OCEAN ENTERPRISE INITIATIVE

Dialogues with Industry

Harmful Algal Blooms (HABs) Dialogue 2 Report Out

User-Driven Ocean Information:
Downstream Services and Growing the Market through Impact and increasing the Demand

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

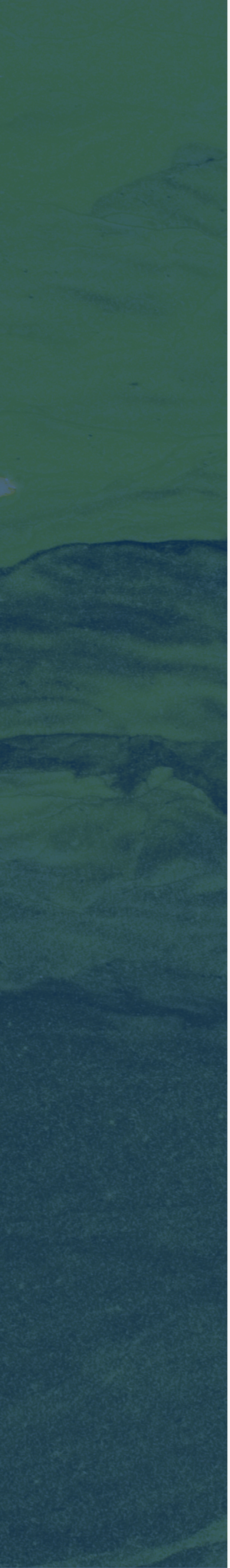

Table of Contents

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

Government has a Key Role in Setting Requirements: In the current situation, requirements and standards for HAB sensors, platforms, and services are often set case by case at a very specific or localized level, making it difficult for industry and academia to respond at scale. Despite the best efforts of all involved, this 'many to many' approach is not providing sufficient scale to attract the investment required. A government-led 'one to many' approach to HABs, with regulatory backing for integrated requirements, would aggregate demand and provide the economies of scale required to focus private sector and academic innovation.

2

Government has a Key Role in Setting Data Standards: Development of HAB services is being constrained by lack of access to data from disparate sources. Government is distinctively placed to set the standard for data to be findable, accessible, interoperable, and reusable (FAIR) [1] by default, through its roles as both a regulator and a facilitator of industry development. The Global Telecommunications System (GTS) for weather and climate observations provides a vision to aspire to, and the IOC-FAO Intergovernmental Panel on Harmful Algae Blooms (IPHAB) can support the development of FAIR data standards to help enable **such a vision.**

3

The Full Size of the HABs Market is currently Unknown: A significant issue is that the full size of the market for HAB downstream services is currently unknown, making it difficult for private sector innovators to develop investable business plans. Having some idea of the number of potential users, the range of potential applications, and the capacity of users to pay would allow potential return on investment to be evaluated. Experience in other markets shows that fantastic products and services can be developed if the market is of sufficient size, and anecdotal evidence suggests that aggregate demand in HABs (including avoided cost) is potentially high. Determining the size of the market for HAB downstream services is therefore considered to be a major opportunity. Developing the tools to determine the cost of a bloom is a related issue.

4

Startups can Create New Business and Licensing Models: Startups are considered to have a lot more flexibility in their business and licensing models, particularly with more and more data going to the cloud. This is promising for the future of the Ocean Enterprise as there will hopefully be many new companies established. Startups using cloud-enabled technologies can be very agile in structuring data and services in ways that work for their clients. Sensor and platform companies are now very focused telemetry systems and presentation of data, including analysis tools and data processing, in a simplified package, and they have ready access to the contemporary technologies required.

5

Integrating or 'Mainstreaming' HABs Into Environmental Monitoring: HAB monitoring programs can be expanded to include more variables for more users, noting that this comes at a higher cost and raises the question of 'who pays'. An alternative approach could be to think about integrating or 'mainstreaming' HAB monitoring into broader, existing, marine environmental observing and monitoring programs on an incremental cost basis, which may be more efficient. This can include both positive (presence) and negative (absence) indicators. The feasibility of scaling up such an approach will be dependent on issues discussed elsewhere, including lowering the cost per observation and making FAIR data the default position.

[1] FAIR Data: https://www.go-fair.org/fair-principles/

6

Workforce Shift between Specialist and Generalist Expertise: The generation of reliable and effective HAB data streams that meet user needs requires specialist expertise, especially in taxonomy and natural products\toxin chemistry experienced with algae. The combination of an aging expert scientific workforce, opportunities for skilled staff outside of traditional science, and rapid uptake of new technologies (including AI) suggests a shift in the balance between specialization and generalization in the future HAB workforce. There may be less traditional, specific expertise, and more general, problem agnostic expertise facilitating faster uptake of new technologies and approaches to the problem of HABs. Micro credentials and short courses will have a key role cross-fertilization of expertise at appropriate levels.

7

Sensor Technologies that can be Tuned: Thinking about HABs at a larger or regional scale means that sensors will need to be able to detect a wider range of HAB species. In response, the sensor developers can think about sensor technologies that can be tuned. For example, with a broadly based capability to measure spectral absorption of species, different sample processing methods could be triggered by detection of different species in an environmental sample processor. There could be a set of sensors that are common in their design but can respond to species of interest at the local level.

Dialogue 2 Description

The second HABs *Dialogues* brought together twenty-two 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 downstream service delivery (across public and private sectors); aggregation of the primary market and consideration of secondary markets; and workforce development. In preparation, the participants were provided with the HABs *Dialogues Background Paper* and the Use Case discussion guidance document (Appendix 2).

The *Dialogue* was moderated by Hans VanSumeren, Senior Director, Ocean Enterprise Initiative, Marine Technology Society. The Use Case was divided into three sections: (1) downstream service delivery – a hybrid solution?; (2) aggregation of the primary market, and consideration of secondary markets for data collected to increase demand for sensors and platforms; and (3) workforce development. Each section included a set of questions to help participants prepare for the Dialogue, which served as a base for the discussions. The discussion prompted participant feedback on operational, technical, and policy issues. This synthesis report presents comments on a non-attributional basis.

Invited experts joined from six countries. Sector representation was as follows: Private – 50%; Governmental/Intergovernmental – 36%; and Academic – 14%. In addition, approximately 74 observers from seven countries joined as observers who provided input mainly via chat. Hans VanSumeren 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 with the participants in an open question-and-answer session.

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

Discussion Synthesis

Section 1: Downstream Service Delivery - A Hybrid Solution?

The first section focused on downstream services and the roles public and private actors play in developing services. Embedded in those roles are significant challenges for both managing and integrating HAB data to produce useful downstream products. Given this 'hybrid' of public and private sector interests, there is a need to establish clear expectations to drive innovative approaches, enable new business models, and create better alignment with academic communities.

Where does the balance lie between the private and public sectors in driving market requirements? Are some functions inherently governmental and should others be left to the private sector?

The private sector has had a long history of success in driving the development of instrumentation for measuring the physical parameters in the marine and freshwater environment. Quality sensors are at the heart of this success, attached to a variety of platforms and connected to users through a variety of communication systems. Innovation is often undertaken in partnership with academic and government research institutions, and grants to catalyze early-stage collaboration make an important contribution. Technological advances in the next generation of ocean sensing[2] in the last two decades have led to new efforts to commercialize measurements of biological parameters. The role of the private sector in turning sensor data into actionable information is currently much less clear.

Provision of operational observation and forecasting systems for weather and oceans to protect life and support commerce is inherently a governmental function, as evidenced by the 193 Member States and Territories maintaining their own meteorological services under the World Meteorological Organisation (WMO) There are several documented global examples of HAB observing and warning\forecasting systems tailored to mitigate impacts of specific types of HABs on food safety and security, tourism-based coastal economies and public health.[3]

[2] Keeping Tabs on HABs: New Tools for Detecting, Monitoring, and Preventing Harmful Algal Blooms: https://ehp.niehs.nih.gov/doi/10.1289/ehp.122-A206
[3] NOAA Operational HAB Forecasts: https://coastalscience.noaa.gov/science-areas/habs/hab-forecasts/

However, generally governmental systems for environmental observation and forecasting are less well developed than global weather systems. Persistent governmental investment in sustaining regional and national ocean observation and forecasting systems to provide situational awareness remains a critical need.

Where operational, governmental, HAB forecasting systems do exist they are currently constrained by instrumentation and data issues. Available instruments are complex and expensive, and samples require laboratory analysis by skilled people. It was noted that HAB instrumentation is more advanced in freshwater systems, and there is an opportunity to leverage capability into marine systems with incremental investment. HAB data (e.g., cell counts) are difficult to organize in an operational context compared with other environmental data, e.g., physical data for weather and climate.

Two key roles for government emerged through this discussion. Firstly, in setting requirements for sensors, platforms, and services to which industry and academia can respond. Secondly, setting standards for data to be findable, accessible, interoperable, and reusable (FAIR).

It is important to note that this is not a call for government to 'do everything' using public funding. Rather it is a call for government to show leadership in aggregating demand and setting integrated requirements and data standards, thereby creating an environment conducive to private sector and academic innovation.

In the current situation, requirements and standards for HAB sensors, platforms, and services are being set case by case, at too low a level. Despite the best efforts of all involved, this 'many to many' approach is not providing sufficient scale to attract the investment required. Examples of current activities discussed largely focused on the human health impacts of HABs with tourism and fisheries (both wild and farmed) benefiting from investment in services dependent upon HAB data. Shellfish aquaculture efforts are largely undertaken by small businesses and are highly regulated. The financial impact of HABs on fish farming can be significant but are infrequent at farm level where the issues manifest and are managed, further entrenching a fragmented approach. Impacts of HABs on other valuable industries such as coastal tourism and water provision (including through desalination) have been documented in each sector but are not currently considered in an integrated fashion, making it difficult to describe a larger market. These and other impacted industries may have capacity to invest but it is currently challenging for them to engage with the issue of HABs at an Ocean Enterprise level.

A government-led 'one to many' approach to HABs, with regulatory backing for integrated requirements and data standards, would aggregate demand and provide the economies of scale required to focus private sector and academic innovation. This is particularly significant for developers of marine environmental sensing and platform capabilities that have broad applicability (e.g., image analysis, uncrewed surface vehicles) as it would help to determine if HABs provide a use case worthy of investment.

Governmental systems may best provide core data generation and downstream services that meet some user needs. Government-led standards can also unlock the strengths of the private sector, but the private sector is more agile and capable of creating derived products and applications to meet the needs of specific user groups with distinct user requirements.

The current constraints on operational, governmental, and HAB forecasting systems noted above also prevent accelerating the development of value-added products and services in the private sector. The effect is a double whammy.

A related issue is the growth in data collected by the private sector that is not publicly available and therefore cannot be used to improve core services or valued added products. Metocean and seabed data collected by the offshore wind industry was noted as an example. Governments could provide a regulatory environment that required such data to be FAIR.

Arguing for greater government leadership in setting requirements and data standards should not be seen as 'one size fits all' because the global impacts of HABs manifest differentially at local and regional scales. Shellfish industry participants pointed out that toxicity, not HABs, is the issue they are most concerned about. An example was also provided from the Gulf of Maine where spatial and temporal measurements of shellfish toxicity are sufficient to enable a reliable, multi-week forecast using neural network analysis. Such approaches could be applied elsewhere as appropriate without the need for additional, top-down definition of requirements and standards. They will not, however, translate to many other industries, places, and environments. The key point is that overcoming current fragmentation requires federation of requirements and standards, not centralization.

Can the needs of the insurance and financial sectors also drive market demand?

An additional thread was opened around the needs of the insurance and financial sectors.

Fish farming insurance is a global market, though one significant event can wipe out the premium pool for a year. This makes HAB losses difficult to predict from an actuarial perspective. It was noted that Governments incur substantial losses from HAB events through lost taxation revenue, unemployment benefits etc. These losses cannot be insured, so governments have a financial incentive to minimize HAB events/impacts on fish farming, and other potentially impacted sectors (i.e., the "avoided costs" argument). It was also noted that the fish farming insurance sector (i.e. four of the biggest insurers) employed HAB monitoring for 20 years to understand and model the risks of HAB-related loss, but that the program was not sustained as it was not cost effective to the sector.

Innovative approaches that are currently being developed to finance climate resilience could provide guidance on how to deal with the complex problem of HABs.

How do we better catalyze research and innovation to advance market opportunities for downstream services? Are there specific approaches that are most helpful in creating and enabling conditions for growth?

The important role of government grants to catalyze early-stage collaboration between private industry and academic and government research institutions was again highlighted. It was noted, however, that such grants can be relatively short term and end before products and services are fully market ready. Greater use of blended finance approaches could help to mitigate this risk, with potential investors being engaged at an earlier stage to maximize the chances that small-to-medium enterprises (SMEs) can deliver their innovations to the market.

A significant issue is that the full size of the market for HAB downstream services is currently unknown, making it difficult for private sector innovators to develop business plans that attract investors. Having some idea of the number of potential users, the range of potential applications, and the capacity of users to pay would allow evaluation of the potential return on investment. Experience in other markets shows that fantastic products and services can be developed if the market size is sufficient, and a small but growing body of published HAB socio-economic impact studies[4] including those being compiled and visualized by the U.S. National Office for Harmful Algae and recent international reports[5] that show that while the aggregate trend in HABs may vary globally by nation or region, some areas (e.g., the United States) have seen a significant increase in HAB events over the last 30 years[6]. Other international reports show increasing national and regional interest in solutions to avoid frequent and often devastating social impacts and private sectors costs associated with HABs. Determining the size of the market for HAB downstream services is therefore considered to be a major opportunity.

Growing awareness of the potential human health impacts of aerosolized toxins from HABs was identified as an opportunity. This is an emerging issue in some heavily populated regions (e.g., Florida, USA) and the prevention of widespread, negative human health impacts is a high priority for civil society. Thinking more holistically about the market for HAB downstream services may engage other actors and stimulate growth and investment.

On the theme of thinking more holistically, it was noted that there are many potential anthropogenic drivers of HABs, including erosion and runoff from agricultural lands, wastewater discharge, deforestation, point sources of industrial pollution, urban runoff, hydrological alterations such as dams and canals, ballast water discharge etc. Many other private sector industries (beyond shellfish aquaculture and fish farming) are therefore relevant to the issue of HABs, and considering their needs in complying with government regulation or meeting corporate sustainability goals further expands the potential market for downstream services.

Are there different business models and licensing models that we need to consider?

Downstream HAB services provided by the consulting industry are typically in response to a Request For Proposal (RFP). Clients are often single entities with their own terms and conditions and views about restriction of access to data and products. This business model is at odds with the approach of data or software as a service. Moving to a model of end user license agreements may provide a way forward, and there may be things to learn from the experience of developing open-source licenses in the software industry.

One interesting development noted was the emergence of agreements which place restrictions on the use of data to train Artificial Intelligence (AI). This will be an issue to watch for HAB downstream services developed using data from multiple sources.

Startups are considered to have a lot more flexibility in their business and licensing models, particularly with more and more data going to the cloud. This is promising for the future of the Ocean Enterprise as there will hopefully be many new companies established. Startups using cloud-enabled technologies can be very agile in structuring data and services in ways that work for their clients. Sensor and platform companies are now very focused on telemetry systems and presentation of data, including analysis tools and data processing, in a simplified package, and they have ready access to the contemporary technologies required.

[4] U.S. National Office for Harmful Algal Blooms Socio-economic Impact Reports: https://hab.whoi.edu/impacts/impacts-socioeconomic/

[5] IOC-FAO Intergovernmental Panel on Harmful Algae Blooms (IPHAB)Website: https://hab.ioc-unesco.org/

[6] Global Harmful Algal Bloom: Status Report 2021: https://unesdoc.unesco.org/ark:/48223/pf0000378691

The discussion also touched on the business model for providing testing and diagnostic services. In many places these services are provided by government laboratories, perhaps more so in the marine environment than in terrestrial environments. There may be scope for the private sector to play a greater role in HAB testing and diagnostic services. Impediments may include differences in toxin regulations between various toxins/exposure pathways, and differences in the existence/non-existence of standardized methods.

Section 2: Aggregation of the primary market, and consideration of secondary markets for data collected to increase demand for sensors and platforms

The second section focused on aggregation of demand, including what the markets are, what the products are, how mature those products are, who they are serving, and how often. Consideration was given to how these variables, in combination, could move the demand needle and gain traction towards a broader understanding of market drivers.

How will HAB sensors need to change to become more attractive to industry users? Would more seamless integration of HAB sensors with contextual physical and chemical variables be desirable?

Advances in HAB sensors and platforms include the Imaging FlowCytobot (IFCB) developed by scientists at Woods Hole Oceanographic Institute (WHOI), manufactured by McLane Labs, and in use by academic institutions and government agencies across the USA, UK, and Europe (based on participant comments). There remains a lot of upside potential in developing onboard processing for such instruments to go from automated image collection to species identification.

A consistent tripping point for internet-of-things (IOT) sensors like the IFCB continues to be making the data available. Ideally, such data would be FAIR by default and there would be a standardized way to access and use the data. The Global Telecommunications System (GTS) for weather and climate observations provides a vision to aspire to.

The cost of such instruments remains a barrier to widespread uptake by HAB-exposed industries such as shellfish aquaculture. While some aquaculture businesses have invested in IFCBs, widespread deployment at the farm site level is currently unaffordable. Progress could be made by scaling up to a regional (vs. site) view, such as a marine farm planning zone, and pooling resources to strategically supply instruments in a region for the benefit of all. Pooling resources across individual enterprises to buy equipment that can be shared is another variation on that theme. Driving down the cost per observation does however need to remain a priority for private sector developers and their academic partners. There is demand for instrumentation that is affordable at farm site level, including to undertake 'lot testing' on a farm rather than waiting for toxin test results from government laboratories.

Nitrate sensors are starting to be used to track nutrients in a HABs context. HABs can flourish in environments where both marine and terrestrial nutrients are present, adding complexity. Thinking about tracking nutrients from terrestrial systems through estuaries and into the ocean may be one way to think about integration and scaling up to engage other industry users.

Integration of HAB sensors with physical and chemical variables was mostly discussed in the context of improving HAB forecasting systems. In some cases (e.g., Gulf of Maine shellfish toxins) the inclusion of additional environmental variables has not improved forecasting due to local conditions and availability of relevant measurements. In other cases (e.g., shellfish safety on the west coast of Scotland) integration of multiple variables has improved forecast skill.

In discussing modelling, we need to understand that there are different types of models for different purposes. For example, in addition to forecasting models, mechanistic models are used to understand the causality of blooms and source attribution/relative influence natural and human derived nutrients versus (say) climate change. This has implications for the type of data collected and how data are used. Another opportunity for integration and engagement of additional users is to think about other applications for models used for HABs. For example, Lagrangian models used to track HABs can also be used to track oil spills.

One theme running through the discussion was that 'measuring everything everywhere all the time' makes ocean observing and monitoring programs prohibitively expensive and is unnecessary for many applications. Perhaps it will be more productive to think about all the different reasons why users observe and monitor marine environments (e.g., water quality, carbon cycling etc.,) and consider how to bring HABs in scope where appropriate. Rather than trying to expand HAB monitoring programs to include more variables for more users at higher cost, perhaps we need to think about 'mainstreaming' HABs in marine environmental observing and monitoring programs. This can include both positive (presence) and negative (absence) indicators. The feasibility of scaling up such an approach will be dependent on issues discussed elsewhere, including lowering the cost per observation and making FAIR data the default position.

Can demand from key industry sectors (e.g., salmon, shellfish, power stations, desalination) that already benefit from HAB management services be aggregated with other sectors to communicate a greater market need? How so?

One way to aggregate demand is to start with a regional perspective, where the focus is on multiple users of the marine environment with some common needs, then drill down to sector specific needs at finer scales as required. Common services meeting common needs have a broader base of users to draw on for support, and, at least in theory, downscaling to sector specific needs can be done more effectively and efficiently if built on top of a well-supported regional platform. In this context, it was noted that plankton are an important indicator of ecosystem health and that HABs come from a certain type of phytoplankton. Thus, broader plankton monitoring efforts at the regional scale could be informative for targeted HAB monitoring efforts at the site scale as indicated by regional data and site-specific user needs.

The role of the public sector in integrating industry needs was again emphasized. The role of the Crown Estate in development of the UK offshore wind industry was cited as a contemporary example.

Heterogeneity of industry sectors was again raised as a key challenge in aggregating demand. Tourism and recreation are huge sectors compared with shellfish aquaculture, but they have very different needs and very different business and cost models.

The importance of defining and valuing the total addressable market for HABs was again discussed as a threshold issue. As part of this discussion, it was noted that we do not currently have the tools to determine the cost of a HAB event. Developing the required tools is a priority.

Section 3: Workforce Development

The third section focused on the development of a workforce to support growth in the market for HABs sensors, platforms, data, and downstream services. As ocean observing activities are rapidly growing, a companion growth is required in a comprehensive workforce to support these efforts as needed. It includes technicians and engineers, scientists including taxonomists, natural product chemicals, and ecologists experienced with marine and freshwater algae, and business development experts. The needs are far from being met. There are not enough new people entering these fields, and there is competing interest in many of the skills required. New strategies are needed to ensure competencies are successfully integrated into career paths that are attractive to talent.

There is concern over a diminishing workforce, particularly in just classic taxonomy skills needed for HAB detection and monitoring. What needs to be done to overcome that challenge and what role does AI and machine learning play in addressing that gap?

Environmental science and management (including HABs) now relies heavily on software engineering expertise, which is in high demand in other sectors that often pay higher salaries.
One approach is to build 'blended' software engineering teams combining environmental scientists who have an interest in learning software engineering with classically trained software engineers. Such teams have people that understand the core environmental problems and have an interest in software engineering as well as true software engineers and computer science majors who bring in the best practices needed to develop operational software.

Other participants noted that a 'blended team' approach can be applied in taxonomy as well. Technicians or fish farm workers can be trained in basic taxonomy skills to identify common species and lighten the load on taxonomic experts.

AI is presenting new workforce development challenges. Early career workers who have grown up with AI can potentially bring new thinking on how it can address gaps in workforce development. In the medium-to-long term there may be fewer experts needed as AI models are trained, though we are currently a long way off having such models in place. Trained taxonomists will remain important. Supporting them to learn how to use modern technologies such as autonomous vehicles, genetic tools, and image analysis keeps their jobs interesting and potentially entices other people to work in this field.

Taken together, these points suggest a shift in the balance between specialization and generalization in the future HAB workforce, with less traditional. specific expertise, and more general, problem agnostic expertise facilitating faster uptake of new technologies and approaches to the problem of HABs. The combination of autonomous image capture and AI-assisted image analysis is seen as particularly exciting, noting that it will rely on data being FAIR.

The importance of developing standards for use of AI was emphasized, from the perspective of users and investors having sufficient trust and confidence in the products and services to rely on them, thereby allowing capital to flow in their direction. It’s not just about training AI but also validating it as well.

Is there a place for micro credentials or short courses? Are there approaches already in use at small scale that could be scaled up, or new approaches that could be developed to upskill the current workforce or attract people from other spaces to become part of a HAB workforce?

Flowing from the previous discussion about growth in general expertise, micro credentials/short courses were seen as having a very useful role in providing certification of different levels of specific expertise. For example, software engineers or GIS experts could be certified at a low-to-moderate level for HAB species identification. Industry workers (e.g., from fish farms) are another target audience. Staff turnover can be quite high, creating a need for ongoing training, and upskilling improves career prospects. Online delivery methods need to be considered for remote workers, or for industry employees without support to travel for training.

The academic sector noted that development of micro credentials and short courses is quite different from the development of an academic curriculum, as the target audiences are very different. It can’t just be assumed that the academic sector will fill this gap. This is a potential opportunity for appropriately qualified organizations (academic or other).

What partnerships are needed with First Nations and indigenous peoples to enhance HAB monitoring and research so it's sustainable, meaningful, and integrated?

No participants identified as First Nations or indigenous peoples during the discussion.

Partnerships with First Nations and indigenous peoples are seen as being of high value to HAB monitoring and research where the context is appropriate. It is important not to generalize. For non-indigenous academics, agencies, and businesses, early and ongoing engagement is essential, as is listening and learning. Incorporating traditional and indigenous ecological knowledge with respect to HABs and related food safety and security impacts is requisite for successful partnerships at the local and regional level.

Can citizen science be useful for HAB detection and monitoring? What additional technologies and training need to be in place, including health and safety? Could AI support greater utility of data from citizen science?

Citizen science is being successfully used to support HAB-exposed seafood industries. Examples given included phytoplankton monitoring to provide surveillance and alerts for the shellfish aquaculture industry, and oceanographic sampling for the salmon farming industry.

Citizen volunteers are also involved in red tide (Karenia brevis) monitoring in Florida, USA using a “HABScope” to generate data supporting the Red Tide Respiratory Forecast. Basic identification of K. brevis can be accomplished using a computer device (tablet) and the approach is very promising, including through use of AI to take it further.

Caution was expressed by the academic sector in relying on citizens to go beyond sample collection and into identification, with expert-trained AI considered to be a more reliable and objective approach.

Open Session

The last session provided an opportunity for open dialogue including both the panelists and the observers. The issues discussed are as follows:

Understanding **how to aggregate demand** for HAB data, products, and services is a big issue, and should be thought about as a 'research project'. It will take time to gather the information required, have the right conversations with key people, and iterate to a product that has wide acceptance and support. The importance of doing this properly should not be underestimated.

Building trust between different actors who are not used to working together is a related issue. Memorandums Of Understanding (MOUs) provide one way of gaining high level agreement and providing clarity. Navigating potential tension between public access to data and non-disclosure due to commercial sensitivity will be a challenge to address.

Potential interaction with the **offshore wind sector** was mentioned several times during the dialogue. It was noted that this sector has significant engineering requirements and will be loath to include additional sensing capabilities if they are not designed in from the outset. Some coastal communities are concerned about the potential impacts of offshore wind development, and where monitoring programs are implemented to address concerns there may be opportunities to include HAB monitoring.

Thinking about HABs at a larger or regional scale means that sensors will need to be able to detect a wider range of HAB species. In response, the sensor developers can think about **sensor technologies that can be tuned**. For example, with a broadly based capability to measure spectral absorption of species, different sample processing methods could be triggered by detection of different species in an environmental sample processor. There could be a set of sensors that are common in their design but can respond to specific species of interest at the local level.

For governments to play a stronger role in aggregating demand for HAB services we need to consider whether **working across local, state, and national levels of government** will be a potential barrier. It was noted that particularly severe HAB events can help to both identify and overcome barriers because there are shared demands and an urgent need. Learning from such events is therefore an opportunity. Planning for future responses is being undertaken via desktop exercises involving state and national levels of government, and industry could be further integrated in these. Thinking about where the levels of government naturally intersect, such as in estuaries, is another consideration. species, different sample processing methods could be triggered by detection of different species in an environmental sample processor. There could be a set of sensors that are common in their design but can respond to specific species of interest at the local level.

Greater top-down direction in setting requirements and data standards was again discussed. The European Union (EU) has some capacity to influence its member states, including through investment in European Research Infrastructure Consortiums (ERICs). The Intergovernmental Oceanographic Commission (IOC) and the Global Ocean Observing System (GOOS) provide other mechanisms at the global level.

Potential Pathways Forward

This is the second of three *Dialogues with Industry* on HABs. Below is an initial take on the key issues and potential pathways forward drawn from the second 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.

- **Grants to catalyze early-stage collaboration between private sector innovators and academic and government research institutions:** The private sector has been very successful in driving the development of instrumentation for measuring the marine and freshwater environment. There is, however, significant upside potential yet to be realized in HABs. Quality sensors are at the heart of this success, attached to a variety of platforms and connected to users through a variety of communication systems. Innovation is often undertaken in partnership with academic and government research institutions, and grants to catalyze early-stage collaboration make an important contribution.

- **Greater use of blended finance approaches:** Notwithstanding the important role of government grants to catalyze early-stage collaboration between private industry and academic and government research institutions, such grants can be relatively short term and end before products and services are fully market ready. Greater use of blended finance approaches could help to mitigate this risk, with potential investors being engaged at an earlier stage to maximize the chances that small-to-medium enterprises (SMEs) can deliver their innovations to market.

- **Greater use of end user licensing agreements:** Downstream HAB services provided by the consulting industry are typically in response to a Request For Proposal (RFP). Clients are often single entities with their own terms and conditions and views about restriction of access to data and products. This business model is at odds with the approach of data or software as a service. Moving to a model of end user license agreements may provide a way forward, and there may be things to learn from the experience of developing open-source licenses in the software industry.

- **Using severe events to better plan for the future:** For governments to play a stronger role in aggregating demand for HAB services we need to consider whether working across local, state, and national levels of government will be a potential barrier. It was noted that particularly severe HAB events can help to both identify and overcome barriers because there are shared demands and an urgent need. Learning from such events is therefore an opportunity. Planning for future responses is being undertaken via desktop exercises involving state and national levels of government, and Industry could be further integrated in these. Examples include the Harmful Algal Bloom (HAB) Preparedness & Response Workshop (2021) and Great Lakes HAB Communication Preparedness Workshop (2023).

- **Persistent governmental investment in developing regional and national environmental observation and forecasting systems to provide situational awareness:** Provision of operational observation and forecasting systems for weather and oceans is inherently a governmental function. Governmental systems for environmental observation and forecasting are, however, less well developed in general, including for HABs. Persistent governmental investment in developing regional and national environmental observation and forecasting systems to provide situational awareness will remain a critical need. The core services provided by governmental systems can meet some user needs, but the private sector is more agile and capable of creating derived products and applications to meet the needs of specific user groups with specific user requirements. Constraints on operational, governmental, HAB forecasting systems are therefore also a brake on accelerating private sector development of value-added products and services. The effect is a double whammy.

- **Complete Market Research to Define Regional, National, and International Markets for Downstream HAB Services:** Such efforts should also help identify potential new users who could benefit from data on HABs and other ocean stressors. Advances being made by socio-economic research programs (e.g., NCCOS SEAHAB Program) by supporting partnerships with technology transfer and accelerator and business development programs focused on advancing the Blue Economy.

- **Sustain and Grow Collaborations to Address the Workforce Needs of HAB Observing and Forecasting Systems:** Capitalize on and create partnerships between existing groups like IPHAB, MTS and national HAB focused government, academic, and private sector groups and communities of practice (e.g., IOSSA NHABON or industry user groups like McLane Labs IFCB User Group) to build support for strategic workforce investments needed to tackle Harmful Algal Blooms and other pressing and complex ocean-based challenges. Partner could cross-promote job opportunities, workforce development\networking workshops, related national and international conferences (e.g., ICHA 2025), trainings such as micro-credential, short-courses and in-depth training opportunities (e.g., IOC HAB Training Courses).

Appendix 1: Participants

Sector	Affiliation	Name
Public/USA	National Oceanic and Atmospheric Administration (NOAA)	Richard Stumpf
Public/USA	United States Geological Survey (USGS)	Jennifer Graham
Public/EU	European Union	Antonio Guarnieri
Public/UK	Department for Environment Food and Rural Affairs (DEFRA)	Rohan Allen
Public/Scotland	Scottish Association for Marine Science (SAMS)	Keith Davidson
Public/Ireland	Irish Marine Institute	Caroline Cusack
State/Agency	Florida Fish and Wildlife Research Institute	Katherine “Kate” Hubbard
State/Agency	Southern California Coastal Water Research Project Authority (SCCWRP)	Jayme Smith
International Data	Woods Hole Oceanographic Institution (WHOI)	Mike Brosnahan
Industry/NGO	AXA XL	Geir Myre
Industry/NGO	Bigelow Laboratory	Steve Archer
Industry/NGO	Maine Aquaculture Association	Chris David
Industry	Aqua RealTime	Chris Lee
Industry	Sea Sats	Neil Trenaman
Industry	Sea-Bird Scientific	Eric Rehm
Industry	Taylor Shellfish	Bill Dewey
Industry	Pacific Salmon Foundation	Svetlana Esenkulova
Industry	RPS, A Tetra Tech Company	Kelly Knee
Economist/Finance	J.P. Morgan	Sarah Kapnick
Economist/Finance	Boundary Stone Partners	Jennifer Garson
Academia	University of Washington	Vera Trainer
Academia	Sorbonne Université	Jean-Olivier Irisson

Appendix 2: Use Case

Dialogues with Industry - Harmful Algal Blooms

Use Case for Dialogue 2: User-Driven Ocean Information: Downstream Services - Public/Private Partnership and Workforce Development

January 28, 2025

Introduction

There is 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 2.

Background and Scope

There are a growing number of companies conducting and overseeing ocean observations and furnishing associated products and services. To meet increasing demands from multiple user communities who require a wide range of services/decision tools, we need more robust engagement across sectors. Making well-informed decisions will rely on sophisticated data products and services from information and collaboration by the public, private, and academic sectors. Minimizing friction between contributors in the ocean observing value chain[7] can provide more streamlined opportunities for increased access to ocean information and the development of more tailored and actionable products and services.

[7] Adapted from the economics concept, to describe a framework for organizing the ocean observing system into a series of subsystems each adding value with inputs, transformation procedures, and outputs, in a continual and iterative process.

The United States and Canada Ocean Enterprise studies identify downstream services as "Intermediaries." Intermediaries make use of ocean, coastal, and lake measurements, observations, and model data as inputs to create value-added information products for end-users. These Ocean Enterprise studies, along with work from the Organisation for Economic Co-Operation and Development (OECD)[8], document Blue Economy growth in areas where new information-based services are emerging.

The Ocean Enterprise studies reveal that there are relatively few businesses in this space, yet many opportunities, such as commercial consultancy services that provide services in modeling and analyzing observations to answer specific questions for private companies, for example in the oil, gas, renewable energy, port, desalination, and nuclear sectors. Other companies offer prediction and observation aggregation services to specific sectors, for example, routing services for shipping and situation room services to maritime search and rescue services. Dialogue 2 focuses early warning and forecasting and there are many private labs, especially in the freshwater "space" that are providing HAB data services (e.g., testing cyanotoxin levels in water). In the marine area, Bigelow Analytical Services (at Bigelow Laboratory for Ocean Sciences) offers 'fee-for- service' analysis of toxin levels in shellfish (e.g., for Maine Dept. of Marine Resources and some aquaculture operations).

A fundamental concept to successfully shifting to a user/intermediary-focused system is co-design. Co-design involves close coordination and collaboration among stakeholder groups, including downstream service providers, to bridge gaps between system design, product and service delivery, and data consumption. The aim is to create a more integrated and agile observing system that directly responds to user and service provider needs. Moving to a multi-sectoral ocean observing architecture (as considered in the *Dialogue* 1 Use Case) requires technical, cultural, and financial shifts that will directly and indirectly affect the availability and usability of data and information services being provided. Cultural issues stem from the reluctance of national/government agencies to cede control of data that they have previously collected. There are concerns about how this shift will impact academic and intergovernmental agreements. There is, however, growing recognition that funding for future ocean observing systems, platforms, data, and information is increasingly coming from outside of the government with blue venture capital and philanthropic organizations having greater roles.

Dialogues Outcome

The goal of the Dialogues is an awareness of where the global community is going in regard to 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 mitigating HAB impacts through the monitoring, forecasting, and control of HAB occurrences, across the public, private and academic sectors.

Format of the Dialogue 2

Dialogue 2 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 understanding downstream service delivery; aggregation of the primary market and understanding of the secondary market; and workforce development.

[8] OECD (2016), The Ocean Economy in 2030, OECD Publishing, Paris, https://doi.org/10.1787/9789264251724-en

The moderator 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. During the last 30 minutes, the observers will be invited to join the discussion.

Section 1 - Downstream Service Delivery - A Hybrid Solution?

As the demand from decision makers for HAB ocean observing products and services increases, there is an opportunity for growth in downstream service delivery. Currently many of the observing networks are funded and operated by government and public agencies. It is envisioned in the future that these networks will be a combination of public and private sensors, platforms, and services which we are using the word hybrid to describe. As we do not know the form this will take, the term is not further defined. It is not abundantly clear that ocean observing data is currently being maximized by or meeting the practical needs of end users in terms of accessibility, timeliness, and even content. When all sectors gain a better understanding of the role that industry can play in downstream service delivery and address the existing barriers to the expansion of that role, the ocean observing sector as a whole sector will see greater success.

Data and information availability and usability are key to driving value and achieving the greatest return on investment. Through co-design concepts, the Ocean Enterprise can address the growing demands for ocean information more efficiently and with a genuine understanding of user/intermediary needs. Recognizing which services can be commercially viable will depend in part on being able to articulate their impact. Increased services will translate to an increased use of the data. This will provide a better return on investment, and value will accrue if the data is used multiple times.

There are significant challenges managing and integrating HAB data and ancillary monitoring information to produce useful downstream early warning or forecasting products. HAB data is generated by many different entities including government agencies, academia, and HAB impacted industries. There is also a diversity of harmful species, toxins, and impacted resources. This translates into a lack of uniformity or standardization in data type or format. These issues pose a challenge to the integration, analysis, and interpretation of HAB data and to the timely generation of information that can readily be useful to resource managers, business owners, and the public. Understanding the market for potential commercial solutions to these data challenges could enable new public/private partnerships.

The purchase of commercial ocean data is rapidly evolving as is the public sector's understanding of how to make these purchases both effectively and efficiently. To deliver informed services and decisions, it will be necessary to draw upon the resources of the public and private sector. In many instances it will be necessary to combine data from the public sustained ocean observing networks, data collected by the public or private sector ('citizen science'), and commercial data licensed by the public sector and other third parties. The commercial sector is also interested in developing and licensing derived products and analysis using these data sources. It will be useful to understand licensing and data sharing models that are mutually beneficial to the government (national) sector and commercial sector.

Discussion Topics

1. What role does industry play in developing and distributing decision making tools as a downstream service? What are the current, leading-edge, best-of-breed examples of downstream services, and what can we learn from these?

2. How do we better catalyze research and innovation to advance market opportunities for downstream services? Are there specific approaches that are most helpful in creating these enabling conditions for growth?

3. 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? What fora are available for discussing and agreeing on roles and responsibilities? How can agreed requirements be made visible/communicated.

4. How are the companies thinking regarding licensing? For example, in the remote sensing sector the government has moved towards End User Licensing Agreements. How does this translate to mission/data as a service that is being evaluated by some of the ocean companies?

   a. What type of licenses exist and how do they handle data sharing restrictions?

   b. Given the take once/use many current data principles what models for licensing from other sectors or in ocean observing are closest to this principle?

   c. Is upholding this take once/use many principle realistic with commercial providers, should we adopt a different/mixed model?

5. What are the risks for the Public sector in moving towards hybrid architecture (e.g., calibration, business failure)? In a future where more HAB management services are commercially delivered, what might we need to maintain or create to ensure that academic users (vital for knowledge creation) are still considered important in setting requirements (e.g., for observing systems)?

Section II - Aggregation of the primary market, and consideration of secondary markets for data collected to increase demand for sensors and platforms

Whereas the impacts of HABs have increased, and demand for this information is growing, there needs to be a clearer understanding of current and future market drivers (e.g., insurance, real estate pricing, and testing mandates). Further, there needs to be a deeper knowledge of who is using the information collected by the sensors and whether there are public or private buyers for these sensors. The "buyers" may require a subsidization for these instruments.

Monitoring for HAB outbreaks should not be done in isolation. For the market sector to grow, the concept of leveraging and multi-use approaches is fundamental. This is important to facilitate the leveraging of assets that are in place and to effectively plan uncrewed vehicle missions, as well as for public and industry sectors outside of the HAB community to use HAB observational data and information derived from those assets to improve their decisions. For example, in the public sector, HAB data also informs hypoxia forecasting, in tagging fish, on stock assessments for some commercial fisheries[9], and understanding their behavior. In the private sector, the fishing

[9] "Enhancing single-species stock assessments with diverse ecosystem perspectives: a case study for Gulf of Mexico red grouper (Epinephelus morio) and red tides", Canadian Journal of Fisheries and Aquatic Sciences, 3 March 2021: https://doi.org/10.1139/cjfas-2020-0257

community can use the information to understand fish locations, to meet insurance requirements, or to determine efficiencies in fish feeding. The multi-use concept also extends to the sensors and instruments themselves, since a technology intrinsically capable of detecting or measuring multiple targets provides a company with increased flexibility in responding to changing market demands. Specifically, developing a device or platform designed to meet certain operational requirements (e.g., rapid, cost-effective, easy-to-use), yet able to detect not only HAB species/toxins but also pathogens, environmental contaminants, water quality indicators, etc. by simply switching recognition elements employed (e.g., antibodies, probes) or using a different 'kit', yields a fit-for-purpose technology simultaneously suitable for different markets.

The total available market (TAM) is a key driver of the available funding and therefore impacts the quality of the services provided, the workforce available, etc.

Discussion Topics

1. Currently, the demand for HAB knowledge and information comes from the government/Public sector. How can we harness the needs for technological innovation and improved biodiversity outcomes to grow the demand for information from the Private sector as well as Public sector?

2. Do we understand the TAM for HABs? If not, how do we collect the information we need to understand TAM?

3. Can demand from key industry sectors (e.g., salmon, shellfish, power stations, desalination) that already benefit from HAB management services be aggregated with other sectors to communicate a greater market need? How so?

4. Are finance and insurance requirements potential drivers of future demand?

5. How will HAB sensors need to change to become more attractive to industry users e.g., shellfish aquaculture, salmon farming? Would more seamless integration of HAB sensors with those for contextual physical/chemical variables be desirable?

6. Are there markets for use of HAB data beyond the HAB community? If so, how do we identify and engage those market sectors?

Section III - Workforce Development

Growth in observing system assets to address the expected increasing demand for HAB information is going to require a corresponding growth in the human capital needed to create, operate, and maintain the technologies we will require in the future. This community needs a diverse pool of talent that can translate their skills to produce instruments, platforms, data management, model development, and decision support tools for HAB monitoring systems. The community is competing for talent and has the additional constraint that salaries are not at the level of other sectors. The workforce needs to span skill levels from technician to PhD scientists. One element of expanding the workforce is adopting a start-up mentality that is intriguing and will attract folks to this community, but for this to be successful, there must be a clearly defined market.

Discussion Topics

1. There is concern over a diminishing workforce, particularly in the classic taxonomy skills needed for HAB detection/monitoring. What needs to be done to overcome this challenge? Is there a role for AI?

2. Significant growth in the development of end-to-end solutions will require a corresponding growth in human capital to create, operate, and maintain the technology and systems that will be needed in the future. How do we hire and train the necessary talent, particularly software, mechanical, and electrical engineers, when competing against established industry players in other sectors that also need this type of talent?

3. Is there a need for focused education and training to better engage students/young professionals to work in HAB monitoring/forecasting? What types of material might need to be generated to increase interest?

4. Is there a place for micro-credentials? Are there types of micro-credentials being envisioned that could also help develop and enable the HAB workforce?

5. Citizen science is being used in HAB detection and monitoring. What additional technologies and training need to be in place (including health and safety)? Can AI be used to support greater utility of data from citizen science?

6. How can partnerships with First Nations enhance HAB monitoring and research, and what steps can be taken to support meaningful involvement and integration of Indigenous knowledge into these efforts?

Areas for Recommendations/Outcomes

The goal of the Dialogues is to come up with actionable recommendations e.g.,

- Cultural barriers to a multi-sectoral ocean observing architecture can be lowered by .....

- A finite set of licensing schema for commercial data with uplift options will make it easier for the inclusion of commercial data streams and for data systems to support .....

- Impacts of moving to the commercial ocean observing data streams to the academic sector can be minimized by .....

- Evolution in business models such as ..... can accelerate a hybrid architecture

- The investment sector can play a role by .....

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.

Sector	Affiliation	Name
Public/USA	NOAA (NCCOS)	Felix Martinez
Public/USA	NOAA National Centers for Coastal Ocean Sciences (NCCOS)	Marc Suddleson
Public/USA	NOAA (NCCOS)	Greg Doucette
Public/USA	NOAA (United States Integrated Ocean Observing System (IOOS))	Tiffany Vance
Public/USA	NOAA (IOOS)	Laura Brenskelle
Public/Intergovernmental	NOAA (NCCOS)/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

OCEAN ENTERPRISE INITIATIVE

Dialogues with Industry

Harmful Algal Blooms (HABs) Dialogue 2 Report Out

User-Driven Ocean Information:
Downstream Services and Growing the Market through Impact and increasing the Demand

For bibliographical purposes, this publication should be cited as follows:

Dialogues with Industry - HABs (Harmful Algal Blooms) Dialogue 2 Report Out (Report no. MTS-202503)

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