation programs. Prediction of HAB outbreaks requires numerical models which account for both the growth and behavior of the toxic algal species, as well as the movement and dynamics of the surrounding water. Numerical models of coastal circulation are advancing rapidly in the U.S., and a number of these incorporate HAB dynamics as well. A model developed to simulate the dynamics of the organism responsible for paralytic shellfish poisoning (PSP) outbreaks in the Gulf of Maine is relatively far advanced in this regard (McGillicuddy et al., 2005), and is now being transitioned from academic use towards an operational mode. Here again, congressional support is needed to provide the appropriations needed to turn these academic tools into operational programs, as discussed below. Note also that scientists from the New England region are working with colleagues in Washington state to help them adapt the Gulf of Maine numerical model for use in Puget Sound waters, since closely related organisms cause PSP outbreaks in both regions.

In the Gulf of Mexico, satellite images of ocean color are now used to detect and track toxic red tides of *Karenia brevis*. Bloom forecast bulletins are now being provided to affected states in the Gulf of Mexico by the NOAA NOS Center for Coastal Monitoring and Assessment. The combination of warning and rapid detection is a significant aid to the Gulf states in responding to these blooms. As is the case with the Gulf of Maine HAB forecasting system and one for the Great Lakes, Congressional attention is needed to provide the mandate and funding to make these HAB forecasting systems operational within NOAA. In FY 2010, funds were requested for this purpose in the President's budget, but were not included in either the House or Senate appropriations. **I would like to see this operational HAB forecasting capacity within NOAA authorized in the HABHRCA legislation, and a specific funding line recommended.**

Other practical strategies to mitigate the impacts of HAB events include: regulating the siting of aquaculture facilities to avoid areas where HAB species are present, modifying water circulation for those locations where restricted water exchange is a factor in bloom development, and restricting species introductions (e.g., through regulations on ballast water discharges or shellfish and finfish transfers for aquaculture). Each of these strategies requires fundamental research such as that being conducted through ECOHAB, but further advances would occur if they are moved to practical application through a new program on the prevention, control, and mitigation of HABs.

Several approaches to directly control or suppress HABs are under study as well - similar to methods used to control pests on land – e.g., biological, physical, or chemical treatments that directly target the bloom cells. Here however, progress towards direct field applications has been slow, and efforts are needed to change the nature and the pace of this line of investigation. To date, other than one study in which copper sulfate was dropped from crop dusting planes to control a Florida red tide over 50 years ago, there has not been a single effort to control a natural HAB in U.S. waters. Another sign of the lack of progress in this topic area is seen in the submissions of scientific papers to the forthcoming 5th US HAB Symposium – a national meeting of US HAB researchers and managers. Of the nearly 200 abstracts submitted to this conference, only two involve bloom control studies.

The reasons for this lack of progress in bloom control will be discussed below, and recommendations will be offered for ways to change this worrisome trajectory, but it is not for lack of possible strategies. One example is work conducted in my own laboratory, again through

ECOHAB support, using ordinary clay to control HABs. When certain clays are dispersed on the water surface, the tiny clay particles aggregate with each other and with other particles, including HAB cells. The aggregates then settle to the ocean bottom, carrying the unwanted HAB cells from the surface waters where they would otherwise grow and cause harm. As with many other new technologies for HABs, initial results are quite promising and small-scale field trials have been conducted, but continued support is needed to fully evaluate benefits, costs, and environmental impacts.

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

In general, bloom control is an area where very little research effort has been directed in the U.S. (Anderson, 1997), yet considerable effort is needed before these means are used to control HABs in natural waters given the high sensitivity for possible damage to coastal ecosystems and water quality by the treatments. The U.S. lags behind countries like Japan, China, South Korea and Australia in pursuing and implementing bloom control strategies. At the current pace of research and development, options for HAB control may not be in place for many years unless a concerted effort is made to encourage and promote these kinds of studies. As discussed below, this could be accomplished as part of a national program on HAB prevention, control, and mitigation, and through cooperation with other fields of science where control of aquatic or terrestrial pests is more common.

Comments on the draft legislation

It is my belief that the 1993 *National Plan* provided the guidance and perspective that led to the creation of several multi-agency partnerships for HAB studies, and to many individual agency initiatives on this topic. Together, ECOHAB and MERHAB have funded over $100 million in marine and freshwater (Great Lakes) HAB research since the programs began in 1996 and 2000, respectively. Significant funding has also been provided by the COHH and OHHI programs. After more than 10 years of strong program growth and diverse research activities, the 1993 National Plan became outdated, however, and thus was replaced by *HARRNESS* (*Harmful Algal Research and Response: A National Environmental Science Strategy 2005-2015*; Ramsdell et al., 2005). Several hundred scientists and managers, from a wide array of fields, contributed to the knowledge base on which this new national science and management strategy is based. *HARRNESS* is the plan that will guide U.S. HAB research and monitoring well into the future, and is one that I enthusiastically support.

At the conceptual level, *HARRNESS* is a framework of initiatives and programs that identify and address current and evolving needs associated with HABs and their impacts. At the programmatic level, several of the existing national programs will continue to function, and new programs will need to be added. In the former category, ECOHAB should continue to address the fundamental processes underlying the impacts and population dynamics of HABs. Research results have been brought into practical applications through MERHAB, a program formulated to transfer technologies and foster innovative monitoring programs and rapid response by public agencies and health departments. MERHAB should also continue under the new *HARRNESS* framework.

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

A number of the recommendations of *HARRNESS* are not adequately addressed by existing programs, however. As a result, the HAB community needs to work with Congressional staff and agency program managers to create new programs, as well as to modify existing ones, where appropriate. Specific recommendations are given below in this regard.

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 OHH HAB programs. This is because NOAA's mandate includes the Great Lakes and estuaries up to the freshwater interface, but does not include the many rivers, ponds, lakes, and reservoirs that are subject to freshwater HAB problems. Freshwater HABs are an important focus within HARRNESS, and therefore **I strongly support the inclusion of EPA in the draft HABHRCA legislation before us. More direction should be provided, however, so that EPA and NOAA move this program forward in a productive and efficient manner.** As the draft legislation reads now, the direction of the freshwater HAB program will be determined by the Regional Research Action Plans. There is certainly a need for prioritization and planning at the regional level, but national planning workshops and a national research agenda for freshwater HABs are also needed, as was done with the 1993 *National Plan* and *HARRNESS* for marine HABs. This is particularly true given that two federal agencies will be involved. Coordination and the division of responsibilities will be important issues to resolve.

It is critical however that appropriations be increased to include this new area of investigation. If appropriations remain level, and a new freshwater program is established, resources will be drawn away from marine issues that are already thinly funded, and research progress will decrease dramatically and the productive scientific community working on HABs will grow smaller and less effective.

The support provided to HAB research through ECOHAB, MERHAB, Sea Grant, and other national programs has had a tremendous impact on our understanding of HAB phenomena, and on the development of management tools and strategies. Since HAB problems facing the U.S. are diverse with respect to the causative species, the affected resources, the toxins involved, and the oceanographic systems and habitats in which the blooms occur, we need multiple teams of skilled researchers and managers distributed throughout the country. This argues against funding that ebbs and floods with the sporadic pattern of HAB outbreaks or that focuses resources in one region while others go begging. **I cannot emphasize too strongly the need for an equitable distribution of resources that is consistent with the scale and extent of the national problem, and that is sustained through time.** This is the only way to keep research teams intact, forming the core of expertise and knowledge that leads to scientific progress. To achieve this balance, we need a scientifically based allocation of resources, not one based on political jurisdictions. This is possible if we work within the guidelines of HARRNESS and with the inter-agency effort that has been guiding its implementation.

New Programs to be Established and Sustained. The 1998 Harmful Algal Bloom and Hypoxia Research Control Act (HABHRCA) and the Harmful Algal Bloom and Hypoxia Amendments Act of 2004 (2004 HABHRCA Reauthorization) authorized the establishment of three national programs on HABs: 1) "Ecology and Oceanography of Harmful Algal Blooms" (ECOHAB) (HABHRCA Sec. 605 (2));2) "Monitoring and analysis activities for HABs" (renamed Monitoring and Event Response for Harmful Algal Blooms or MERHAB) (HABHRCA Sec. 605 (4)); and 3) "A peer-reviewed research project on management measures that can be taken to prevent, reduce, control, and mitigate HABs." (HABHRCA Sec. 605 (3)). Under HABHRCA the ECOHAB program was authorized as an interagency (NOAA, NSF, EPA, NASA, ONR), competitive research program, led by NOAA, and the MERHAB program was established as a NOAA competitive research program. A Federal Register Notice (FRN), published 5/04/2009 (http://edocket.access.gpo.gov/2009/E9-10187.htm), announced that NOAA was establishing the Prevention, Control, and Mitigation of Harmful Algal Blooms (PCMHAB) Program.

Guidelines for the PCMHAB are given in the National Scientific Research, Development, Demonstration, and Technology Transfer Plan on Reducing Impacts from Harmful Algal Blooms (RDDTT Plan; Dortch et al., 2008). The proposed RDDTT program has two other essential components. These are: 1) a comprehensive national HAB Event Response program: and 2) a Core Infrastructure program. **Together with the PCM component, these are interdependent and critical for improving future HAB research and management, and I therefore urge the Committee to include these as specific, named programs in the draft legislation**. Justification for this emphasis is as follows.

Prevention, Control, and Mitigation of HABs. Congress mandated a program for HAB Prevention, Control and Management in the legislation reauthorizing the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 and again in the 2004 reauthorization. Further rationale for this program is that much of the focus of past HAB research has been on fundamental aspects of organism physiology, ecology, and toxicology, so less effort has been directed towards practical issues such as resource management strategies, or even direct bloom suppression or control (Anderson, 1997). As discussed above, progress in the area of bloom suppression or control has been very slow. I have attached a commentary that I wrote for the journal *Nature* more than 10 years ago (Annex 1) that discussed why progress in bloom control was advancing so slowly. Unfortunately, many of the points in that discussion are still valid today. Among the impediments to progress is that scientists have chosen to focus more on less controversial, and therefore more easily funded lines of work. Societal concern about bloom control strategies that might involve the use of chemicals or engineered or non-indigenous organisms is significant, and therefore it has been difficult to move research from the laboratory to the field. In the case of my own laboratory's work on the use of clay dispersal to control blooms, we have seen that a few vocal opponents can raise environmental concerns that delay or stop field applications, even though this method is environmentally benign in comparison to the damage from the HAB itself, and that this same bloom control strategy is used routinely elsewhere in the world to protect fish farms (e.g., Korea).

Yet another impediment is that there is no specific funding specified for PCM research. As a result, PCM proposals compete with ECOHAB and MERHAB submissions for funds. Given the controversial nature of many PCM strategies, it is not surprising that peer reviews of the proposals are variable and sometimes negative, and that more conservative projects on bloom dynamics, toxin chemistry, or other topics are selected. **I therefore strongly recommend that specific wording be inserted in the draft HABHRCA legislation to establish and sustain a national program on Prevention, Control and Mitigation of HABs, and that specific funds be authorized for that program.**

In this context, Congressional oversight may be needed to establish an agency mandate for control of marine and freshwater nuisance species. Unlike the Agricultural Research Service of the USDA, which has a mandate for control of terrestrial plant pests, there is no federal agency with this resonsibility for marine waters. This is an area where the growing concern about invasive species could be of great help to the HAB field, as technologies, regulations, policies, and environmental concerns are common to both fields. I can see a great deal of value in the convening of a workshop to in which HAB investigators would meet with those working on control strategies for invasive species, insects, aquatic vegetation, other pest infestations, as well as with those working on bioremediation strategies used for oil spill and pollution events.

Event Response. A major HAB outbreak in the Gulf of Maine in 2009 highlighted the need for an Event Response program as part of the national HAB program. During this event, virtually the entire coastline of the state of Maine was closed to shellfish harvesting due to dangerous levels of toxicity. The same was true for New Hampshire, and for portions of Massachusetts. Government officials, resource managers, and the general public were anxious for information on the offshore extent of the bloom, and it's potential duration, yet there were no research programs ongoing to provide such information. Senator Snowe made a direct request to NOAA to provide this type of information, resulting in a scramble to find funding for ships and research personnel on short notice. Had there been a national HAB Event Response Program, as described in the RDDTT report (Dortch et al., 2008), the response would have been significantly more comprehensive, rapid, and efficient.

This is but one example of the need for rapid response to HABs that occur throughout the US. In some cases, local resources are sufficient, but in unexpected events, or those that are more significant and dangerous than normal, additional resources are needed that can be rapidly mobilized and used to protect the public health and fisheries resources. **It is therefore my recommendation that specific wording for a national HAB Event Response program be included in the HABHRCA legislation, and that specific funds be authorized for that program.**

Infrastructure. Researching and implementing new PCM strategies and improving event response will not be possible without certain types of infrastructure, including chemical analytical facilities, reference and research materials, toxin standards, HAB culture collections, tissue banks, technical training centers, and databases. At the present time, many of these facilities or resources are maintained by individual investigators or laboratories, with no centralized coordination or support. Personally, I maintain a culture collection of HAB species that exceeds 400 strains, yet I do not receive direct funding for its expenses. For other infrastructure needs, the necessary resources to not exist, and therefore funds are needed to provide these to the HAB community. For example, analytical standards for some HAB toxins are not available, severely restricting research and management progress. Likewise, molecular probes that allow the accurate and rapid identification of HAB species are also not universally available.

The RDDTT report (Dortch et al., 2008) identifies and prioritizes infrastructure needs for the national HAB program. What is needed is the Congressional recognition of the need for such a program, and therefore **I recommend that specific wording for a national HAB infrastructure program be included in the HABHRCA legislation, and that funds be authorized for this specific program.**

Although PCMHAB will be the program that the public will most readily perceive as 'progress' in the management of HABs, the program is part of an integrated approach to HAB risk management that must include Event Response and Infrastructure programs. **Furthermore, since many agencies are involved in HAB research and response, it will be necessary to specify that these new programs should be interagency partnerships, and funding should be provided to agencies with major roles.** In addition to NOAA, NSF, and EPA, other agencies, such as FDA, CDC, NSF, and NIEHS also contribute substantially and should be named as partners in the national HAB program.

Regional Research Action Plans. As emphasized above, HAB phenomena are diverse throughout the US, and therefore impacts and research needs will vary across regions. I therefore support the congressional directive to create regional research action plans through a series of meetings involving managers, scientists, government officials, industry, and other stakeholders. My only concern here is the timescale for these meetings. Having participated in a very successful meeting of this type in Florida, I know that a significant cost is involved, and that considerable time is needed to plan, convene, and then report on the results of such a meeting. Given the inclusion of "freshwater" regions involving inland states, of which there may be many, I can envision NOAA HAB program officials struggling to organize and run a large number of meetings in a short period of time, and having to commit significant funds that would otherwise be directed to research. **I would thus recommend a more gradual approach to the regionalization**.

SUMMARY AND RECOMMENDATIONS

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

In summary:

- Marine HABs are a serious and growing problem in the U.S., affecting every coastal state; freshwater HABS are an equally significant problem in inland states. HABs impact public health, fisheries, aquaculture, tourism, and coastal aesthetics. HAB problems will not go away and will likely increase in severity.
- HABs are just one of many problems in the coastal zone that are affected by nutrient inputs and over-enrichment from land. They represent a highly visible indicator of the health of our coastal ocean. More subtle impacts to fisheries and ecosystems are likely occurring that are far more difficult to discern.
- A coordinated national HAB Program was created over 15 years ago and partially implemented. That *National Plan* has been updated with a new plan called HARRNESS that can guide the next decade or more of activities in HAB research and management.

Recommendations:

- Sustain and enhance support for the national HAB program HARRNESS.
- Sustain and enhance support for the ECOHAB, MERHAB and OHH programs, and authorize new programs. In the latter context, a separate program on the practical aspects of HAB prevention, control and mitigation (PCMHAB) needs to be authorized, as it was in past HABHRCA legislation, and two new programs (HAB Event Response and HAB Infrastructure) should be authorized as well, each with a specific amount of funds to insure that resources are indeed directed to these programs by NOAA and EPA.
- 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.
- Encourage interagency partnerships, as the HAB problem transcends the resources or mandate of any single agency.
- Freshwater HABs are an important focus within HARRNESS, and therefore EPA should be included in the draft HABHRCA legislation. More direction should be provided, however, so that EPA and NOAA move this program forward in a productive and efficient manner. For example, national planning workshops and a national research agenda for freshwater HABs are needed, given that two federal agencies will be working on the topic. The direction of the freshwater program should not be determined solely by Regional Research Action Plans.
- Encourage methods and instrument development for land- and mooring-based HAB cell and toxin detection, and for bloom forecasting through instrument development support for the Integrated Ocean Observing System.

- Recommend appropriations that are commensurate with the scale of the HAB problem in both marine and fresh waters. The national HAB program is well established and productive, but it needs additional resources if new topics, responsibilities and tasks are added through new legislation. Research should be peer-reviewed and competitive, and should take full advantage of the extensive capabilities of the extramural research community.

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

Respectfully submitted,

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Annex 1. Turning back the harmful red tide. (Nature 388: 513-514. 1997)

Turning back the harmful red tide

Harmful algal blooms are a serious and increasing problem in marine waters, yet scientists and funding agencies have been slow to investigate possible control strategies.

Donald M. Anderson

Each holiday season I await the visit of one relative with trepidation. Years ago he asked whether I had "stopped that red tide problem yet?" — a simple question from one convinced that science solves problems directed to a so-called expert on the destructive and often visible 'blooms' of phytoplankton that kill fish, make shellfish poisonous and cause numerous other problems in coastal waters. I explained that we did not understand the causative organisms, their ecology or oceanography well enough to propose control strategies, but that one day we would.

Although temporarily satisfied with my argument, each year thereafter my brother-in-law repeated the question, and each year my answer was the same. Whatever progress had been made, there were new questions to be addressed. Eventually, he concluded that I did not want to solve the problem, as that would end my research programme. He is wrong, of course, but the explanation is far more complex than he would think, and is in part the subject of this article.

Throughout history, blooms of microscopic algae have had a major impact on fish, birds, mammals and other organisms in the marine food web. These 'red tides' (now termed harmful algal blooms) take many forms and have many effects. Some toxic algae kill wild and farmed fish. Others produce potent neurotoxins that accumulate in filter-feeding shellfish and poison human consumers. Algal toxins can alter the structure and function of marine ecosystems, affecting fecundity and survival at all levels.

Even non-toxic algae can be harmful when they accumulate in sufficient numbers — sometimes millions of cells per litre — to discolour the water, shade submerged vegetation, disrupt food-web dynamics and cause oxygen depletion. At the other extreme, toxic algae can be a tiny fraction of the total phytoplankton population and still be dangerous. Diarrhetic shellfish poisoning, for example, has been reported with *Dinophysis* concentrations of a few hundred cells per litre.

The scale and timing of harmful algal blooms is highly variable. Some are localized, occurring in bays or estuaries; others are massive, covering thousands of square kilometres. Some occur at the same time and place each year; others strike in random fashion. Some last a few weeks, others years.

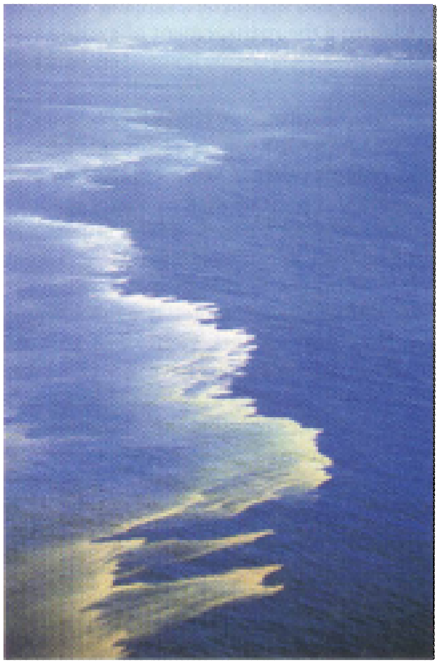
Harmful algal blooms are not new phenomena. Red tides are recorded in the Bible and in the fossil record. What is new is the recent proliferation of harmful blooms[1]. There is debate about the nature and causes of this expansion. Some call it a global epidemic linked to pollution and human changes to coastal ecosystems[2]. Others argue that the expansion is in part an artefact reflecting increases in the number of scientists, advances in toxin detection, and the proliferation of aquaculture and other activities requiring product monitoring[1,3].

One thing is certain — there is a growing global problem at a time when human reliance on coastal zones for food, recreation and commerce is rapidly expanding. Nevertheless, there is practically no exploration of direct control of marine blooms — attempting to kill or remove the cells or reduce their toxicity. At an international conference on harmful algae held in Vigo, Spain, in June, only one contribution of more than 400 abstracts from 58 countries addressed direct control of marine blooms. Imagine the difference if the conference had been on agricultural pests or on algal blooms in fresh water, where control efforts are common.

Research efforts on mitigation strategies such as shellfish-monitoring and aquaculture site management are critically important, but they treat the symptoms without attacking the problem. Government officials and the public want to know what is being done, or what can be done, in terms of direct intervention. So far, we have little to offer other than tentative predictions of bloom reductions decades from now if nutrient loadings are reduced.

I believe that some harmful algal blooms can be controlled or managed, not 20 years from now, but in the near future, economically and without disastrous environmental consequences. This belief may brand me as a heretic among my colleagues, some of whom fear that the ocean will be further despoiled by inept human attempts to manipulate ecosystems we do not understand.

At the heart of this negativism is a conviction that mankind does not possess the skills, knowledge or right to manipulate the marine environment on any significant scale. We are, however, already doing exactly that. By polluting coastal waters, we change the abundance and relative amounts of critical plant nutrients, which in turn alters the species composition of planktonic ecosystems. Indeed, this may be why there is an increasing number of harmful algal blooms. We are harvesting fish and shellfish at an alarming rate, removing components of the food-web with little knowledge of how such enormous manipulations affect other levels.



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Some red tides, such as this non-toxic bloom of *Noctiluca* off California, cover huge areas, making it difficult to foresee environmentally benign bloom-control strategies (see also http://www.redtide.whoi.edu/hab/).

To replace dwindling natural fishery resources, we are turning coastal waters and wetlands into marine farms at an extraordinary rate. Whether by fish or shrimp farms (which have been likened to small cities with respect to their production of organic matter as pollutants), or by shellfish or seaweed culture (which strip plankton and nutrients from the water), we are altering near-shore waters significantly. Coastal ecosystems are no longer pristine and will not revert to their 'natural' state without intervention.

From land to ocean

Distrust of our ability to control pests and diseases seems to be based more on pessimism than on fact. When biological control is discussed, for example, some are quick to point out failures such as the introduction of the mongoose to oceanic islands or the giant toad to Australia[4]. Obscured by these failures is a multitude of successes in terrestrial biocontrol of weeds and pests[4]. Overall, 165 insect pests and 35 weed species have been controlled. Less than 2 per cent of the introductions became pests themselves, and many of those were 'generalist' predators — an approach that is no longer practised.

Other examples of terrestrial management strategies include integrated pest management, which combines biological control with chemical agents such as narrow-spectrum pesticides, and ecologically based pest management, which attempts to work with ecosystem processes in the management effort[5]. The conceptual framework for pest management on land is far advanced, and should be a valuable resource in planning the management of marine systems. Instead it is largely ignored and misunderstood.

Extrapolation from land to the ocean will admittedly be difficult, as marine and terrestrial systems differ in scale, complexity and dynamics[6]. Application of a control agent to a single crop on a parcel of land is certainly simpler than the marine equivalent, where water motions will change the distribution and abundance of target organisms and applied control agents. Control of an outbreak at one site may have no effect on blooms in later years at the same location[6]. Another difference is that the community of organisms in marine ecosystems is more diverse and complex than that in single-crop agricultural systems.

Yet another factor that has stalled progress is the tendency to generalize that all blooms are massive. One colleague argues that blooms, like tornadoes or hurricanes, can be tracked and their movements predicted, but never controlled. He may be right about the larger blooms, but many are small or localized, either permanently or during key stages of development. For example, destructive brown tides in Texas or New York are thought to begin in certain bays and then to spread to adjacent waters. A widespread coastal bloom might be localized and accessible at an earlier stage.

Another constraint is that most countries have no official policy for funding marine pest management. In the United States, the Department of Agriculture puts extensive resources into terrestrial pest management. By contrast, the equivalent agency responsible for the oceans, the National Oceanic and Atmospheric Administration, has no marine pest-control programmes. Lacking strong leadership or targeted funding programmes at the national level, scientists opt for research on fundamental ecological or oceanographic issues less likely to be rejected during peer-review.

Control options

But there are signs of change in at least some parts of the world. South Korea has established a harmful algal bloom engineering division at its National Fisheries Research and Development Institute. And Australia's Commonwealth Scientific and Industrial Research Organization has established a Centre for Research on Introduced Marine Pests, which plans a proactive approach to marine pest management consistent with the country's aggressive reliance on terrestrial biological control. It is not clear whether this new programme will support research on control of harmful algal blooms.

During a red tide in Florida 40 years ago, copper sulphate was applied to 10,000 acres of shoreline using crop-dusting planes[7]. The treatment was initially effective, but blooms reappeared within weeks. Copper was deemed too expensive and non-specific to be used other than for short-term, small-scale bloom control. In another study, 4,700 chemicals were screened for use against Florida's red-tide alga, but none was sufficiently potent in natural sea water without also having adverse effects on other organisms.

Since then, chemical control options have received little attention, and no significant bloom-control research has been undertaken in the United States. Japan, China and Korea are exploring control strategies because they 'farm' their coastal waters heavily through aquaculture. Faced with significant economic losses from red tides, Japan initiated a broad evaluation of bloom-control strategies in the mid-1970s. Much of our knowledge of possible approaches comes from this outdated but useful series of studies[9], which continues to this day, but at a much-reduced level of effort.

One promising strategy treats blooms with flocculents such as clay that scavenge particles, including algal cells, from sea water and carry them to bottom sediments. Removal efficiencies of 95–99 per cent have been achieved in laboratory cultures using clay, and small-scale field trials near fish farms have also been successful, though expensive[8]. New clays that are an order of magnitude more efficient in cell removal have been tested in China; this capacity can be further increased using coagulants such as polyhydroxy aluminium chloride[9].

Applications in China have been limited to tests in shrimp aquaculture ponds but, in 1996, 60,000 tons of clay were used in Korea to control a *Cochlodinium* red tide threatening near-shore fish farms. About 100 km^2 were treated over several weeks, and nearly 100,000 tonnes of clay are now stockpiled in anticipation of the next bloom.

Clay is a non-toxic, naturally occurring material. Fish and bottom-dwelling organisms are unaffected by extremely high clay loadings near pottery industries[10]. The prospects look good, but considerable research is needed before large-scale field applications can be attempted. Obvious concerns are the fate and effects of sedimented cells and toxins on bottom-dwelling animals, and the collateral mortality of co-occurring planktonic organisms.

Biological control of harmful algal blooms also has potential. Zooplankton that graze on bloom species have been proposed as control agents[8] but remain untested because of the impracticality of growing and maintaining predators in sufficient quantity. Viruses are abundant in marine systems, replicate rapidly and tend to be host-specific, suggesting that a single algal species could be targeted[11]. Parasites[12] also have potential to control algal bloom species, but specificity is largely unknown. There are numerous examples of bacterial strains[13] exhibiting strong and specific algicidal activity, although no field applications have yet been attempted.

Prognosis for the future

I have mentioned only a few of many potential control strategies. We must cautiously explore all possible approaches, but this requires funding at the scale needed to provide data to support informed decisions and override our preconceptions. We also need to establish guidelines for acceptable marine treatments.

In one sense, the problems we face with harmful algal blooms are similar to those encountered in agriculture or medicine, fields in which control of pests and diseases is a practical reality. The marine environment is admittedly different, but our hesitancy reflects a *de facto* acceptance that the problems are insurmountable. I believe they are not, and that we can make progress if new resources are made available and if we learn from the mistakes and successes of more than 100 years of experience controlling terrestrial pests.

There is a thin line to walk here — to argue that we have been too cautious and that success is possible, without promising more than we can deliver, unrealistically raising the expectations of the public and politicians. I also worry that funds needed for ecological studies might be diverted to control. I see the risks, but I also see the chance that this article may initiate a debate that will ultimately direct scientific thought and resources towards practical solutions. My brother-in-law would no doubt approve. ☐

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