

# Dialogues with Industry

## Harmful Algal Blooms (HABs) Background Paper

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# Introduction

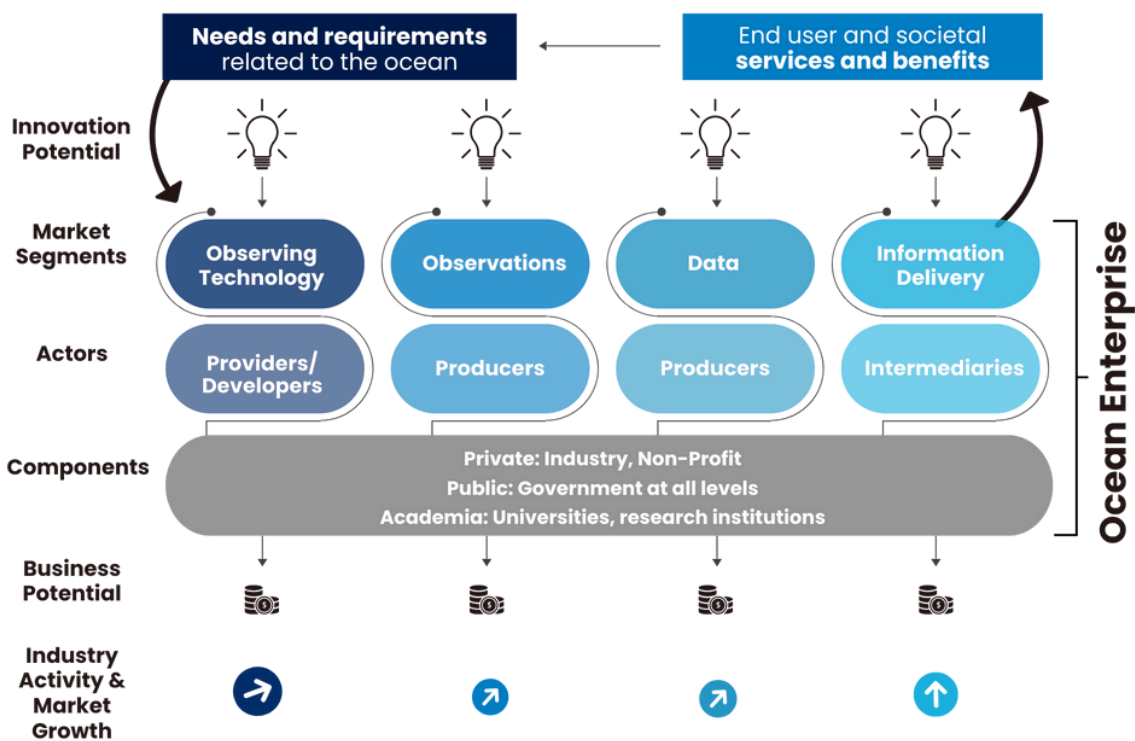
The Ocean Enterprise Initiative is a global effort that spearheads innovation, thought leadership, and economic development within the Ocean Enterprise.

It is led by the Marine Technology Society (MTS), Global Ocean Observing System (GOOS), National Oceanic and Atmospheric Administration (NOAA), and industry (Kongsberg Discovery and L3Harris). The first successful series of the [Dialogues with Industry](#) (hereafter *Dialogues*) took place in September 2022 - January 2023 and explored how to mature the Ocean Enterprise to deliver essential societal, economic, and environmental benefits.

This effort culminated in the [Dialogues with Industry Roadmap](#) (hereafter Roadmap). The Ocean Enterprise Initiative is the structure to implement recommendations from the Roadmap guided by three goals:

- **Improving the Marketplace;**
- **Collaboration to Grow and Impact Change;**
- **Shaping the Future.**

Past efforts at industry engagement have often been piecemeal and incomplete. The success of the *Dialogues* comes from bringing together all the components of the Ocean Enterprise with facilitated discussions across the entire Ocean Information Value Chain, depicted in Figure 1.



**Figure 1:** This graphic visualizes the Ocean Enterprise and its interconnected components and activities across the Ocean Information Value Chain. The Industry Activity & Market Growth discs visualize the current level of private industry involvement in the segment, i.e. they offer an estimate of the current relative market size. The arrows indicate our estimate of private industry growth potential in each area (vertical is high). All market segments can benefit from innovation and can be commercially exploited. This graphic was developed as a product of the [Dialogue with Industry Roadmap](#).

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The second *Dialogues with Industry* (hereafter *Dialogues*) series, focused on harmful algal blooms (HABs), consisted of three curated dialogues held in January and February 2025. The HABs *Dialogues* explored and defined the market dynamics, including barriers and opportunities, for maturing the public/private/academic partnership, capability, and capacity to support the growing societal need for delivery of actionable, fit-for-purpose ocean data, information, and knowledge based on regional requirements and use cases. The HABs *Dialogues* were less focused on technical and scientific discussions, except as they influenced the market dynamics. Reliable access to HAB data is critical to the success of prevention, control, and mitigation strategies commonly used to cope with HABs and their impacts.<sup>1</sup>

This *Dialogue* series supports the following priority action pathways of the Roadmap:

- **Market Visibility:** Understanding the market dynamics of generating sustainable HAB observations, incorporating HAB data into forecasting, early warning, and monitoring programs to mitigate HAB impacts and bolster efforts to develop HAB control methods and assess their safety and cost-effectiveness.
- **Data as an Asset & Mission as a Service:** Determine the viability of a commercial HAB data marketplace.
- **Public-Private Exchange:** Fostering active engagement.
- **Intermediaries:** Determine the opportunity and challenges of commercially provided HAB downstream services (e.g., support for forecasting, early warning, and control).
- **Workforce Development:** Determine gaps in workforce development.

The *Dialogues* are market-driven rather than focused on technical and scientific discussion. Technical and scientific issues are considered to the extent that they influence market dynamics. The deliverable from the *Dialogues* is a set of actionable recommendations the HAB community, private sector, professional societies, or agencies can take to forge a stronger, more robust cross Ocean Enterprise sector system to initiate or enhance programs to mitigate HAB impacts and advance efforts to control HABs or their mode of harm (e.g., toxicity). For example, MTS could explore creating a HAB-related MTS Professional Committee; Agencies could advertise relevant HAB funding opportunities via MTS; Industry can engage in international HAB societies and related conferences (e.g., [ISSHA](#) and [ICHA](#)).

This background paper sets the scene by focusing on the terminology, concepts, challenges, and opportunities related to generating sustainable HAB observations, incorporating HAB data into forecasting, early warning, and monitoring programs to mitigate HAB impacts and bolster efforts to develop HAB control methods and assess their safety and cost-effectiveness. Experts recognize that the large number of harmful algal species and the diversity of their impacts make it difficult to identify universal causes and mechanisms driving both the initiation and termination of HABs in marine and freshwater environments. The *Dialogues* aim to serve as a starting point for understanding the barriers to advancing the HAB data market through the Ocean Information Value Chain. They seek to identify the demand, key actors, challenges, and opportunities to unlock economic potential and meet the growing need for actionable HAB information to navigate an uncertain future.

Changes in water temperature, salinity, carbon dioxide levels, rainfall, nutrient levels, sea level, and upwelling systems all can affect the incidence, duration, and severity of known harmful algal blooms and result in the emergence of new HAB problems.

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# High Level Market Analysis and Drivers to Aggregate Demand

While there are documented cases of millions of dollars of economic loss due to HABs, no systematic global effort routinely assesses the economic impact of HABs, the value of HAB data, or related services. Where individual cases have been documented, many nations have not conducted economic analyses of HABs and have not collected data that can be used to generate reliable quantitative estimates of net economic studies and socio-economic impacts.<sup>ii</sup> Further - "Results show that most economic studies on HAB valuation do not consider any cost-benefit analysis of a defined policy intervention. The predominant economic valuation methodology uses market information to estimate a proxy for welfare measure of the impact of HABs (loss revenue, sales, exports). Moreover, non-use and indirect use values are ignored in the literature, while stated preference methodologies are underrepresented."<sup>iii</sup>

Non-toxin-producing but high biomass blooms, including proliferation of macroalgae, can also be harmful. These "nuisance" blooms can disrupt ecosystem services with impacts on the economy and human health; for example, desalination systems, the seafood industry, fisheries and aquaculture activities and resources, the tourism sector, and recreation and maritime facilities such as ports.<sup>iv</sup>

Examples include:

- **United States:** A preliminary and highly conservative United States estimate of the average annual costs of HABs is approximately \$50 million.<sup>v</sup>
- **United States:** The loss of tourism-related businesses during the 2018 Florida red tide bloom was estimated to be \$2.7 billion USD.<sup>vi</sup>
- **United States:** 2015/2016 West Coast marine heatwave and associated *Pseudo-nitzschia* HAB caused the commercial Dungeness crab fishery to experience a \$97.5 million USD (almost 47%) decrease in revenue compared to the previous year and resulted in an appropriation by Congress of \$25 million USD in disaster aid.<sup>vii</sup>
- **United States:** The Centre for Disease Control (CDC) provides a comprehensive overview of Harmful Algal Bloom (HAB) - Associated Illness, and potential effects on people and animals, though the potential impacts are not quantified.<sup>viii</sup>
- **United States:** The US is most advanced in undertaking a national summary and regional case studies to fully characterize the economic impacts of HABs.<sup>ix</sup>
- **Korea, Japan, China:** \$94 million USD in farm fish, aquaculture economic losses in 2021-2026.<sup>x</sup>
- **Norway:** a fish-killing HAB (*Chrysochromulina leadbeateri*) resulted in the loss of 14 thousand tons of Atlantic salmon (May 2019) - total loss estimated at up to \$308 million USD.<sup>xi</sup>
- **China:** loss of up to 330 million USD to mariculture industry (mostly cultivated abalone) caused by a single *Karenia mikimotoi* event (2012).<sup>xii</sup>
- **Japan:** mass mortality of oysters and clams from a 1998 *Heterocapsa circularisquama* HAB in Seto Inland Sea resulted in losses of about \$39 million USD based on market price of lost product.<sup>xiii</sup>
- **Chile:** a HAB caused by *Pseudochattonella* caused the mortality of 39 million farmed salmon with an economic impact of \$800 million USD.<sup>xiv</sup>

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In evaluating the “demand” signal, a *Communications Earth & Environment* article found “no uniform global trend in the number of harmful algal events and their distribution over time, once data were adjusted for regional variations in monitoring effort.” The study suggested the perceived increase in HAB events was associated with intensified monitoring efforts related to increased aquaculture production.<sup>xv</sup> The author continues with, “Being at the crossroad of several different societal and scientific issues, questions on HABs are best addressed on a species-by-species and site-by-site basis, and considering the respective impacts on local human activities, rather than handled as aggregates of microalgal HAB cell or species numbers, phycotoxin concentrations, or their global distributions.” Given this recommendation, where do we go in the future, and how would we share information, prediction/monitoring technologies, and controls?

## Market Issues Include:

- Multi-sectoral demand must be harnessed for commercial viability as no one sector is able to support.
- Role of government investment (e.g., where there is ‘market failure’) relative to private investment.
- Relevance of HABs as a driver for emerging ‘nature repair markets’ and ‘financing solutions for nature.’
- Sectors impacted e.g., aquaculture, mariculture, commercial fishing, recreational fishing, tourism, water management, human and animal health, First Nations.
- Sectors impacting, where there is interest in reducing nutrients that can fuel some HABs e.g. farming, forestry, construction/development.
- Many HAB-related needs of specific communities (e.g., tribal, indigenous, and remote/rural communities), such as information on potential contamination of subsistence foods and drinking/recreational waters, have not been adequately addressed.

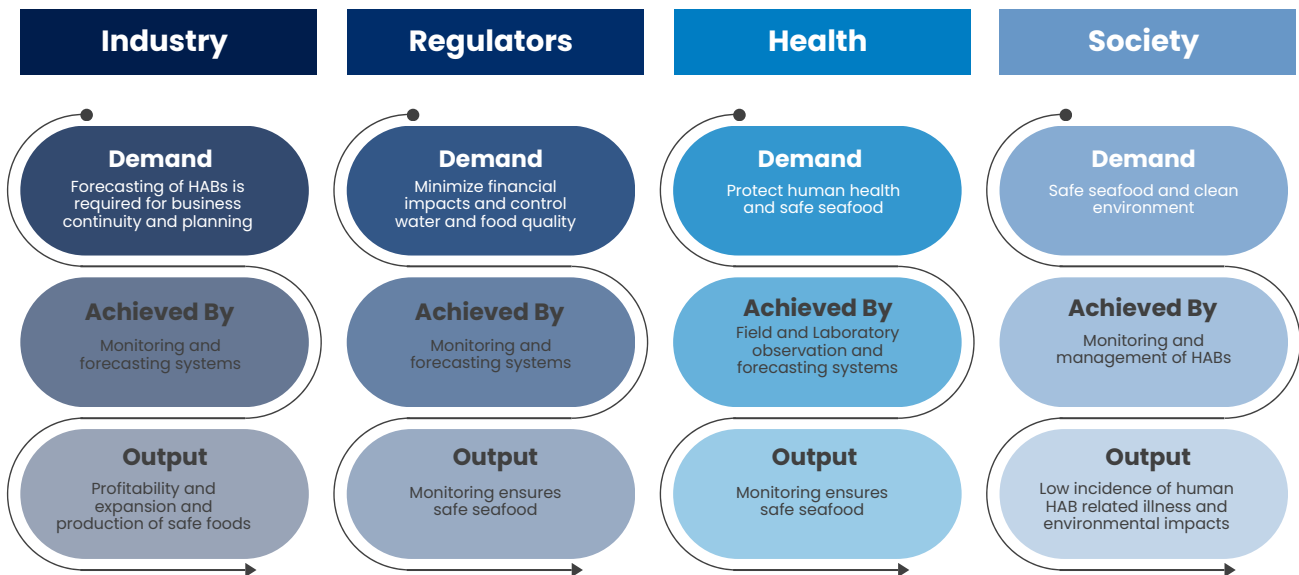
The wide range of market issues is unsurprising as the economic impacts of HABs are widespread and diverse. They cover toxins, nutrients, and eutrophication; freshwater and marine systems; aquaculture, mariculture, commercial fishing, recreational fishing, tourism, water management, and human and animal health. The potential for HABs to adversely impact local and regional food safety and security is also widely recognized. It suggests that the *Dialogues* approach of bringing together all the components of the Ocean Enterprise with facilitated discussions across the entire Ocean Information Value Chain may be particularly useful in the case of HABs.

Extensive work has been done by the international HAB community to identify and understand geographically diverse stakeholders and their needs. The findings are outlined in the FAO, IOC, and IAEA, “Joint technical guidance for the implementation of early warning systems for harmful algal blooms”.<sup>xvi</sup>

The below figure is taken from the above document and is one example of depicting the interdependences of four categories of stakeholders. The definitions of the stakeholder groups are quoted from the Joint technical guidance:

<b>Industry</b>	all coastal industries and businesses (for example, aquaculture, desalination, plants, tourism, entertainment sector, and so on) that may be impacted by HABs.
<b>Regulators</b>	scientists, policy makers, resource management and monitoring agencies who are responsible for HABs monitoring and forecasting and issuing warnings.
<b>Health</b>	the health sector and managers of water and food security who are responsible for monitoring food safety, water quality conditions, and human health.
<b>Society</b>	community members, fisherman and tourists who may be affected by HABs while practicing their activities in the sea, such as fishing and recreation.

### Different needs of different stakeholder groups, and the different configurations of EWSs that might best serve those needs



**Figure 2:** Source modified from CoClima. 2023. Co-development process. In: Adapting to a changing marine ecosystem. Galway Cited 14 February 2023. [www.coclima.eu/Co-Development-Processes](http://www.coclima.eu/Co-Development-Processes)

See additional information on stakeholders in Appendix 2.

# Drivers

From a global perspective, the social and economic impacts of HABs have potential to affect communities with limited resources to respond, making humanitarian aid and regional security additional drivers for developed nations to consider.

## Global

**The United Nations (UN) Sustainable Development Goals (SDGs)**, including Goal 2 Zero Hunger, Goal 3 Good Health & Well-Being, Goal 6 Clean Water & Sanitation, Goal 11 Sustainable Cities & Communities, and Goal 14 Life Below Water.

**Sendai Framework for Disaster Risk Reduction** acknowledges HABs as a natural hazard that can cause significant damage to ecosystems, human health, and economies, especially in coastal areas. The framework encourages countries to conduct thorough risk assessments to identify areas vulnerable to HABs, considering factors like water quality, climate change, and human activities contributing to bloom formation.

## Regional

**The European Marine Strategy Framework Directive<sup>xvii</sup> The Marine Strategy Framework Directive (MSFD)** is a European legislation that aims to protect and conserve the marine environment and achieve a good environmental status of the EU's marine waters.

**Water Framework Directive:** Sets out rules to halt deterioration in the status of EU water bodies and achieve good status for Europe's rivers, lakes and groundwater.

## National

**HABHRCA: Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA)**, legislation within the United States. In 1998, the United States Congress recognized the severity of the threats posed by HABs and hypoxia, and authorized the Harmful Algal Bloom and Hypoxia Research and Control Act, or HABHRCA ([HABHRCA 1998; embedded in Public Law 105-383](#)). Amendments enacted in 2004 ([HABHRCA 2004, Public Law 108-456](#)) and 2014 ([HABHRCA 2014, Public Law 113-124](#)). In 2018, HABHRCA was reaffirmed ([HABHRCA 2017, S. 2200](#)) and this legislation expanded the mandate for NOAA to advance the scientific understanding and ability to detect, monitor, assess, and predict HAB and hypoxia events. (United States)

**Clean Water Act: The Clean Water Act (CWA)** establishes numeric standards for pollutants that endanger water quality. The EPA can use its authority under the CWA to publish water quality criteria for algal toxins in recreational waters. (United States)

**2015 Drinking Water Protection Act (Public Law 114-45):** amends the Safe Drinking Water Act to provide for the assessment and management of the risk of algal toxins in drinking water. (United States)

# Terminology

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## **Ocean Enterprise**

All entities in the public, private, non-profit, research and academic sectors that provide infrastructure and capacity of ocean observations, measurement, and forecasting, or who deliver operational ocean information projects and services.

## **Downstream Services**

Value added ocean information services supporting societal and economic benefits.

## **HAB Community**

A subset of the Ocean Enterprise. Entities in the public, private, non-profit, research and academic sectors that provide infrastructure and capacity of ocean observations, measurement, and forecasting, for HABs.

## **Harmful Algal Bloom**

The generic term “harmful algal bloom” (HAB) includes accumulations of toxic or non-toxic microalgae, macroalgae, and cyanobacteria in marine, brackish, and/or fresh waters that can cause water discoloration and massive kills of fish, shellfish, and wildlife, contaminate seafood and drinking water with toxins, or alter ecosystems and services in ways that humans perceive as detrimental.<sup>xviii</sup>

## **Observing**

Observing data on HAB cells and toxins helps track, predict, manage, and adapt to changes in marine and freshwater environments.

## **Monitoring**

Environmental monitoring is a tool to assess environmental conditions and trends, support policy development and its implementation, and develop information for reporting to national policymakers, international forums, and the public. For example, monitoring data such as chlorophyll from satellite remote sensing and physical, chemical, and biological oceanographic information from observing systems and ship-based cruises (e.g., currents, wind, sea-surface temperature, nutrients) can inform predictive HAB models, identify factors controlling or influencing bloom growth and toxicity as well as bloom initiation and transport.

## **Control**

Strategies that directly kill HAB cells or destroy their toxins, physically remove cells and toxins from the water column, and/or limit cell growth and proliferation.

## **Prevention**

Reduce incidence and extent before initiation.

## **Mitigation**

Limit, delay, or inhibit undesirable impacts on ecosystems and communities.

# Observing Tools

Stakeholder engagements have called for sustained access to data products and services based on timely, regional HAB observations from uncrewed in-situ systems. Examples of monitoring tools are included in Appendix 1.<sup>xix</sup>

There are several challenges in both transitioning these tools to full scale operational use in the numbers necessary as well as ensuring the commercial viability of these tools. The *Dialogues* will focus on fleshing out the issues associated with these observing tools and provide actionable recommendations in overcoming the challenges.<sup>xx</sup>

<b>In-Situ</b>	<ul style="list-style-type: none"> <li>• Integration with uncrewed systems/platforms e.g., AUV, USV, UAS</li> <li>• Issue with consumables not being available</li> <li>• Price point; reliable, accessible, cost-effective in situ sensors and platforms a major barrier</li> <li>• Bespoke, complex instrumentation</li> <li>• The role of citizen science and data collection (following collection safety protocols)</li> </ul>
<b>Remote Sensing</b>	<ul style="list-style-type: none"> <li>• Accessibility to the images</li> <li>• Processing capability</li> <li>• Storage capability</li> <li>• New satellite missions requiring redevelopment of new, improved products</li> <li>• While some high biomass blooms can be detected from space. Lower biomass blooms largely cannot, yet may be very important from environmental, economic, and human health perspective</li> <li>• Hyperspectral imagers are now being deployed on airborne and uncrewed aerial systems, which minimize the impact of cloud cover, improve spatial resolution, and can be used to guide targeted HAB sampling by uncrewed surface and subsurface vehicles. Challenges are like those for satellite-based imagery; however, accessibility to complex coastal regions and inland lakes is improved</li> </ul>
<b>Field Portable/ Rapid Test</b>	<p>There are known issues associated with portable kits which are summarized in recent reports. <sup>xxi</sup>  <sup>xxii</sup> Market barriers to scaling up HAB toxin detection include:</p> <ul style="list-style-type: none"> <li>• Change in the landscape as companies go out of business or merge with other companies. Maintaining continuity is a big challenge when looking to create an operational system. Reliability is a must</li> <li>• Usually not the primary business for any provider</li> <li>• Certification: Within the United States the certifying body is the US Interstate Shellfish Sanitation conference; Internationally, AOAC provides certification of methods designated as an “Official Method of Analysis” or OMA</li> <li>• How does industry view this certification?</li> <li>• If a company relocates its processing facility, does it need to be recertified?</li> </ul>
<b>Data Challenges</b>	<ul style="list-style-type: none"> <li>• Acquiring and managing data at time and space scales relevant to the impact of a HAB event</li> <li>• Providing actionable data products/services that are easily accessible to and can be used by resource managers and public health officials to support decision making</li> <li>• Sharing of biological data gathered within state or national borders with other states or nations</li> <li>• Data sets are often large image files that are laborious to tag and identify HABs</li> </ul>

# Forecasting and Service Delivery

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Forecasting systems are developed within national and international frameworks but require a regionally specific approach due to unique stakeholder needs, the state of scientific knowledge, modeling capabilities, and specific health and ecosystem impacts due to different HAB species and toxins. Similar approaches and methods, however, can be used across regions to develop and operate these regional systems to create a national HAB forecasting approach.

Common elements for success include co-development with stakeholders throughout the development and service delivery process, utilization of extensive regional partnerships for optimal development and support of system dependencies, and utilization of transition plans to manage the long-term development timelines, including improvements to forecast products and extensive service delivery needs associated with these forecast systems.

## 3 Challenges to transition operations/commercialize

**Challenge 1:** Major challenges associated with forecasting HABs in complex coastal environments.

**Challenge 2:** Where is the line between public good/public warning and commercial opportunity for service delivery.

**Challenge 3:** One of the major challenges that proponents of early warning systems for HABs have been communication and/or dissemination of data and information and forecasting predictions to the stakeholders, that is, how to package data, model output, products. In many instances, stakeholders do not have the computational resources to access the data, or even if they do, it is presented to them in a format that is not readily understandable.

# Control

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HAB control in coastal marine and estuarine environments lags the significant advances in terrestrial pest control (agriculture, silviculture), aquaculture, and freshwater HAB control. In the United States, NOAA uses a 4-stage approach to tackle this problem by developing and implementing HAB control technologies.

Using internal expertise and external academic and industry partners, NOAA has developed ideas and taken them through a proof-of-concept stage to assess their effect on HAB species. Promising ideas move through a research and development stage to assess their effectiveness. In this stage, NOAA tests its ability to reduce or eliminate algal cells and their toxins without harming the environment. If successful, ideas are moved into a demonstration and validation stage to demonstrate their feasibility and scalability. At this stage, we can demonstrate that a new technology can be deployed successfully at reasonable costs over the appropriate scales to control a particular HAB situation. Those feasible and scalable technologies then move into the fourth and final stage, their transfer into the application.

For the United States, the majority of the HAB control technologies remain in development. Some of the more promising strategies include the use of ozone for destruction of cells and toxins, clay flocculation for aggregation and settling of HAB cells, and the use of bacterial exudates, or viruses to selectively control and/or suppress HAB growth within the plankton community. While clay flocculation has been used in Asia for more than two decades, within the United States there have been limited testing largely due to public perception and full understanding of the ecosystem that has slowed acceptance.<sup>xxiii</sup>

Concern for independent evaluation of HAB control technologies led the United States (NOAA) to establish the [HAB Control Technologies Incubator \(HAB-CTI\)](#). The HAB-CTI is a partnership between the National Oceanic and Atmospheric Administration (NOAA), the University of Maryland Center for Environmental Science Institute of Marine and Environmental Technology (IMET), and Mote Marine Laboratory (Mote). The goal of US HAB-CTI is to streamline the vetting process for novel HAB control ideas, allowing the research community and funding agencies to focus on efforts that promise to be feasible, environmentally acceptable, scalable, and cost-effective at controlling the impact of both freshwater and marine blooms.

Within the United States, regulatory barriers impede the field testing of new HAB control technologies and approaches to natural blooms on small and large scales. This includes restrictions under the National Environmental Protection Act (NEPA), Federal Insecticide Fungicide and Rodenticide Act (FIFRA) algicide registration, the National Pollutant Discharge Elimination System (NPDES) pesticide general permits and inconsistent or undefined individual state requirements.<sup>xxiv</sup>

Control Tools	How They Work	Technology Readiness Level
<b>Nano bubble generating instrumentation (NBOT)</b>	Ozone impregnated nano-bubble technology to address water safety & security issues	Field testing of commercial instruments is ongoing in marine, brackish, and freshwater systems
<b>DinoSHIELD</b>	A slow-release alginate hydrogel containing algicidal bacteria as 'mini in situ bioreactors'	
<b>Flocculation (e.g., clay, biochar)</b>	Through natural electrical charges algal cells bind to flocculant and causes them to sink to the bottom	Lab and mesoscale tests within the United States

## 5 Challenges to transition to operations/commercialize

**Challenge 1:** Lack of national, regional or global scale programs.

**Challenge 2:** Lack of investment to advance the technologies and assess ecosystem impacts.

**Challenge 3:** Overcoming negative perception.

**Challenge 4:** Communicating the return on investment.

**Challenge 5:** Regulations and Permitting.



# Workforce

This community needs a diverse pool of talent who can translate their skills to produce instruments, platforms, data management, model development, and decision support tools for HAB systems. The community is competing for talent and has the additional constraint that salaries are not at the level of other sectors. Further, we need a workforce that spans skill levels from technicians to PhD scientists. One element of expanding the workforce is adopting an intriguing start-up mentality that will engage folks in this community, but for this to be successful, there must be a market clearly defined.

## Workforce challenges identified within the HAB community include:

- The field of understanding taxonomy is not a field that is attracting today's workforce
- Training for individuals operating monitoring programs to understand what to look for in a sample. One example of training is conducted by Bigelow, which is conducted across the United States. This type of training is also important to the development of technologies and tools to ensure that the technologies/tools are working correctly from the beginning of the development stage all the way through testing and deployment.
- How to manage and use the data effectively
- Training in associated technologies such as uncrewed vehicles

One example of training courses is through the Bigelow National Centers for Marine Algae and Microbiota. Courses include (1) Algal Culturing Technique Course and (2) the Karen A. Steidinger Marine Harmful Algal Taxonomy Training Course.<sup>xxv</sup>

Photo Source: Southby, J. (2024). *Students on research vessel*. MTS Summer Workshop, Northwestern Michigan College, Traverse City, MI.

# Acknowledgement

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Public - United States	NOAA (IOOS)	Laura Brenskelle
Public/Intergovernmental	NOAA/IOC	Maggie Broadwater
Intergovernmental	IOC	Henrik Oksfeldt Enevoldsen
Intergovernmental	IOC	Yun Sun
Nonprofit	MTS	Hans VanSumeren
Nonprofit	MTS	Caisey Hoffman
Nonprofit	MTS	Zdenka Willis
Nonprofit	MTS	Tim Moltmann

*The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the author(s) and do not reflect the views of NOAA or the Department of Commerce.*

*Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.*

# Appendix 1: Monitoring Technology (Examples)<sup>xxvi</sup>

## In-Situ

Sensor	Manufacturer
Environmental Sample Processor	<a href="#">McLane Research Labs</a>
The United States National Phytoplankton Monitoring Network (PMN)	<a href="#">NOAA</a> (250 coastal sites)
Imaging FlowCytobot (IFCB)	<a href="#">McLane Research Labs</a>
FlowCam	<a href="#">Yokogawa Fluid Imaging Technologies</a>
Optical Phytoplankton Discriminator (OPD) – BreveBuster <sup>7</sup>	<a href="#">Mote Marine Laboratory</a>
CytoSense	<a href="#">Cytobuoy</a>
TriLux	<a href="#">Chelsea Technologies</a>
LabSTAF – Phytoplankton Primary Productivity	<a href="#">Chelsea Technologies</a>

## Field Portable

Sensor	Manufacturer
LightDeck System	<a href="#">LightDeck</a>
Freedom4; Liberty16 (qPCR)	<a href="#">NOAA</a> (250 coastal sites)
HABScope	<a href="#">GCOOS</a>
CyanoDTec and DinoDTec	<a href="#">Phytoxgene</a>

Reveal 2.0 for PSP	<u>NEOGen</u> N.B. Neogen products for ASP and DSP toxin detection have been discontinued and are no longer available
Microcystins-ADDA specific and other algal biotoxin ELISA test kits	<u>Gold Standard Diagnostics</u> (formerly Abraxis)
MARBIONIC Brevetoxin ELISA Test Kit; Domoic Acid ELISA Kit	<u>SeaTox Research Inc</u>
Domoic Acid, Total Saxitoxins Test Kit	<u>Mercury Science</u>
Lab-On-A-Disc (LOAD) Platform	Maguire I, Fitzgerald J, Heery B, Nwankire C, O’Kennedy R, et al. 2018. Novel microfluidic analytical sensing platform for the simultaneous detection of three algal toxins in water. <i>ACS Omega</i> 3(6):6624–34; (Not yet available as a commercial product.)

## Remote Sensing

Sensor	Manufacturer
Ocean Land Color Imager (OLCI); Sentinel-3 satellite	EUMETSAT
Multispectral Instrument (MSI); Sentinel-2	ESA
Aqua – Moderate Resolution Imaging Spectroradiometer (MODIS)	NASA
Terra – Advanced Spaceborne Thermal Emission and Reflection Radiometer	NASA
Deployment of hyperspectral imagers on airborne and Uncrewed Aerial Systems, in marine and FW environments	<u>Great Lakes example</u>

Optical Phytoplankton Discriminator (OPD; Mote Marine Laboratory (MML)), aka the 'BreveBuster'	
Fluoroprobe (and related optical fluorescence-based sensors)	<a href="#">bbe modaenke</a>
National Polar Partnership Program-Visible Infrared Imaging Radiometer Suite (VIRS)	NOAA
NASA – Plankton, Aerosols, Clouds, ocean	NASA
Copernicus Marine Environmental Management Service (CMEMS)	EU
Aquawatch	CSIRO (Australia), SSTL (UK)
CyAN	NASA, NOAA, EPA (US)

## Technology in Development

Effort	TLR Level	Status
LightDeck Diagnostics Duplex Assay for PSP and ASP toxins	8	Laboratory Validation submitted to US ISSC for consideration as a 'Limited Use Method' for rapid screening of samples
ESP redesigned as 3rd generation instrument	7	Prototype demonstrated in the marine and freshwater operational environments; not licensed for commercial manufacturing/sales; doi: 10.1002/lom3.10627
AUTHOLO	7	<u>Prototype testing/eval underway</u>
Toxin aerosol measurements – A concern with both Red tide \ brevetoxin and Microcystis \ Microcystin toxins. Data is needed to evaluate human exposure \ risks.	Unknown	Currently there are no HAB toxin 'aerosol sensors', only aerosol sampling devices, with samples needing to process in the laboratory for analysis and measurement data

# Appendix 2: HAB Data Stakeholders



Source: US National Office for Harmful Algal Blooms, "[Harmful Algal Research & Response: A National Environmental Science Strategy \(HARRNESS\), 2024- 2034.](#)" Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, 2024, DOI 10.1575/1912/69773

# Appendix 3: References

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# Dialogues with Industry

## Harmful Algal Blooms (HABs) Background Paper

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