Implementation Strategy for a
National Harmful Algal Bloom Observing Network (NHABON)

February 2021

Summary

The economic, environmental, and health impacts of marine and freshwater harmful algal blooms (HABs) are increasing around the country as new HABs emerge and existing problems get worse due to a range of factors, including nutrient pollution, coastal development, aquaculture expansion, and a warming climate. The impacts vary depending on the species of HAB, the toxins that are produced, the hydrographic drivers, detection methods, and the needs of managers and stakeholders. Many regions are now experiencing multiple HAB problems every year, posing a significant challenge to managers who must deal with a range of toxins, impacted resources, and bloom timings. One promising approach to augment traditional HAB monitoring is the use of *in situ*, autonomous sensors capable of detecting and quantifying HAB cells and toxins, as demonstrated in many recent research projects (see Boxes 1, 2, 3 and 4 for examples). However, research funding is sporadic, short-term, and therefore cannot support the operational HAB observing needed to produce early warnings and forecasts that can protect human health, ecosystems, and coastal economies. The Framework for a National HAB Observing Network (NHABON) describes a cost-effective approach for rapid, early warning of HABs tailored to the needs of each region while taking advantage of leveraging, economies of scale, and coordination. Five pilot projects are currently implementing parts of that NHABON Framework and demonstrating how such a system might work. Ongoing regional research projects funded through other programs are also demonstrating the power of HAB observing capabilities. Based on an in-depth analysis of needs and expenses, the overall cost for full implementation of NHABON is estimated to be $30 million, with annual operating costs between $5-7 million. The system would be scalable and could be implemented incrementally as need and resources dictate.

Need

NHABON is needed to integrate local, state, regional, and federal HAB observing capabilities and deliver products operationally. Implementation of NHABON would:

- **Enable HAB detection, early warning, and forecasting;**
- **Leverage economies of scale and information and technology transfer between regions;**
- **Determine baselines and discern patterns/trends to assess the impacts of climate change, eutrophication, and other environmental forcings;**
- **Be tailored to the unique environmental and community needs of each region; and**
- **Provide observations to support state, tribal, and national missions of understanding, predicting, mitigating, and managing HABs.**

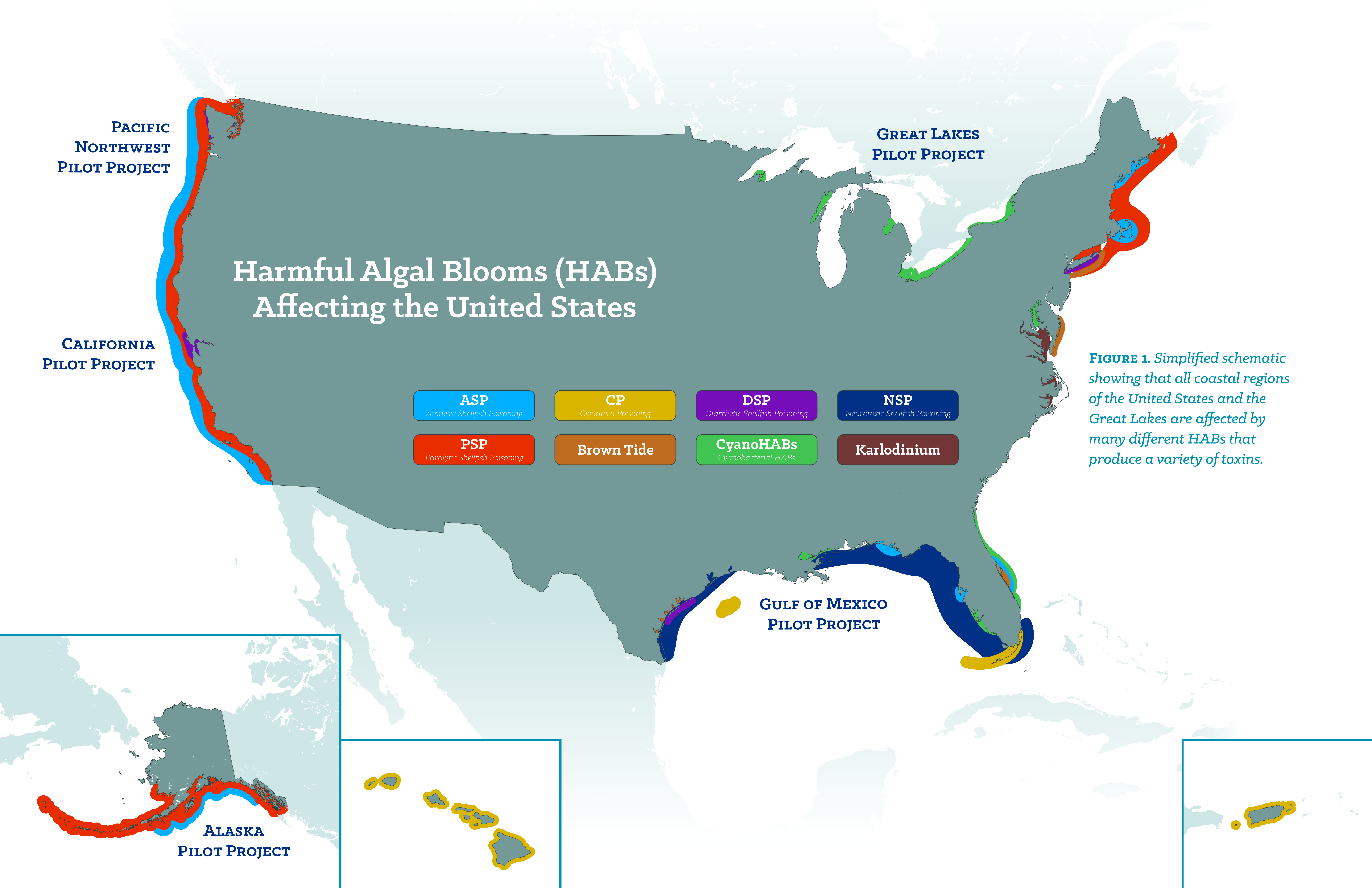


Figure 1. *Simplified schematic showing that all coastal regions of the United States and the Great Lakes are affected by many different HABs that produce a variety of toxins.*

Leveraging IOOS

The diversity of species, toxins, habitats, and impacts implies that there is no "one-size-fits-all" approach to developing a HAB observing network. The U.S. Integrated Ocean Observing System (IOOS), with its national network of 11 Regional Associations (RAs) that operate coastal observing systems for the entire U.S. coastline, including the Great Lakes, could provide a foundation for implementing the NHABON. Each RA is a nongovernmental organization managed by a board that is drawn from regional partners and stakeholders, and each faces a unique set of HAB problems. All RAs are certified by NOAA that they meet strict standards for data management and governance. Leveraging the regional IOOS network and its infrastructure would build synergies, be cost effective, and prevent the implementation of standalone observing systems for a single issue.

Observations Support Early Warnings and Forecasts

HAB observations have intrinsic value in providing accurate, timely, and actionable warnings of developing HAB events. Observations also underpin and inform forecasts developed from numerical and statistical models, analogous to how weather forecasts ingest and assimilate meteorological observations to improve their accuracy and provide advance warning of an event. This network would focus on ensuring that critical observations of HABs were being made to detect cells and toxins, provide early warning, enable forecasts, and support management decisions to mitigate or prevent harm.

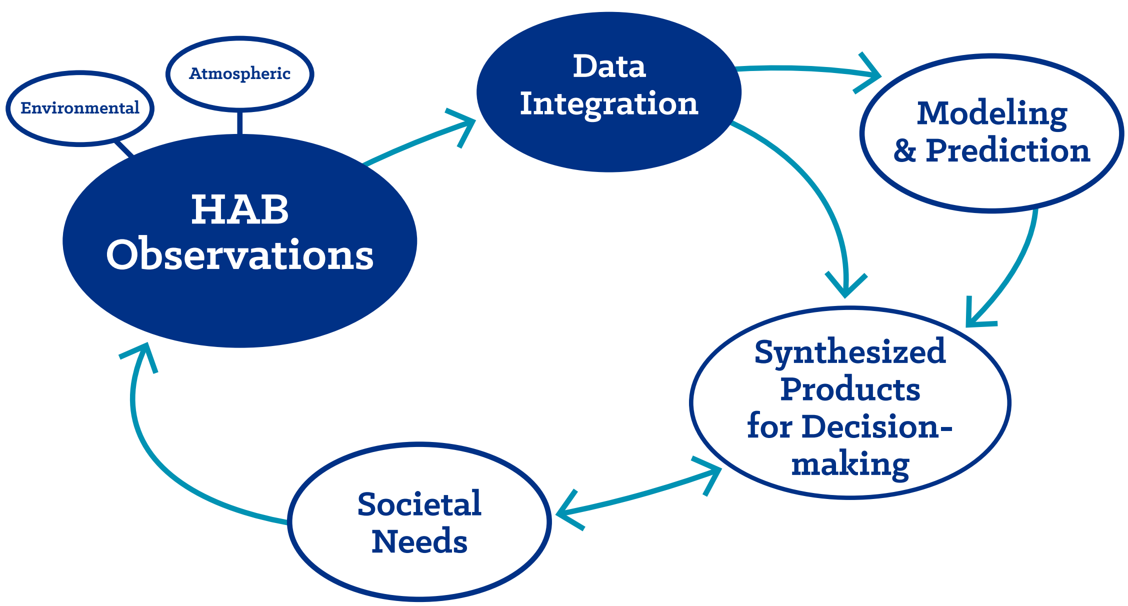


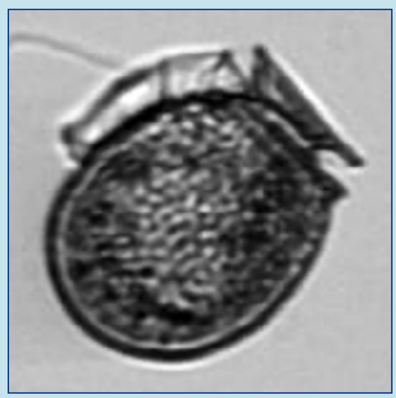
Figure 2. *HAB observations support early warnings and forecasts that are key to keeping communities safe.*

Harnessing Autonomous Technology For Cost-Effectiveness

In many areas, HAB observations have been costly, time-intensive, and lacking in broad spatial and temporal coverage. The continuing expansion of the national HAB problem amplifies these challenges. Implementing NHABON would result in an automated and integrated system of monitoring, detecting, and reporting technologies that maximizes cost efficiency while providing resource managers with timely, actionable information. Use of autonomous and portable instrumentation would enhance the spatial and temporal coverage of monitoring systems, reduce the need for costly vessel-based sampling and time-consuming detection methods with slow data returns, and provide a reliable presence for monitoring HABs regardless of weather conditions and other logistical impediments. Continuous, real-time detection of HAB species and toxins relies on innovative yet proven methods and integrate advances in ‘omics, artificial intelligence, and cloud computing, enabling a more adaptive, effective response to dynamic bloom conditions across diverse regions. Automated data ingestion and assembly, with the generation of accessible, user-friendly products and services, ensures that NHABON would effectively support protection of public health, local economies, and ecosystems by vastly improving HAB early warning and forecast capabilities.

Box 1. Surprise Detection of Toxic *Dinophysis* in Texas

In 2007, an autonomous instrument called the Imaging FlowCytobot (IFCB, microscope-in-a-can) detected an unprecedented bloom of toxic *Dinophysis*, which causes Diarrhetic Shellfish Poisoning (DSP). State health managers closed oyster harvests to prevent DSP illnesses, a first in the U.S. Occurring just before the annual Rockport- Fulton Oysterfest (~30,000 attendees), the warning prevented many people from becoming sick. See *Framework* Boxes 1 and 11.



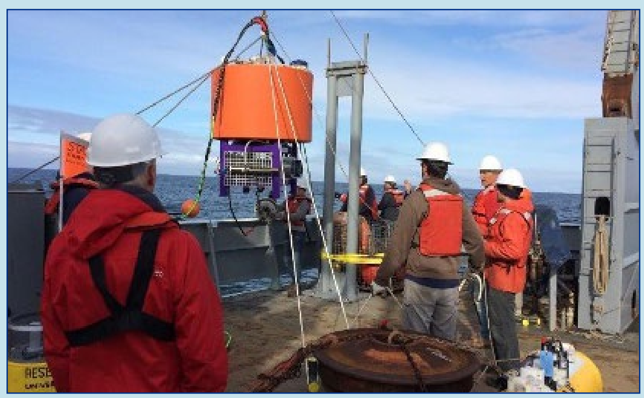
Left: Oysters shucked and served at Rockport-Fulton Oysterfest (credit: Courtney Sacco, Caller Times); Center: IFCB (credit: M. Brosnahan, WHOI); Right: Dinophysis *cell (credit: L. Campbell, TAMU).*

Linking the Network Into a National System

NHABON would integrate the regional HAB observing systems in the IOOS RAs into a single, nationwide network that provides a link to the ongoing research and technology development being done and supported by NOAA, NASA, and other federal agencies. It will require active participation at the federal and regional levels, with distributed expertise in the regions to operate the system, engage with users, and deliver data and early warnings. The system would continue to be optimized as new technologies become ready for operational deployment, data management and machine learning tools are refined, and communications of risk and threats are improved. National coordination would ensure smooth operation of the network, facilitate the exchange of ideas and expertise, coordinate communication between the regional systems and national partners, and ensure data are available for forecast models and other purposes. Collaboration with NOAA's National Centers for Coastal and Ocean Science (NCCOS) and U.S. IOOS Office would provide ongoing interface for system implementation, facilitate the coordination of emerging science with the operational systems, and allow for better NHABON coordination across NOAA line offices and federal agencies.

Box 2. Early Warning Toxic Blooms West Coast

Blooms of the diatom *Pseudo-nitzschia (PN)* on the U.S. West Coast sometimes produce the potent neurotoxin domoic acid (DA). In 2015, a PN bloom unprecedented in its geographic extent and toxicity resulted in multiple fishery closures along the entire West Coast, some of which lasted over a year. Ecosystem disruptions from the bloom included sick and dying marine mammals. Recently, an Environmental Sample Processor (ESP, laboratory-in-a-can) capable of rapid, *in situ* measurement of *PN* species abundance and DA concentrations, was deployed in the transport pathway of *PN* from an offshore "hot spot", where many *PN* blooms originate, to outer WA coast beaches. Knowing the concentration of cells and toxicity offshore can greatly improve the lead time for predicting blooms, minimizing impacts on public health and coastal economies. See *Framework* Boxes 2 and 9.



Left: Razor clam diggers on the Washington coast; Right: Deployment of ESP near La Push, WA and south of the Juan de Fuca eddy, for remote, near-real time detection of PN *and DA (credit: S. Moore, NWFSC).*

Resource Requirements

The main costs of NHABON will be capitalization of the system and the annual operation and maintenance, including data management, dissemination of information, and coordination of the network partners and stakeholders. NHABON is focused on detecting HAB cells and toxins and would leverage existing federal, state, tribal, and local observing efforts for the environmental observations (e.g., temperature, currents, and upwelling) needed to support forecasts.

A rigorous analysis based on the experience of regional systems that currently operate new HAB sensors and platforms, such as the examples in Boxes 1, 2, 3, and 4, along with an assessment of regional needs, was the basis for the cost estimate. As noted above, the design and costs will vary for each region depending on the frequency and type of HAB, the instruments deployed, and geographic extent.

The overall cost for full implementation of NHABON is estimated to be around $30 million. This can be scaled as the need and resources dictate. Sustained support would also be essential for an operational system to cover the recurring costs of annual servicing, instrument repair and calibration, retrieval and deployment, telecommunications, and personnel. Based on past experience, annual operating costs are estimated to be between $5-$7 million for a fully implemented national system. Included in this estimate are costs for a national HAB Data Assembly Center (HABDAC) as well as national coordination to facilitate technology support, access to data for forecasts models, and integration with NOAA and other federal agencies.

The system could grow incrementally over time based on available resources and prioritized needs. The initial pilot projects, described below, provide a base from which the network could be expanded to other areas where HABs threaten public health, coastal economies, and/or ecosystems. Sustained support would be critical to the operational success of the network to enable annual maintenance required to ensure high-quality data and the uninterrupted flow of data and information to users.

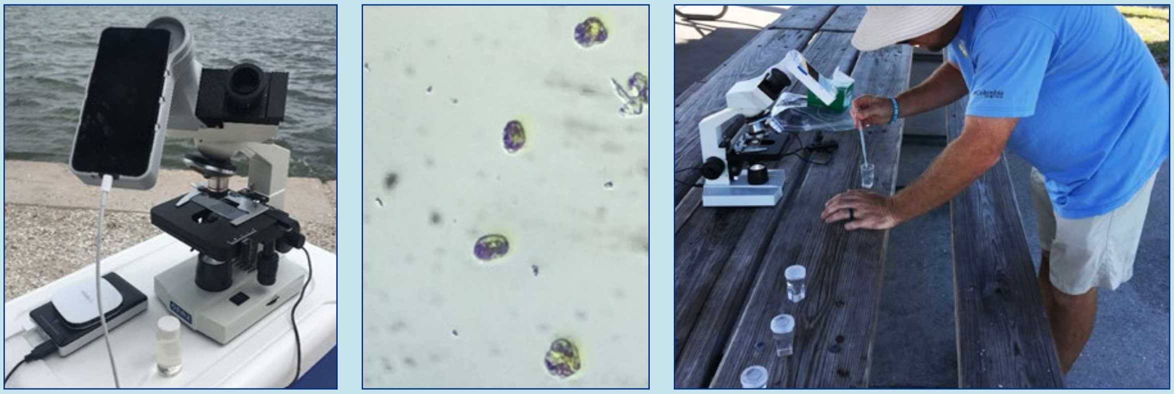
Proposed Investment Plan

	Year 1	Year 2	Year 3	Year 4	Year 5	5-year Total
New Acquisition	$3,308,000	$3,012,000	$2,612,000			$8,932,000
Existing Operations and Maintenance	$1,772,835	$2,281,905	$3,115,060	$3,321,815	$3,321,815	$13,813,430
Replacement				$1,500,000	$1,500,000	$3,000,000
HABDAC	$800,000	$800,000	$800,000	$800,000	$800,000	$4,000,000
Coordinator		$100,000	$100,000	$100,000	$100,000	$400,000
Total	**$5,880,835**	**$6,193,905**	**$6,627,060**	**$5,721,815**	**$5,721,815**	**$30,145,430**

Table 1. *Proposed Investment Plan to build up a National HAB Observing Network over time and in accordance with evolving needs (inflation and indirect costs, which vary widely, are not included).*

Box 3: HABscope Piloted during Florida Red Tide 2017-2019

The HABscope combines a cheap microscope, a cell phone, and machine learning to identify and count the Florida red tide organism, based on its unique swimming behavior. Wielded by citizen scientists and local officials, this field portable, easy-to-use device was piloted during the 2017-2019 red tide. Models utilizing the counts were providing web-based early warning and forecasts of respiratory impacts from red tide toxins at spatial and temporal scales that may someday achieve every beach every day. See *Framework* Box 5.



Left: Image of the HABscope comprising a field-portable microscope, a cell phone, and data storage device (credit: C. Holland, NOAA/NCCOS); Center: Photo of Karenia brevis *cells as viewed via the attached cell phone (credit: C. Holland, NOAA/NCCOS); Right: Volunteer prepares a water sample for viewing under the HABscope in the field (credit: R. Hardison, NOAA/NCCOS).*

Pilot Projects Underway

In FY 20, Congress recognized the need for an operational HAB observing network and provided support for several pilot projects as a proof of concept. The U.S. IOOS Office and NCCOS collaborated on the selection of the pilot projects, which demonstrate how varying regional efforts can be linked into a national network with the IOOS regional systems as a foundation. Other promising regional projects were considered in this evaluation, but limited funding restricted the number of awards to the list below. Activities include support for detecting HABs, data management, image analysis, data archiving, communication, and coordination activities. The following sections describe how these funds are supporting a variety of tools and partnerships throughout the pilot regions. No single observing system is fully implemented, but these pilot projects are an important first step.

Alaska - Alaska Ocean Observing System (AOOS): Provide a coordinator and new detection capability for the nascent system.

The Alaskan pilot project is supporting the nascent Alaska Harmful Algal Bloom Network (AHAB) to improve HAB monitoring and event response across Alaska, especially in the U.S. Arctic, by coordinating disparate projects, improving detection of domoic acid by providing field kits, providing data management services, and improving access to information products.

California - Southern California Coastal Ocean Observing System (SCCOOS) and Central and Northern California Ocean Observing System (CeNCOOS): Provide operation and maintenance to sustain a system to support forecasts.

This project is maintaining a network of detection instruments called Imaging FlowCytobots (see Box 1) along the California coast to identify HAB species in real-time to improve forecast models so that fishers, shellfish growers, and managers can have timely and accurate information about potential threats.

Great Lakes - Great Lakes Observing System (GLOS): Provide support for enhanced data management and Environmental Sample Processors (ESPs) that identify HAB organisms and toxins.

This project supports deployment of ESPs (see Box 2) and modernization of data systems to support assimilation of multiple near-real-time toxin measurements into NOAA's HAB forecasting model (HAB tracker) to improve forecast accuracy for bloom location, size, and toxicity with a five-day lead time.

Gulf of Mexico - Gulf of Mexico Coastal Ocean Observing System (GCOOS): Provide support for warnings for "every beach, every day."

GCOOS is expanding the use of the portable HABscope (see Box 4) to support beach-level risk forecasts so beachgoers know expected impact at specific beaches at different times of the day.

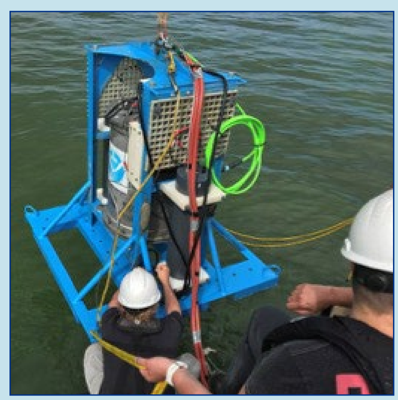
Pacific Northwest - Northwest Association of Networked Ocean Observing Systems (NANOOS): Provide operational support for popular HAB bulletin.

The project supports key elements needed to develop the popular Pacific Northwest Harmful Algal Bloom Bulletin forecast, including offshore sampling, beach sampling by tribes, analysis, and circulation modeling. The Bulletin is used by state and tribal resource managers to protect the health of shellfish harvesters and consumers, and by fisheries managers at NOAA to protect marine mammal health.

Lessons learned from these pilot projects can pave the way for similar systems in other regions impacted by recurring and emergent HABs.

Box 4. Cyanobacteria in Lake Erie: Beyond Cell Counts

Cyanobacterial blooms occur annually in Lake Erie, and their magnitude and toxicity vary considerably from year to year. While the magnitude of the bloom is correlated with nutrient loading from the Maumee River, the factors affecting bloom toxicity are not yet fully understood. Biomass is easily measured with satellite remote sensing and, in combination with models of bloom transport, is used by NOAA to forecast bloom location and movement several days in advance. In 2014, the bloom moved over the Toledo, OH water intake pipe, but this bloom was not nearly as severe in terms of cell concentration as the one that occurred in 2017. However, because the 2014 bloom contained high levels of microcystin, a liver toxin, the City of Toledo was forced to issue a "Do Not Drink" order and provide bottled water for 48 hours. To address the non-predictive nature of cell concentration for toxin levels, NOAA has been testing the use of ESPs to remotely measure microcystins in the water (see *Framework* Box 2). The intent is to couple remote sensing, toxin and cell detection, and models to predict bloom biomass and toxicity, and provide that information to stakeholders, including water utility operators, charter boat captains, and beach goers, to inform mitigation strategies and decision making.



Left, Center: Cyanobacterial bloom in Lake Erie; Right: ESP carrying microcystin toxin sensor deployed in western Lake Erie on (blue) bottom lander (credits: NOAA GLERL).

Conclusion

The rationale for a National HAB Observing Network is clear and urgent. HABs are happening more frequently, lasting longer, and having increased impacts on public health, coastal economies, and ecosystems. By harnessing the power of new observing technologies, machine learning, and telecommunications, resource managers, fishers, shellfish producers, harvesters, beach goers and drinking water managers can have access to the timely data and early warnings they need to prevent, mitigate and manage the impacts of blooms. Operational expertise in the IOOS regions, along with their certified data management systems, provide the foundation for a national network that is tailored to the specific regional oceanography, communities, and economies, while being linked to the national programs. NOAA's NCCOS has the scientific, technical, modeling, and data management expertise to guide the development of this operational network.

Further Information

The Framework for the National HAB Observing Network includes extensive details on HABs, the status of regional systems, the array of tools and technology available to provide observations, and the roles and responsibilities for the various players involved. Please refer to the document for more information. Questions and requests can be directed to Josie Quintrell at the IOOS Association.

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