OCEAN ENTERPRISE INITIATIVE

Dialogues with Industry

Harmful Algal Blooms (HABs) Dialogue 1 Report Out

Instrument Provision: Challenges and Opportunities for sensors and platforms to achieve multi-sectoral harmful algal bloom systems

MTS marine technology society Opportunity runs deep™

GOOS Global Ocean Observing System

NOAA National Oceanic and Atmospheric Administration U.S. Department of Commerce

IOOS Integrated Ocean Observing System

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Dialogue Purpose

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), industry (Kongsberg Discovery and L3Harris), and the United States Integrated Ocean Observing System. To collectively face the demand for a resilient and responsive global ocean observing, forecasting, and information delivery system, we have identified a significant need to improve and expand communication.

The *Dialogues* series have been co-designed for compact, meaningful discussions with new and established companies, academia, and government to identify challenges and ways these sectors might overcome and to highlight opportunities for increasing industry involvement, capitalizing on existing and new technologies and fostering public-private partnerships to achieve mature and vibrant Ocean Observing Enterprise Working together will solve problems faster.

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.

7 Key Takeaways

The following main takeaways were summarized from the comments of the assembled leaders.

1

Disparity in Market Size and Diversification: The market pull from the finfish sector appears more significant than the pull from the shellfish sector. It was noted that these two HAB-impacted sectors have similar information needs, and collaborations on observing technologies and observing data services could benefit both markets. Observing technologies and applications that can provide data on HABs and other stressors (e.g., ocean acidification) can meet multiple needs and offer solutions to more than one sector or adjacent markets. A more extensive maritime domain awareness system could integrate HAB observing systems. However, implementing such diversification is challenging, as stakeholders must determine who pays and how they pay.

2

Disaggregation of Regulatory Demand is an Impediment to Scaling Up: Often regulation drives demand. The regulatory environment is not homogeneous and is often influenced by cultural, political, and governmental factors. There are national and regional differences, but working through intergovernmental organizations may provide transparency, enable navigation of the different regulatory regimes, and advance similar solutions.

3

Need for Market Analysis and Sharing of Technological Innovations: As identified in the first *Dialogues* series, there is a lack of comprehensive, credible market reports that companies can use to secure non-public funding. A repository to identify technological innovations that can be matched to stated requirements is also needed.

4

Advancing Operational HAB Observing Systems will Accelerate Research and Unlock New Opportunities for Industry and Public-Private Partnerships: Efforts supported by time limited funding (e.g., research projects or annually renewed pilots) have demonstrated the effectiveness of HAB observing systems to help mitigate impacts. Advancing operational HAB observing systems will sustain these benefits will accelerate research to keep pace with the expanding global HAB problem.

5

New Market Models can Create Demand: Some regulatory-driven markets exist to protect public health from known HAB impacts. Such markets can provide an informative signal for guiding sensor development. In many cases, regulatory limits are unclear (e.g., anatoxin-a), or sensor development is immature (e.g., ciguatoxins). Non-regulatory markets also exist to understand the role of HAB species and plankton in general in supporting healthy ecosystems and how they respond to change. Other sectors are more financially motivated to develop HAB sensors and solutions to support the optimal production of farmed seafood products (e.g., salmon aquaculture). Whether markets are regulatory, non-regulatory, or financially driven, it is worth exploring untapped opportunities for public-private collaboration in HAB technologies and data generation. Further discussion is needed to explore the potential for a "mission" or "data" as a service concept, including whether the market sectors that can benefit from actionable HAB data (e.g., shellfish growers, finfish farmers, water treatment and desalination facilities) would be receptive to a third party providing the sensors and missions and/or data services.

6

Establishing Standards is Crucial to Transform Data into User-Friendly Services: The need for standards first identified in the inaugural *Dialogues* series was raised again. Standards for validating, formatting, and organizing data need to be developed, implemented, and communicated. In addition to data standards, other related issues were seen as important considerations. Data sets, especially those generated by imaging sensors, are extremely large, and often require further processing and analysis. Support is needed to maintain certified reference materials for use with toxin-specific sensors and standards for validated image classifiers. Consideration of integrating data collection by various national, subnational, or private sector entities is needed. Further, focusing on international and national bodies that promote collaboration can help the field adapt as standards change with new legislation, instruments, or methodologies.

7

Sustainable Investment in Operational HAB Observing Systems will Benefit Impacted Industries: The most continuous and consistent investment has been from the public sector (e.g., U.S. federal government), which has driven the development, testing, and piloting of HAB sensors and regional observing systems. Engagement between public and private sector partners helps generate data and systems that support ecosystem research, regulatory actions, and business decisions. There are a variety of end users that would benefit from coordinated ocean observing and data, but innovative thinking is needed to incorporate public-private partnerships to design and manage these systems. Governments cannot fund the whole bill. Yet, governments often have the capacity to manage aspects such as data collection, analysis, maintenance, and distribution. However, for the system to be sustainable and flexible enough to adopt technological advances, public-private partnership funding may be necessary.

Dialogue 1 Description

The first HABs *Dialogues* brought together twenty-four leaders from industry, government, and academic sectors (see list of the participants in Appendix 1) for a virtual discussion on the challenges and opportunities associated with maturing the commercial market for HAB observing platforms, understanding the influences on demand for these technologies, harmonizing and leveraging of public and commercial HAB observing networks. In preparation, the participants were provided with the HABs *Dialogues Background Paper* and the Use Case discussion guide (Appendix 2).

The Dialogue was moderated by Chris Ostrander, Chief Executive Officer, Marine Technology Society. The Use Case was divided into three sections: (1) challenges and commercialization of HAB sensors and platforms; (2) understanding the demand for HAB technologies (Supply Side); and (3) building multi-sectoral systems with public and commercial networks. Each section included questions to help participants prepare for the Dialogue, which acted as a guide for the discussions. The discussion prompted participant feedback on operational, technical, and policy issues. Sections 1 and 2 were merged during the event. This synthesis report presents comments on a non-attributional basis.

Invited experts joined from nine countries. Sector representation was as follows: Private – 50%; Governmental/Intergovernmental – 29%; and Academic – 21%. In addition, approximately 116 individuals from sixteen countries joined as observers who provided input mainly via chat. Chris Ostrander facilitated the discussion among participants for the first two hours and integrated comments and questions chatted by observers. During the last thirty minutes, observers engaged in an open question-and-answer session with the participants.

This event was the first of three HABs *Dialogues*. The key takeaways and potential paths forward provide a foundation for subsequent *Dialogues*.

Discussion Synthesis

Section 1: Challenges and Commercialization of HAB Sensors and Platforms

The first section focused on developing and commercializing HAB sensors and platforms, including lab-based, point-of-use, and *in-situ* systems. HABs and their impacts have become more widespread and frequent over the past few decades. The collective need for observing technologies that enable the prediction, prevention, control, and mitigation of HAB impacts has also grown across industry regulators, health managers, and society. The development of sensors and the integration of those sensors into uncrewed mobile and fixed platforms at sufficient geographical scales is needed to support decision-making at that level. The market for HAB sensors and platforms continues to evolve and grow, with consistent and predictable demand for ubiquitous, cost-effective, reliable, easy to use, multi-targeted sensing systems – the supply for such systems is still to be realized.

Underpinning this session is the regional nature of HABs, the variability in regulatory structure, and the vastly different drivers for impacted sectors as diverse as tourism and recreation, drinking water, and aquaculture (e.g., farmers of shellfish and finfish). If there is no perceived market or if the people who need this do not have the money, industry will not invest in technological development.

Understanding End User Needs is Critical to Designing Successful Sensors and Data Services

HAB data must be timely and presented so that end users (e.g., shellfish farmers) can quickly assess the potential impact on their operations. Some HABs produce toxins that can accumulate in shellfish and cause serious human illnesses to shellfish consumers. Regulations require agencies and industry to collaborate on routine monitoring of toxin levels in shellfish when such a HAB threat is present. This reactive system effectively ensures the safety of commercially available seafood. However, in the absence of a toxic HAB threat, there is little incentive for the farmer to maintain the type of intensive monitoring or analysis of the resulting data that would be needed to provide a proactive response to HABs that threaten human health or disrupt aquaculture operations.

Some entities have implemented a 'tiered' approach where phytoplankton monitoring or a proxy (e.g., chlorophyll) provides an early indication of a potential HAB event, and more targeted, HAB-specific monitoring is used when indicated. This approach may allow early warning of a HAB event with a lower cost investment and can inform industry harvest decisions to prevent commercial product losses. The shellfish industry depends on partnerships with the public and academic sectors for grants to capitalize on the development of sensors, and often for data interpretation. One of the larger U.S. oyster companies relies on a commercial data portal that automatically uploads and organizes the data, but they are costly. For example, one such portal costs $12,000 per year and is only affordable because a grant subsidizes it. The costs of sensors, data management, and expertise to interpret the data are barriers to advancing the technology.. If the data interpretation was made clearer and impact focused, the farmers would be more willing to host the sensors.

Diversifying HAB Data Collection is Key to Expanding Monitoring Efforts

For a market pull, the perspective on monitoring and management must extend beyond looking for a specific HAB species or toxin. A shift from HAB-specific monitoring and sensors to more holistic observing efforts and related data/information products could aggregate demand across multiple sectors or end users, which inherently increases value. For example, framing the problem in terms of maritime domain awareness, multi-robotic systems, autonomous surface craft, and cooperation with autonomous underwater vehicles to do coordinated, targeted observations might include a HAB surveillance mission. One example is ongoing work in the Gulf of Mexico, where uncrewed vessels are actively surveilling for both HABs and hypoxia.

Diversifying both missions and data comes with a significant price tag. Investment is needed to drive down the costs of developing and manufacturing sensors and to develop more multi-parameter sensors. Further, a market is required to justify the costs of producing sensors. One possible solution is to leverage adjacent markets. If HAB detection methods can be low cost and deployable at scale, they may also be attractive to public health pathogen (e.g., vibrio bacteria) monitoring and other similar efforts, providing that detection of these new targets can be easily integrated into the sensor technology.

"Who pays" for diversified use was not discussed and should be tied to discussions on new market models.

Regulatory and Governance Structures are Localized and Hinder Market Integration

Often regulation drives demand for new HAB observing technology. That demand drives the perceived market for new HAB sensors, which will increase investment. That increase in investment lowers unit costs and hopefully lowers the threshold for adopting new observing technology.

The regulatory environment is not homogeneous and is often influenced by cultural, political, and governance factors. There are countries and regional differences, but it was suggested that working through intergovernmental organizations might provide transparency and enable navigation of the different regulatory regimes offering a start to discussing similar solutions.

It is essential to include regulators early in developing new technologies to ensure that once the technology is developed, the information derived from the sensor will be fit-for-purpose. The discussion centered around whether the latest technology will replace the old methods or be complementary. If the sensor is complementary, it is a more complex challenge economically because then you must convince users that the extra measurements add significant value. However, the issue of data compatibility must be considered when replacing old methods.

Within the European Union, the market is fragmented as member states buy their own solutions, which may or may not include HAB monitoring. For an organization like the European Commission, a funding entity, it is important to better understand the needs for HAB monitoring and the existing infrastructure so that their funding opportunities encourage working together to develop instrumentation that will support the common Commission regulatory framework.

Finally, agreed upon threshold levels for some toxins do not exist, which hinders technological development. In the absence of regulation, it is very difficult for a sensor designer to move forward, particularly in biosensing, which needs to target a regulatory threshold or suitable detection range. If there is a good regulatory market or basis for the regulatory market, then it opens doors in terms of development.

While not discussed during the dialogue, a question was raised in the chat about whether there was an insurance market providing parametric insurance products for aquaculture farms impacted by HABs. Could this be used to encourage the installation of advanced monitoring equipment more broadly? Two examples provided in response to the topic of insurance are:

- axaxl.com/insurance/products/aquaculture-insurance
- longline.co.uk/site/aboutus/publications/aquaculture_insurance_en.pdf

Market Service Models

Even if governmental agencies are driving the monitoring, the question should be asked whether this service can be done more cost-effectively by a “mission” or “data” as a service. Similarly, a discussion is needed on whether the market sectors that can benefit (e.g., shellfish growers, finfish farmers, and desalination facilities) should rely on a third party to provide the sensors and missions.

There are examples of companies that offer "mission" or "data" as a service; however, this is a nascent market, but more and more companies are seeing the potential. A focused discussion that brings together the platform operator, the sensor company, and the public and private end-users could help flesh out potential services. Several models can be considered. A company might offer "missions" as a service where a private company takes on the cost and risk of operating the platform, but the paying entities control the data. Another model is where the private company collects the data and provides a value-added product to the customer.

Yet another market model example could be the public sector maintaining a scale of production and local operators having a co-pay to deploy instruments. One idea was to pilot case studies where we demonstrate a tax and credit system for a consortium of users. A smaller firm will make a smaller contribution but will contribute. The bigger firm with much larger gains and much more significant damage loss to be avoided will make bigger contributions.

The Role of Pubic Sector in Making the Case to fund HAB Monitoring (Market Failure?)

Well-established markets respond favorably to predictable demand signals from large customer bases. Government agencies are the primary customers of the sensor and platform markets. Regarding HABs, the primary demand still comes from the public sector, which is responsible for food safety/security and human safety. In many cases, sensor developers are also reliant on government funding for their sustainment. Engaging with them and ensuring that this dependency on jobs is tied to government funding is an important aspect of communicating the value of the Ocean Enterprise.

Are science questions or business decisions the driver for HAB monitoring? In the United States, legislation supports research to understand the causes and persistence of HABs, their ecosystem impacts, and the development of improved detection technologies, monitoring approaches, predictive models, forecasts, and control strategies. While no operational HAB observing system currently exists, a framework and implementation strategy has been developed for a U.S. National HAB Observing Network (NHABON). Frameworks have been adopted likewise in the E.U,, but support for sustainable HAB observations has not reached a scale like monitoring systems to respond to other disasters such as hurricanes or tsunamis. To appropriately scale HAB monitoring, a paradigm shift is needed away from considering HAB monitoring as research, where long-term data sets must continue, as this is a barrier to introducing new technologies. Continuing time series data on HAB locations and seasonal outbreaks is necessary, but a perspective shift to reframe HAB observing in the context of meeting public health and food security needs will foster new innovations. Another challenge with scaling and sustaining HAB observing is the diffuse markets for HABs.

Another way to frame the need for HAB monitoring and observing is by emphasizing "cost avoidance." What is the likelihood of a HAB event and what costs are avoided by accurate early warning that a HAB event will occur? For example, shellfish harvests can be delayed, protecting commercial products and industry time/effort/testing costs. Can the regulatory regime for food security provide a basis for this discussion? For example, European regulations are strict and inhibit the selling of products if HABs are detected in some areas, and this can take months to resolve. Working across the public, private, and academic sectors to find a common framework for articulating "cost avoidance" could bolster the national agencies' funding requests.

Can the regulatory regime for food security provide a basis for this discussion? For example, European regulations are strict and inhibit the selling of products if HABs are detected in some areas, and this can take months to resolve. Working across the public, private, and academic sectors to find a common framework for articulating "cost avoidance" could bolster the national agencies' funding requests. Can a system be developed that indicates there is no or minimal/acceptable risk, and maybe downstream costs of testing could be the cost benefits that drive the innovation?

Ultimately, we want to achieve a model that leverages and utilizes capacities at the national, state, and local levels of government to provide some level of market stabilization but does so in a way that incentivizes or provides a framework through which there is either a user-driven cost recovery structure or some other type of model that allows for a much easier gain of access to the data, data products, or capabilities.

Remote Communities are Increasingly being Impacted by HABs

The growing need to detect HAB species, especially HAB toxins, in rural and remote communities highlights the importance of monitoring subsistence use of marine resources. In western and northern Alaska, people practice subsistence as the comprehensive utilization of the marine environment for food, not just shellfish. These communities lack access to high-tech toxin testing facilities or laboratories, rely entirely on marine resources for subsistence, and often receive little support from both government and the private sector. When depending on the broader marine environment for subsistence food without other nutritional sources, communities may have to accept higher levels of risk due to regulatory thresholds. To address this challenge, stakeholders must explore incentives for building capacity, such as subsidizing capital equipment purchases. Equally important, agencies and private farms in rural and remote areas must invest in continuous workforce training to counteract high staff turnover.

Section 2: Understanding the Demand for HAB Technologies (Supply Side)

This section focused on how broad the market is. Can it be sustained without public/government funding? What barriers and opportunities exist to achieve the depth of demand required for commercial sustainability? Requirements drive what the industry will deliver. Industry can move faster and is nimbler than the public sector. Still, if there is no standardization of the regulatory regime, then the industry cannot adapt, and it limits the customer base that the industry can aggregate. This is further hampered by inconsistency in interpretation and no standardization of data for industry to use.

Integration with Uncrewed Vessels is Considered to have a Low Readiness Level for HABs

Integration of HAB sensors with uncrewed platforms is bespoke and has been mostly demonstrated under limited public funding. Both sensors and platforms are expensive, making sole application deployments cost prohibitive. Technology advancements such as edge computing for onboard data processing for large imagery or complex analysis capability for molecular analysis are still at low technical readiness levels.

Additionally, since the algae are mobile, sampling must be done throughout the water column and utilize adaptive surveillance patterns. Investment in further demonstrations is needed with close collaborations between the platform and sensor developers to optimize cost, weight, and power. It was noted that other platforms are being used, such as ships of opportunities and ferries, which can be lower cost but may not be able to address the monitoring needed due to the patchy (spatial and temporal) nature of HABs.

A Broad Market Lacks the Depth for Commercial Sustainability

Aquaculture markets vary significantly in size and production methods. The oyster industry faces high barriers to entry due to small farms and regulatory costs. Concerns about public health might lead to a delay in the harvest of some toxin-producing HABs. However, other types of HABs can kill shellfish larvae in hatcheries or young oysters, costing farms time and money. Finfish farming, similarly, faces the risk of total stock loss and no harvest after a four-year investment. Therefore, without subsidies or viable market models for the necessary HAB-related technologies, the rise of HABs will likely drive many small farms out of business. For finfish, there are some significant offset costs for HABs. Despite some high-profile billion-dollar losses, the salmon farming industry continuously faces daily HAB impacts, thus investing heavily in identifying immediate and developing threats.

It was suggested that there could be better collaboration between the aquaculture sector industries to tackle this common issue in both sectors. There is an opportunity for technological development as the technology developed for finfish is transferable to shellfish and identification of threats to public health on beaches for recreational harvests. Moreover, the finfish industry is currently testing and implementing a variety of innovative observing technologies that are being developed to support the growing needs of that sector.

There is a need for a consolidated market report specifically for the aquaculture sector that would show current users the available technology that might be targeted for adopters. This could include industry representatives such as current conglomerates or businesses trying to expand. There is a need for better market size information breakdown of the sectors and the adjacent markets, looking at the regulations and the standards competition, what's already out there, and current techniques and best practices. These reports must also be realistic analyses of how conservative some of these markets are and potential routes to the market. If sales increase because of dedicated marketing reports, the user base, and the variety of use cases increase, which will drive further innovation.

For industry, demand is driven by the “pain” felt by the customer, not policy.

Section 3: Building Multi-Sectoral Systems for HAB Observing and Monitoring

In recent decades, the growth of global ocean observing networks, traditionally funded and maintained by governments (sometimes in partnership with academia), has been complemented by new commercial entrants to the marketplace – spanning the entire value chain from sensors and platforms to downstream data services. This session focused on the roles of and interdependencies between public and private actors with respect to the HAB observing market.

The Role of Blue Tech Clusters, Incubators, and Accelerators

Incubators are important, but they have limitations in getting technology to market. For example, in the United States, NOAA's National Centers for Coastal Ocean Science (NCCOS) has funded the United States Harmful Algal Bloom-Control Technologies Incubator (US HAB-CTI). In the near term, the US HAB-CTI is focused on understanding the landscape and promoting HAB control technologies in the marine environment, which significantly lags the freshwater environment. Long-term will be the facilitation of a commercial-based enterprise for control technologies. NOAA NCCOS HAB research programs have also succeeded in accelerating the development, demonstration, and adoption of HAB observing technologies.

NOAA and the United States Integrated Ocean Observing System (IOOS) have recognized this issue and funded two programs: Ocean Enterprise accelerators and the Ocean Technology Transition program. Both are modest programs that are focused on all aspects of ocean observing inclusive of HABs. IOOS investments in HAB Observing pilot projects in all eleven IOOS Regional Association programs have helped demonstrate a ready infrastructure. Yet, while the infrastructure is in place, scaling continues to be challenging. There has been no commensurate funding increase for the mission agencies in the United States to either transition to operations or be a market driver for the new technologies. Even after demonstrating its capabilities, there is a delay in convincing funding entities that the technology is viable and valuable enough to warrant long-term support.

Supply Chain

Supply chain issues remain post-Covid. Individual companies must remain flexible and continually evaluate new technologies and redesign electronics when supplies are not available. This reinforces the need for technology partners to work together with system users, businesses, and institutions to make HAB monitoring and mitigation work.

The availability of reagents and chemicals is a supply chain challenge. Some toxin assay materials (e.g., antibodies, radiolabeled reagents) are like fine wine – a specific "lot" only lasts so long and eventually you run out and you have to create a new batch. Notably, potential synthetic replacements for antibodies, such as 'aptamers,' are more stable than antibodies.

Aptamers are selected to specifically recognize a given target (e.g., a specific toxin or class of toxins), and can be synthesized at scale to produce exact structural replicates. Investment is required to support the design and selection of aptamers that recognize the major HAB toxins. When operations are seasonal, at the local to regional scale, it is hard to keep enough supplies on hand. Can this be solved at the global level, i.e., is there enough pull to establish a centralized production and/or distribution facility for some toxin assay reagents?

National Research Council of Canada (NRCC) and CIFGA Laboratory in Spain have funded efforts to provide certified standards and reference materials. This NRCC facility will put new toxins and new reference materials into the program once they know they can sustainably provide it in a cost-effective manner and that there is sufficient demand for the product. This is where a small amount of public funding is being used to prove that an innovative system can be sustainable. Additionally, the Food and Agriculture Organization (FAO) of the United Nations has established a Reference Centre for Bivalve Mollusc Sanitation, addressing testing needs for marine toxins and pathogens in bivalve shellfish safety, at the United Kingdom's Center for the Environment, Fisheries and Aquaculture Science (CEFAS).

Rapid Test Kits - Is there a Stable Market?

One challenge with the rapid toxin test kits is a stable market. It was noted that a well-known and established company recently withdrew from the shellfish toxin testing marketplace, which was a warning sign that after 10 years of effort in optimizing an assay and gaining a large share of the market, this effort was ultimately deemed not critical to the company's bottom line. This resulted in several companies now working to fill the gap in the market by either improving and refining existing technologies or starting from scratch to develop antibodies, along with all the associated reagents, and to work towards delivery of new commercial assays. In the meantime, the US National Shellfish Sanitation Program's Guide for the Control of Molluscan Shellfish lists the "Reveal 2.0 ASP test" that is no longer available to consumers who employed this test as an "approved limited use method" as part of shellfish management programs.

Industry needs help in assessing the performance of marine toxin test kits, as it was noted that there is variability in the performance of available kits. While some organizations certify the performance of test methods, the fees are too costly for most small businesses and must be subsidized with funding from grants or other sources. Another barrier is that little available data can guide industry in deciding which kits are most fit-for-purpose, and which have met their needed performance criteria. It was noted that IOOS had historically supported the Alliance for Coastal Technology (ACT), which conducted a transparent, rigorous evaluation process that generated reports on technologies and sensors that could be used in the field. The repository still exists, but folks are not aware of it. It was noted that an "ACT" - like process is needed for companies to independently validate their global technologies in the field for assessment and independent validation of performance.

The testing required by the regulatory standard is complex. The shellfish industry operates on a weekly testing schedule and is highly competitive. There is a potential opportunity to develop a toxin test kit that is easy and simple for farmers to interpret, providing them with an early read on risk as they await regulatory agency results. However, it is important to note that in the EU, whereas regulatory agencies conduct official control testing under the authority of Competent Authorities, Food Business Operators (FBOs) are also required to conduct their batch testing for risk evaluation and management. Despite this requirement, most EU regions—except for Scotland and Ireland—do not enforce it effectively, leading to heavy reliance on regulatory testing for batch quality management. As a result, there is currently limited commercial demand for independent test kits, a gap that must be addressed to strengthen risk management practices.

Another barrier is validating assays on different species, methods, and matrices. While you may get a small commercial foothold in one application, every new application must undergo a complex and lengthy certification process, almost akin to bringing a new drug to the market.

Points were raised on new test kit technologies such as lateral flow systems, genetics, sustainable production of antibodies, assays, molecular techniques, etc. Please refer to the dialogue recording for that discussion.

Data and Standards

As in the first *Dialogues with Industry* series, the need for the development, implementation, and communication of universal standardization of how that data is organized was identified as a barrier.

Standardization is necessary to have FAIR[1] data, which extends to the standardization of collecting and observing methodologies. Data adhering to FAIR principles may impose costs for the observing parties and the data management agencies. This requires consensus and is an iterative process. A potential solution is the Ocean Best Practices System (OBPS), a global initiative to improve and standardize practices for collecting, analyzing, and sharing ocean data and information.

It was recognized that maintaining the data costs money, and currently, most of these data reside in the public domain. There is also a question of when and how much of the publicly funded data should be released to the public. While the release of data funded by public dollars is mandated within the United States, further discussions are needed on the sensitivity of the data and the need for interpretation and generation of data products/services.

The dialogue did not discuss how privately collected data could be made available. If data are commodities, there needs to be an agreed licensing scheme. This has been established for terrestrial commercial remote sensing and weather data such as radio occultation. It was noted that encouraging a public-private partnership focused on sharing data can benefit not only the private sector but can be used to build skills for students and early career ocean professionals. It is important that as sensors are being developed, that thought is given to how the data can be widely accessible and easy to interpret.

Open Session

Communication

Academic drivers are different, e.g., when publishing papers. Much more could be done to raise awareness of scientific and technological innovations and bring them closer to on-farm and other applications. During the life of the grant, there is partnering with industry, but there are limited avenues to showcase platforms and sensors after the period of performance has ended. Presentations are at conferences that do not reach potential end users who could benefit from the research conducted. Creating fora for cataloging these research advancements and matching user requirements is necessary.

Efforts should be made to enhance private sector participation in international HAB societies and related conferences (e.g., ISSHA and ICHA) while also integrating the HAB community into blue economy-focused events. This would foster collaboration among the private, public, and academic sectors, providing global exposure for emerging technologies and their developers. While some countries have widespread access to these technologies, others do not. Establishing a dedicated technical track, exhibition, and interactive workshops would facilitate direct engagement and knowledge exchange.

Accelerating Tech Transfer

Mechanisms for fast-tracking technology exist, but there is still an educational need, even in industries with strong financial motivators, to manage HABs and their impacts. It is important to identify and explain HAB threats and communicate that a given approach can realistically be used to manage or mitigate the effects on their target process, whether farming, desalination, or other public health considerations. One of the most helpful activities would be establishing independent data, papers, and results that show the actual significance and value, or the actual quantifiable mitigation outcomes that have been achieved – effectively a cost-benefit analysis.

[1] FAIR: Findable, Accessible, Interoperable, Reusable. https://asklib.hms.harvard.edu/nih-dmsp/faq/377100

Increased funding and support for technology transfer and operational HAB observing systems would significantly accelerate this transition, given the complexity and scale of the HAB problem and the fact that there are other scientific applications and benefits for a lot of this instrumentation. However, there must be an accompanying realization that the transition may take several years. While there is funding for proof-of-concept instrumentation within the lab, commercialization for things like platforms/instruments that operate in the ocean is a big step. Oftentimes, people have a mindset to think about it like computer programming. You finish the beta test, the alpha test, and do a little more testing, and it is ready to go. This is not the case for ocean instrumentation, which operates in difficult and variable environments, and requires considerable time and people. In the ocean community, there is a bottleneck of people who can take the instrumentation to sea, and as a result, the time to market is much longer compared to biotech or software.

It was noted that academia working with industry early in the development path accelerates commercialization. This was also mentioned in the first *Dialogues with Industry* series.

Decision Support Tools, other Technologies

The use of satellites, aerial observing, and drones was brought up in the open session. The planning team recognizes the importance of satellite (including hyperspectral) imagery and the need for a suite of sensors; however, due to timing and logistical constraints on the numbers of participants, this topic was not fully discussed in Dialogue 1.

Further, it was brought up that what is really needed is decision support tools, not just a focus on sensors. The planning team also recognizes this, and it will be covered further in Dialogue 2.

Training

Several threads were identified. First, the need for loaner platforms so that students can get certified on a system was identified. While individual programs were identified, are there strategies for partnering and piggybacking and a centralized database to identify where these platforms exist?

The second was in emerging new technologies that move from the traditional techniques that rely on individuals and specialized skillsets to computer-aided analysis, which can process samples much quicker but will require different skills.

Several training programs were noted in the chat:

- The Pacific Plankton Program (P3) is a collaborative effort at Cabrillo College to monitor plankton levels at two sites in the greater Santa Cruz area. The program provides a scientific experience for volunteers and Cabrillo students who enroll in Bio-450. Designed and modeled as an internship experience, the course teaches field and laboratory skills at absolutely no cost to the student, offering exposure without obstacles. Participants are eligible for certificates of achievement documenting their skills gained over this semester-long experience. The over 900 total data entries they have consistently collected since 2018 directly contributes to NOAA's nationwide Phytoplankton Monitoring Network (PMN)- a nationwide participatory science program. https://www.pacificplanktonprogram.org/about-the-program
- Phytoplankton identification training developed with NOAA funding and now sustained by Bigelow Laboratory: https://ncma.bigelow.org/training-courses
- IOC Training Course for Harmful Marine Microalgae - https://oceanexpert.org/event/4683
- High school level partnership to train students: https://www.maosmontereyhigh.org/

Potential Pathways Forward

This is the first of three *Dialogues with Industry* on HABs. Below is an initial take on the key issues and potential pathways forward drawn from the first dialogue. The results from all *Dialogues* will be synthesized in a final summary paper for the series and a concise set of practical and implementable recommendations will result from the process.

- **Professional societies, like the Marine Technology Society, as well as intergovernmental programs like IOC, GOOS, and the UN Decade in partnership with ISSHA could set up focus groups to develop concrete steps to resolve challenges in scalability, cross market reach, and regulatory regimes:** Ad hoc and permanent committees can be established to encourage ongoing conversations across the Ocean Enterprise. For example, having a professional society establish a 'community of practice', work group, etc. that would provide a reliable avenue for communication between providers/producers on the 'supply side' and the diverse range of user groups.

- **Development of Market Studies:** The first step could be a framework developed by private and public sectors that would enable seeking support from multiple sources to conduct these studies. Standardization is necessary so that reports can be compared. Once developed, a central repository should be established – as proposed by the Ocean Enterprise Initiative.

- **An interchange of information based on requirements and available technologies as well as funding opportunities could be a strong mechanism for bringing the sectors together:** This interchange could be an interactive repository for market studies, end user requirements, technology landscapes, and funding opportunities.

- **Entrepreneurs, governments, and professional societies should seek to participate in and foster the further development of incubators and accelerators, which serve the interests of their membership in expediting access to information resources, mentorship, and funding opportunities:** For example, the United States has launched two efforts - the HAB Control Technology Incubator and Clearing House as well as the Ocean Enterprise Accelerators. The Ocean Enterprise Accelerators are in the process of identifying companies and HABs falls under the ecosystem theme.

- **Communicate on the impact of not sustaining funding for HAB observing networks (e.g., US National Harmful Algal Bloom Observing Network (NHABON), GlobalHAB, etc.):** Create a discussion piece on the potential cost to society of continual short-term thinking about key observing infrastructure.

Appendix 1: Participants

Sector	Affiliation	Name
Public/USA	National Oceanic and Atmospheric Administration (NOAA)	David Kidwell
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Public/EU	European Union	Zoi Konstantinou
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Public/Chile	Fisheries Development Institute (IFOP)	Leonardo Guzman
Intergovernmental	GOOS/IOC (IFREMER)	Philipp Hess
Intergovernmental	GOOS/IOC (Irish Marine Institute)	Dave Clarke
Industry	Cytobuoy	George Dubelaar* Harrie Kools
Industry	Chelsea Technologies	Kevin Oxborough
Industry	Yokogawa Fluid Imaging Technologies	Leah Anne Gibala-Smith
Industry	McLane Research Laboratories	Yuki Honjo
Industry	Phytoxigene	Mark Van Asten
Industry	SeaTrac	James “Jigger” Herman
Industry	Poseidon Ocean Systems	Matt Clarke
Industry	Hog Island Oyster Company	Maxwell Rintoul
Industry	SAAB	Judson Jevon
NGO	Monterey Bay Aquarium Research Institute (MBARI)	Chris Scholin Jim Birch
Non Profit	National Oceanographic Center	Matt Mowlem
Non Profit	Southern California Coastal Ocean Observing System (SCCOOS)	Clarissa Anderson
Academia	Moss Landing Marine Laboratories	Holly Bowers
Academia	Israel Oceanographic & Limnological Research Kinneret Limnological Laboratory	Ilia Ostrovsky
Academia	Université Côte d'Azur, Nice	Yasmine Bottein
Academia	Dublin City University	Fiona Regan

**Information provided ahead of the event*

Appendix 1: Use Case

Instrument Provision: Challenges and Opportunities for sensors and platforms to achieve Multi-Sectoral HAB systems

Introduction

There is now worldwide recognition that healthy and safe oceans are fundamental for thriving ecosystems and for resilient global economies. Efforts to advance robust and innovative ocean data collection and dissemination practices, and wide-reaching collaborative data sharing and analysis efforts, demand engagement and partnerships between the public, private and academic sectors.

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 *Dialogues with Industry* explored how to mature the Ocean Enterprise to deliver essential societal, economic, and environmental benefits.

The second series, focusing on Harmful Algal Blooms (HABs), will consist of three curated dialogues that will be held January – February 2025. The *Dialogues with Industry* – HABs (hereafter *Dialogues*) will explore and define 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 uses cases. The *Dialogues* are less focused on technical and scientific discussions, except as they influence the market dynamics.

This use case outlines the scope, format, and proposed discussion topics for HAB-focused Dialogue 1.

Background and Scope

Monitoring, detecting, and predicting HAB events is a scientific, technological, and economic challenge. In evaluating the "demand" signal, a 2021 article in Communications Earth & Environment found that although statistics do not show a global increase in HAB events, there are increases regionally, and increased monitoring by the aquaculture industry contributes to the perceived increase in HAB events[2]. Further the authors state, "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, would current and future HAB observing efforts benefit from new public\private partnerships? It was noted in the comments received that there is discussion around the paper's perspective on the global increase in HAB events.

[2] Perceived global increase in algal blooms is attributable to intensified monitoring and emerging bloom impacts. Commun Earth Environ 2, 117 (2021). https://doi.org/10.1038/s43247-021-00178-8

Whereas there are documented cases of millions of dollars of economic loss due to HABs, there is no systematic global effort that routinely assesses the economic impact of HABs. When 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 losses and socio-economic impacts.[3,4]

Dialogues Outcome

The goal of the *Dialogues* is an awareness of where the global community is going about standing up of services for delivery of data and the generation of forecasts that has a sustained investment from the public sector and presents the opportunity of funding from the private sector.

The deliverable from the *Dialogues* is a set of actionable recommendations to be acted upon by those globally engaged in the mitigate HAB impacts through the monitoring, forecasting, and control of HAB occurrences, across the public, private and academic sectors.

Format of the *Dialogue* 1

Dialogue 1 is divided into three sections described below. Each section will engage leaders from the public, private, and academic sectors to explore challenges and opportunities associated with maturing the commercial market for HAB observing platforms; understanding the influences on demand for these technologies; harmonizing and leveraging of public and commercial HAB observing networks. The facilitator will provide a short review of each section below and then discuss the questions outlined in each section with the participants. The purpose of the questions is to draw out the different perspectives of the participants. The moderator will ask follow-up questions as needed to flesh out the discussion in more detail. Observers will be able to provide their input to the questions via the chat function. The last 30 minutes the observers will be invited to join the discussion.

Section I - Challenges and commercialization of HAB sensors and platforms

Industries, resource managers, communities and other stakeholders impacted by HABs have called for sustained access to data products and services based on timely, regional HAB observations from *in-situ* autonomous systems, from field-portable detection that supports screening, regulatory, and participatory science applications, and from targeted satellite imagery and other remotely sensed imagery. While there have been significant advances in these systems and some commercial availability, persistent scientific, technological, and regulatory challenges continue to create market barriers such as ease of use, scalability, and affordability. HABs are caused by diverse organisms and occur in fresh, brackish and marine waters in many different regions and impact a range of resources and stakeholders. Scientific research has advanced to identify potential for multiplexing of some target cells and toxins.

The observing technologies are starting to demonstrate that they can detect species and toxins on the same platform are feasible. Presently and likely for the near future a variety of applications and platforms (lab-based, point of use, and *in-situ*) will always be needed. The integration of HAB sensors. with uncrewed platforms in some areas has extended the geographical and temporal extent of the monitoring but has not reached scales that support the real-time decision making needed to respond to HAB outbreaks. Further, many of these instruments remain bespoke and do not offer the reliability, cost-effectiveness, and ease-of-use that many stakeholders desire.

[3] 2020. Global HAB. Evaluating, Reducing and Mitigating the Cost of Harmful Algal Blooms: A Compendium of Case Studies. PICES Sci. Rep. No. 59, 107 pp, https://repository.oceanbestpractices.org/handle/11329/1850;
[4] Harmful algal blooms and coastal communities: Socioeconomic impacts and actions taken to cope with the 2015 U.S. West Coast domoic acid event, Harmful Algae, Volume 96, 2020,101799,ISSN 1568-9883, https://doi.org/10.1016/j.hal.2020.101799.

The market for field-portable HAB toxin detection devices has been particularly challenged by the complexity of the HAB problem, phycotoxin regulatory requirements, and by an increasing public demand for safe seafood. Many companies operating in this space are small, university spinoffs focusing on the detection of one or two HAB toxin targets. One company cannot independently support the need for field-portable detection of many HAB toxins and there is instability in the marketplace for these kits.

Discussion Topics (questions in bold used during the Dialogues)

1. **Considering the current landscape, what economic and regulatory forces are driving growth in the HAB sensor and platform market today? What challenges exist in shaping and sustaining that growth in the future?**

2. **Markets respond favorably to predictable demand signals from large consumer bases. For the HAB sensor and platform market, government agencies (spanning local to national, and inclusive of international bodies) are a primary customer. For folks on both the supply and demand side of this equation, what challenges and/or barriers exist for the government customer, and other customers, communicating aggregated requirements for sensors and instruments to the industry supplier? How can these barriers be overcome?**

3. **How successful has the integration of sensors with uncrewed platforms been in detecting/monitoring HAB species outbreaks and toxins? What is limiting further adoption and innovation of these coupled systems?**

4. What challenges exist in growing the HAB sensor and platform markets?

5. Are there barriers to government agencies (national to local) communicating requirements for sensors and instruments? If so, how can these barriers be overcome?

6. Are we being successful in bringing innovation to the detection and monitoring of HAB outbreaks, such as integration of sensors with uncrewed platforms? Are there constraints to the adoption of these systems and other innovations?

7. Are there sufficient market reports that will appeal to a start-up community in HABs observing/monitoring technology? If not, what specific reports are needed?

8. To what degree does the certification of sensors or diagnostic devices by regulatory bodies (e.g., US Interstate Shellfish Sanitation Conference; Internationally, AOAC) drive the market and influence sensor purchase decisions? Should these certifications be a part of every acquisition for sensors or devices?

9. How can we identify opportunities to fast-track promising technology in an efficient and standardized way - interface between the innovation and mature markets?

10. What is needed to position remote and airborne sensing platforms as a stronger asset in monitoring HAB outbreaks?

11. Are there attempts to bring awareness to the availability of HAB technologies in developing countries?

Section II - Understanding the demand for HAB technologies? (Supply Side)

HAB observing has been largely funded by government and private sector Research and Development (R&D) investments to date, with limited support for delivery of sustained observing services. However, increasingly commercial ventures (e.g., aquaculture) drive the demand for reliable, high-quality data and data products tailored to specific user requirements. Scaling up observations and developing observation networks is needed to meet this demand. Moreover, increased stakeholder engagement will be required to better harmonize existing technologies with specific user requirements and to foster the innovation needed to bring new types of technologies to the market. Leveraging expertise in the private sector through expanded and new public-private partnerships and exploring alternative funding approaches, while maintaining support for government and private sector R&D programs, has been identified as a key to tackling the expanding global HAB problem.

1. **Is the potential end-user market for HAB sensors and platforms broad and clear enough to generate the revenue needed to establish/grow/sustain your business? If not, what needs to be done to identify, activate, and aggregate the consumer base? Are there examples of 'market shortcomings' where public investment and subsidization might be necessary to spur the market? Where do those investments target?**

2. What (if any) shortcomings do industry partners see in the HAB sensor and platform market - *in-situ*, field kits, remote sensing? Is the potential end-user market for HAB specialized sensors and platforms broad enough to generate the revenue needed to establish/grow/sustain? If not, what could be done to address this?

3. Are there any good examples of testing mandates driving the market? If so, what can be learnt?

4. Are the potential buyers of HAB technologies clearly identified? Are there examples of 'market failure' where subsidization might be necessary to spur the market? If so, how might this be done?

5. Is there sufficient market information available to attract interest from a start-up community in HAB observing/monitoring technology? If not, what specific market reports are needed?

6. Are blue-tech clusters, incubators, accelerators, and entities such as US HAB-CTI Clearinghouse a good way to facilitate market growth? Or is their impact more limited to creating and growing competition? Are there successful examples of these mechanisms facilitating market growth? If so, what can be learnt?

Section III - Building multi-sectoral systems with public and commercial networks

Up until recently the global ocean observing networks have been government funded, ocean research or meteorological services, with the understanding that the data they provide are for the public good and flowing into areas like HABs. Recently, however, there have been disruptive new entrants into this marketplace, businesses offering networks of platforms and downstream data services. These are filling niches in the ocean observing enterprise, be it in terms of ocean information or capacity to undertake and process ocean observations. Is this same trend being seen in the HABs networks?

Several observing projects include collaboration between government, academia, and industry for the development of technology, demonstration of concepts, and execution of pilot projects. The landscape is varied, however, depending on which sectors are responsible for funding R&D, training the next generation of technical workers, and developing the next generation of technologies that will be commercialized. Understanding the present-day constraints in this space can help us to unlock future modes of operating across the various sectors.

The Space Sector has adopted the term New Space and within the United States government is now adopting a philosophy of the Hybrid Space Architecture (HSA) which is the integration of emergent "new space" smallsat capabilities with traditional US Government large space systems. How does the existing and predominantly research funded ocean observing system integrate and work with these new network and data service entrants? What are the opportunities, standards, barriers and norms that we need to look at for greater efficiency and integration? How have other sectors approached this? How can the Ocean sector learn from the Space or Meteorological sectors in developing a 'Hybrid Ocean Architecture' for the global ocean observing system?

Discussion Topics

1. **Are blue-tech clusters, incubators, accelerators, and entities such as US HAB-CTI Clearinghouse (many of which receive substantial public money) a good way to shape and support general market growth? Or is their impact more limited to creating and growing competition? Are there successful examples of these mechanisms facilitating market growth and stability?**

2. **Rapid testing kits for HAB toxins are a growing part of the larger market. For new and small companies with a limited customer base certification like the AOAC performance testing program can be prohibitively expensive. What level of data quality and performance assurance is required by the customer for such tests to be deemed fit for purpose?**

3. **Do supply chain vulnerabilities and requirements for system resilience affect the adoption of new technology? What can be done to stabilize the supply chain, so companies and consumers see a future and remain in the HAB business?**

4. **Who is responsible for ensuring data follows FAIR (findable, accessible, interoperable, reusable) and CARE principles (collective benefit, authority to control, responsibility, ethics)? Does this sit with academia and government, or does industry have a role as well? Are there commercial issues to consider?**

5. Where does the balance lie between the private and public sectors in driving the market requirements? Which functions are "inherently governmental," and which should be left to the private sector?

6. What fora are appropriate for establishing and discussing guard rails on roles and responsibilities?

7. Are there new technologies that can bring down the cost of managing HABs if they are made more accessible and widely used? If so, what are the challenges in bringing them to market?

8. How can we identify opportunities to fast-track promising technology in an efficient and standardized way - interface between the innovation and mature markets?

Questions used in the open discussion

1. **Are there new technologies that can bring down the cost of managing HABs if they are made more accessible and widely used? What opportunities and mechanisms exist to fast-track promising technology in an efficient and standardized way?**

2. **Is there sufficient market information available to attract interest from a start-up community in HAB observing/monitoring technology? If not, what specific market reports are needed?**

3. **Recognizing, though, that these dialogues are aimed at uncovering targeted recommendations, the final set of pointed questions:**

    a. **What discrete recommendations can you share that serve to mature the commercial market for HAB technologies; advance new technologies and methods; clarify and aggregate demand for these technologies; and/or harmonize and synergize HAB observing networks?**

Appendix 3: Planning Team

The second Dialogue series, the writing of the background paper and use cases are the work of the planning under the auspice of the Ocean Enterprise Initiative. The authors and organizing committee core members would like to express our sincere gratitude to all the participants and observers of the Dialogues with Industry initiative. MTS efforts identified in this report are largely funded by the Department of Commerce NOAA – grant, in support of the Ocean Observing Community Engagement Framework Cooperative Agreement detailed in NA23NOS0120322.

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OCEAN ENTERPRISE INITIATIVE

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Harmful Algal Blooms (HABs) Dialogue 1 Report Out

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