OCEAN ENTERPRISE INITIATIVE

Dialogues with Industry

Harmful Algal Blooms (HABs) Dialogue 3 Report Out

Advancing Control Technologies

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.

5 Key Takeaways

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

1

Education and Outreach for Control Methodologies needed to Change Perception: Control methods must be environmentally friendly and sustainable. There is negative perception associated with most control methodologies, particularly those involving 'chemical' control like that associated with pesticides.

2

There is a Disconnect between the Drivers and the Push for Implementation: While drivers across the aquaculture, tourism, desalination, and nuclear sectors were identified, the push for control technology implementation has not been realized. Factors contributing to the lack of implementation include: (1) lack of market analysis for control compared to response, (2) lack of budgets within local and regional governments, (3) lack of understanding of available control methodologies, and how and when to best employ them. There is a need to monitor before, during, and after a control effort. Support for HAB monitoring\observing is critical for successful development and testing of the safety and effectives of HAB control methods.

3

Permitting is a Big Obstacle for Commercialization: The lack of consensus across jurisdictions on the requirements to achieve permitting approval is a major issue for industry and academia working regionally, nationally, and globally. Even when a particular method has been proven effective in a test case, it is difficult to get approval for larger scale demonstration of the technology. The mentality is understandably risk averse – "do no harm," but as a result a method needs to be 100% proven before a testing permit is issued. Yet there is no consideration for the fact that without any control methods, HABs will continue to cause serious environmental problems, direct impacts on aquatic organisms, and great economic losses.

4

Insurance Industry has not kept Pace with the Introduction of Control Methods: Farmers across the aquaculture sector who have demonstrated a proven record of using effective HAB controls are not benefiting from lower insurance rates. There are relatively few underwriters, and they evaluate the market globally spreading the risk evenly over farmers that employ control practices and those that do not.

5

Working with Economic Development Agencies, Tourism Boards, and other Associations can Influence the Acceptance of Control Methodology: Putting ownership and control in the hands of managing authorities is important for promoting acceptance and supporting them is key to securing budget needed to invest in control technologies. Part of this is an evolution in thinking about what constitutes green infrastructure – from 'build it and they will come,' to 'manage it and they will come.'

Dialogue 3 Description

The third HABs *Dialogues* brought together fifteen leaders from industry, government, and academic sectors (see list of the participants in Appendix 1) for a virtual discussion on exploring challenges and opportunities associated with market use cases, the current landscape of control technologies innovations, and strategies for implementation of public/private partnerships 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) market uses cases (2) landscape of control technologies innovations; and (3) public/private partnership – strategies for implementation. 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 is delivered on a non-attributional basis.

Invited experts joined from four countries. Sector representation was as follows: Private – 33%; Governmental/Intergovernmental – 40%; and Academic – 27%. In addition, approximately 79 observers from nine 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 third of three *Dialogues* for HABs. The key takeaways and potential paths forward provide a foundation for the synthesis across the series of *Dialogues*.

Discussion Synthesis

Section 1: Market Use Cases

The first section focused on market use cases. Due to varying market demands for HAB control across multiple sectors, geographic regions, organisms, or toxins, it is realized that a one size fits all approach is not feasible and the application of specific techniques and technologies all have merit and potential for success. However, these approaches may suffer from a lack of coordinated understanding of the specific incentives or barriers that they may present for a given application.

Do we have a clear picture of the market demand and where that demand comes from?

Optics and Perception

There is a demand for environmentally friendly products, sustainable solutions, and control methods that can scale up. There are different types of controls, e.g., biological, chemical, and mechanical (often interchanged with physical). When chemical control is considered, the immediate public reaction is one of concern. Also, such controls can be classified as pesticides, which further elicits a negative perception. But all control strategies can elicit concern among those who worry that impacts from treatments can be damaging. All too often, opponents of control methods fail to compare the impacts from a treatment to the "no treatment" option. Environmental conservation groups are challenging practices, including in court. A robust strategy is needed to overcome this negative perception. Strategies offered include: (1) clearer and stronger outreach started in the earliest stages of projects, (2) unbiased evaluation of methods that have worked, (3) development of uniform guidelines for testing of methods, and (4) transparency when a method is not viable. The need for monitoring before, during, and after a control effort is critical, as is the importance of this in gaining community support (i.e. social license to operate) for HAB control, particularly in the open ocean.

Controls need to extend beyond HABs

For the aquaculture industry to invest in control technologies they need to positively impact the bottom line. Some secondary effects being induced by HABs could be major concerns of aquaculture stakeholders, including the oxygen depletion during cell decomposition. In the meantime, excessive and unbalanced nutrient loadings which would fuel some specific algae species to proliferate, also require some level of control. A suite of approaches to reduce nutrients, inhibit the growth of vibrio and viruses, improve the oxygen level in the water and to control HABs would be highly valuable to aquaculture stakeholders. Along with educating on how control methods can reduce uncertainty, this must also be done by collecting data as well as improving predicative technologies, to provide additional value that will in turn help generate more stable demand. Two examples are presented. Example 1. The use of seaweed and seagrass may not only keep HAB in check but also bring multiple benefits, including improving fishing grounds and conservation. This approach can also be integrated into Integrated Multi-Trophic Aquaculture (IMTA) systems, where seaweed itself can serve as an additional source of revenue for aquaculture producers. Seaweed has a wide range of potential benefits as a source of food, medicine, animal feed, fertilizer, and even carbon dioxide removal. Example 2. In recent years, excellent monitoring technologies for identifying and quantifying HAB-causing species have been developed, including the Environmental Sample Processor (ESP), the Imaging FlowCytobot (IFCB), NOAA's HAB prediction models, and remote sensing. On the other hand, it has become clear that the formation and disappearance of HABs are greatly affected by interactions, such as competition, predation, and the suppression and promotion of growth among various biological communities.

These suggest that a comprehensive HAB monitoring system that includes factors affecting the dynamics of harmful algal blooms, such as viruses, bacteria, and other microbial communities, overall water quality, sediment conditions, and distribution of benthic macrophytes, etc., using advanced technology, sensors, and ocean robotics would be valuable to help manage a number of pressing issues, such as infectious disease risk, environmental pollution, accessing suitability for sustainable aquaculture, marine resource conservation, etc., in the future. These multi-benefit strategies along with control strategies will help generate stable demand and generate stronger momentum for implementation.

Disconnect between market drivers and a push for implementation

Three categories of market divers were identified. First agriculture and aquaculture, which need to mitigate crop/product loss. The second is local authorities who need to mitigate the negative impact of HABs on tourism, hotels, restaurants, and recreational areas (e.g. golf courses). The final category is coastal industries such as desalination and nuclear plants that need to minimize clogging of water intakes. The push from these sectors is inconsistent, whereas in freshwater systems, regulations for keeping these systems safe for swimming, fishing and drinking often drive a broad and widespread demand. Regarding the marine and coastal areas, some solutions are expensive and unaffordable for large water bodies and local governments do not have budgets for implementation of control. There is also the question of who pays for this and what is the priority for HAB control in comparison to other pressures on local budgets. A related issue regarding cost is the preference of authorities to invest in hard infrastructure (e.g. culverts) that can be seen and valued by the community versus investment in less tangible things like beach water quality where prevention of an event may be where the value lies in something that is never seen. Regulatory frameworks do not have penalties that are commensurate with societal impact, translating to a lack of incentive to invest. In coastal industries such as desalination and nuclear plants the response has been mixed. For example, within the United States despite outreach and a handbook written for the desalination sector[1], there has not been a strong response from the industry, which tends to invest in cell or toxin removal methods within the plant rather than efforts in the intake areas. Similarly in China, drinking water companies often use internal filtration systems. However, in the nuclear industry, China has found support for control methods because internal filtration systems are not sufficient to block HABs from entering the system. It was noted in this example the control is not complete control but just to the level necessary to permit cooling water to flow at a sufficient rate.

The response to control methods will always be driven by commercial imperatives, and if faced with a choice between preventing HABs entering a production system or engineering them out of a system, they will choose the least costly option.

How can collaboration with affected industries and gain market insights that lead towards potential solutions? How can farmers enhance their risk management strategies and improve insurance practices?

Experience in Japan highlighted the importance of considering the optimal approach to HAB control by dividing it into different HAB stages. For example, (a) pre-bloom (reducing likelihood through influencing environmental factors such as water quality and nutrients, understanding cyst distribution and removal, maintaining healthy coastal vegetation such as seaweed and seagrass beds and also improving aquaculture techniques such as types of bait, maintaining proper scale and density of cultured organisms, and selecting proper fish cages to reduce the risk of HABs); (b) in the early to mid-stages of development (e.g., net cage transfer, sediment lifting to bring up competitor diatoms, algicidal viruses); and (c) at bloom peak (clay dispersal, ozone nanobubbles, and strong removal technologies) and after (e.g., monitoring of hypoxia resulting from HAB events and how to mitigate it). For collaboration to be successful, long-term relationships need to be developed between growers and HAB researchers and regulators. A participatory science approach has proven helpful in engaging farmers.[2]

[1] HABs and Desalination: a Guide to Impacts, Monitoring and Management: https://repository.oceanbestpractices.org/handle/11329/644

[2] For more detailed information, Imai, I., Inaba, N. & Yamamoto, K. Harmful algal blooms and environmentally friendly control strategies in Japan. Fish Sci 87, 437–464 (2021). https://doi.org/10.1007/s12562-021-01524-7

Data, information, and automation

Information sharing is a basis for improving collaboration. An example comes from finfish aquaculture where capturing, sharing, and aggregating data from farm levels that would have been lost in the past, is used to train a HAB forecasting model producing 3-day forecasts with 95% confidence. Accuracy of observations taken by farmers is a key issue as they are looking for numerous plankton species (13 in the case discussed), so operators must be well trained. Farms in high risk (i.e. high likelihood) areas tend to be better at monitoring, whereas some of the biggest losses have occurred in lower risk (i.e. lower likelihood) areas i.e. low likelihood/high consequence HAB risk. A key takeaway from this experience is that measuring at finer spatial and time scales in coastal environments reveals just how dynamic HABs are, and that the rate of change at this scale can have damaging effects on aquaculture before or without ever manifesting at larger scales. This highlights the importance of developing working relationships with aquacultural operations in multiple locations. Some of the biggest losses in the Canadian Pacific region came from human error and not operating the control systems correctly or in a timely manner. An interesting example was given for finfish aquaculture in the U.S. Pacific Northwest, where fish survival was shown to improve by not feeding before a HAB event, i.e. fish fed during a HAB event performed relatively poorly. Fish farmers then became very conservative in feeding when conditions were conducive to bloom formation. A later study, however, showed that the loss of production from not feeding was greater than any loss from HABs over 20 years. This highlights a critical need for centralized, accurate, trusted data and access to specialized staff to interpret the data. There is an opportunity for industry to provide improved early warning systems coupled with automated mitigation systems. There were discussions regarding a HAB industry collaborative shared portal for all information that is captured. For example, when remote sensing or physical samples are collected, this could be used to aid in the Canadian shellfish sanitation program (CSSP). As well as citizen science, including many First Nation programs are all collected every day, but knowledge is not shared due to a lack of consolidated systems.

Insurance Industry has not kept pace with control practices

Farmers can decide to pay for insurance as an alternative to investing in control. It was noted that even as the growers started having a proven record of using controls to avoid the loss, the insurance rates did not decrease. There are relatively few underwriters, and they evaluate the market globally, spreading the risk evenly over those that put control practices in place and those that do not. As a result, there are disincentives to control. If, however, the price of insurance is increasing and/or the availability of insurance is decreasing due to greater frequency and intensity of HABs, the economic case for industry investment in control systems becomes compelling.

Are there enough market landscape impact reports out there that are accessible for the commercial HAB community? And if not, what do we need to do to address this issue?

In general, the answer is 'no,' though it does depend on the market sector. One of the challenges is that HAB events are dynamic, ephemeral, and hit different industries at different times around the country. An impact on the tourism industry is different than an impact on a seafood source such as Dungeness crab. To date the studies are regional; there has not been a focus on aggregating studies to show the larger impacts of HABs that may result in greater enthusiasm for deploying control technologies. It was noted that getting the information needed to conduct these studies can create additional work for the client.

The clients want an immediate solution and do not have a scientific background, so it is incumbent on the provider of the solution to offer the compelling case as to why the farmer needs to collect the additional information that enables the baseline data needed to develop the solution.

Identifying the correct metrics

An important issue raised in this context was the metrics that are used to trigger the consideration of HAB impact. Chlorophyll a is often used as a proxy for all algal biomass, but it is a poor indicator of toxicity. Consideration of pigments may be more useful. Reaching agreement on the type of metrics required to inform responses and developing standard operating procedures (SOP) to gather the required information across industry, government, and academia would be a big step forward. The importance of being able to measure toxins, in addition to or rather than algae, was again noted from an industry perspective. Toxin sampling tends to be reactive, periodic, and time-lagged, so there is an opportunity for automated, in situ measurement of toxins to be very valuable if done proactively. Many biotoxins remain unclassified or lack validated measurement methods. Additional research is needed to determine the impact of these unknown biotoxins through various bioassay techniques, alongside the development of technologies that can break down these unknown chemicals, as identifying all of them individually would be impossible. Further there was discussion on a lack of knowledge when it comes to toxins. For example, many species can be in full bloom and not cause mortality to finfish. The relationship between concentration and toxicity is widely unknown. It is worth conducting closed trials to better understand this relationship.

Understanding the best control strategy

There are not enough studies to understand the impacts of different control strategies and when is it better to do nothing. Lack of information about valuing the impact of blooms in the marine environment was raised. The discussion also considered whether, from an economic perspective, it is better to 'ride out' certain types of blooms (e.g. by not harvesting) than to invest in expensive control mechanisms.

Section 2: Landscape of Control Technology Innovations

The second session focused on the overall landscape of control technology innovation. The discussion centered around the incentives and barriers affecting the growth and introduction of HAB control technology into commercial markets. The participants were asked about approaches to expedite implementation.

What developmental and implementation shortcomings of control technologies do industry partners identify, and what obstacles hinder commercialization?

Lengthy permitting approval is the largest barrier

Permitting was widely agreed to be the biggest obstacle. The lack of consensus across jurisdictions on the requirements to achieve permitting approval is a major issue for industry and academia working regionally, nationally, and globally. The cost to industry of proving efficacy jurisdiction by jurisdiction is prohibitive. The participants understood the cautious nature of the permitting process and the need to guard against bad actors, but it also reflects a lack of understanding of business models of the companies who focus on control. These companies are looking for opportunities to prove their technology. Even when a particular method has been proven effective in a laboratory test, it is difficult to get approval for larger demonstration of the technology. The mentality is one that is risk averse – "do no harm," so until a method is 100% proven the permitters will not take a chance.

A recent requirement for a toxicity test was discussed. While the company saw the benefit of a toxicity test in future marketing, the lack of standardization on what should be tested, the need for tests for each organism, and the expense of each test are large barriers to overcome. Especially when it is unknown whether the results of the test will be accepted by a different permitting organization.

The United States HAB-Control Technologies Incubator (CTI) is developing a 'clearinghouse' of HAB control methods and permitting requirements for the United States, and this concept was well received. It was noted that within the United States, there are some examples of nationwide permits issued by the United States Army Corps of Engineers and US Environmental Protection Agency. Nationwide permits take time to negotiate but this is a potential framework that could be used elsewhere.

Testing metrics and types of testing

The participants discussed what the metric of success is. For example, is it 90% cell reduction and 90% toxin reduction? There are methods that can achieve 90% of the cells and only 50% reduction of the toxin - is that sufficient? It is important that this concept be explored and tested in a step-by-step method. The demand and targets will be 'use case' specific. For example, for nuclear plants, they may only wish to have some level of without considering too much on the toxin problems. For the cell removal in this case, it is not necessary to be 90% or even higher. Instead, the plants always use the metric "differential pressure" of the filter to indicate a control is efficient or not.

What type of testing is necessary? One type of testing is replicated trials that include a 'no treatment' control. Testing a particular method is not helpful to a regulator because they will want to know what would have happened if there was no treatment. A second type of test is one that evaluates impact relative to that of existing strategies. When testing ozone nano bubble treatment, it will be compared to a copper-based and a hydrogen-based method to look at relative impact of the treatment. The results then need to be evaluated against the impact of a no treatment strategy. This enables a discussion with regulators of outcomes such as one zooplankton being affected by a method, yet the overall algae biomass decreased. Had no control method been employed for comparison, the effect was that all the zooplankton was decimated. As new methods come into practice these types of comparisons will become more important to overcome the regulatory barriers.

Importance of remotely sensed data as an aide to help direct control methodologies

The important role of satellite remote sensing and modelling tools was reinforced in terms of surveillance, monitoring, and situational awareness as an aid to help direct application of control methodologies. There are limitations (sub-surface, identification at species level), and there is a need to complement it with in-water sampling and observations when required. The tools are out there, but there is a need to train people in how best to use them. Understanding the growth curve of plankton (i.e. lag phase, exponential phase, stationary phase, senescence) was noted as important in terms of targeting control. By using satellite remote sensing and modelling tools coupled with routine water quality monitoring it may be possible to hit the growth curve before it enters the exponential phase, and to be more proactive with treatment and control rather than being reactive in the peak phase. An interesting example was given from the finfish aquaculture industry in the U.S. Pacific Northwest of the industry doing daily sampling to calibrate spectrometer data from the European Space Agency satellite. It proved to be a very promising tool to monitor where blooms were, but increased smoke from wildfires interrupted the trial. This approach could however have application in other regions (e.g. less fire prone). Another satellite program within the United States is the Cyanobacteria Assessment Network (CyAN), a multi-agency project to support the environmental management and public use of U.S. lakes and estuaries by providing a capability of detecting and quantifying cyanobacteria algal blooms.

Besides the U.S. Control Technologies Incubator, are there other global programs designed to accelerate HAB control technologies entry into the market? Where are we with our test beds in terms of independent third parties available to evaluate these types of performances? And how much buy-in do we get from the users of those technologies based on the ability to test them in realistic environments?

The need for independent third-party testing and standardized evaluation was discussed. Third party testing is considered the Gold Standard. Industry supports third party testing, but it needs to be equitable. Everyone needs to have the same opportunity, and testing protocols and methods need to be transparent so a true comparison can be established. The Florida Red Tide Mitigation Technology Development initiative was noted as an example of a tiered, methodical, testing process that considers ideas from all over the world. An example was given from Japan where a sediment lifting method traditionally used for improving fishery grounds had sufficient support in terms of biosafety, local understanding, and regulation to pave the way for a HABs countermeasure using macroalgae and seagrass to be accepted.

The challenges of creating test beds in the open ocean were discussed. An example was given in the U.S. State of Florida where a structured process to establish five test bed sites led to statewide permits. This was a promising development and perhaps a model for other regions.

It was noted that the ballast water control sector is very mature in its approach to sampling, testing, and responding, and there may be things the HABs sector could learn in terms of scaling up. It was also noted that the Lake Superior Research Institute's Great Waters Research Collaborative provides unbiased, independent data in support of the accelerated development of water treatment technologies.

Effective intellectual property management is crucial when developing HAB treatment technologies with government and industry partners, as it protects innovative investments and establishes clear ownership boundaries. Strong IP rights attract investment, facilitate commercialization pathways, and create sustainable market opportunities that extend beyond research phases. By proactively addressing IP considerations, developers can forge more productive collaborations while ensuring their technological advances maintain competitive advantage and generate appropriate returns in the marketplace.

What are some other considerations that we need to think about in terms of streamlining the process for rapidly deploying promising technologies and justifying that transition of new technology into existing markets?

The concept of 'fast tracking' was refuted given the regulatory issues raised throughout the Dialogue. Additional issues were raised about things like products' shelf life and the transport of hazardous materials. There is, however, work going on to develop a roadmap and decision tree for HAB management in the U.S., which could be very useful if it gets traction.

Modernization of the regulatory environment was noted as a threshold issue. In Canada, many of the regulatory frameworks are based on the Fisheries Act, which has not been updated in many years. It was noted that regulations can take three to five years before a prototype can be tested, making the barrier too high. It was recommended that there needs to be a mechanism that allows the testing of innovative ideas to be done outside of the normal regulatory framework. Industry will partner with innovative companies but much of the testing must be done on full production sites, which remains too high risk. Areas for scale testing are necessary to lower the risk.

Section 3: Public/private partnership - Strategies for Implementation

The final section focused on public-private partnerships and implementation strategies to grow HAB control solutions. What are methods that can be employed to open the dialogue and bridge the public and private viewpoints on strategy, scalability, and value realization?

What is the role of policy and regulation? Can exceptions be identified and applied in the case of certain HAB control methods?

Inconsistent regulations hinder acceptance

It was noted that current regulation (at least in the U.S.) does not cover 'surface water,' and regulations come from a wastewater perspective. This is problematic in terms of taking a more integrated approach to HAB management. While noting a streamlined framework is necessary, a concern was raised as to whether a single surface water act would be sufficient because of the occurrence of HABs in the benthic environment.

Inconsistency in the regulatory burden placed on different industries was noted as a key issue in a discussion about who pays. A view was expressed that the burden placed on fishing and aquaculture industries is far greater than that placed on processing facilities located on the coast (e.g., wastewater, desalination, processing facilities with water intake and/or discharge).

This creates a downward spiral where industry is not willing to invest in new control technologies if the burden is too high.

Policies and regulations are necessary as they set the framework for what can and cannot be done. It was noted that they are dependent on the interpretation of a public/government official. The point was made that often there is a "do no harm" mentality and that can hamper proactivity. It was brought up that for the public/government official – what is the incentive to solve the problem? Better outreach and available economic understanding could support local municipalities in making decisions on actively pursuing HAB control mechanisms.

What are the roles of tourism boards, economic development organizations, other similar groups? What can they do and what role can they play in speeding up the testing and implementation of HAB control mechanisms?

The importance of early engagement of the community was highlighted. Although it is more complex to engage the community when we are still building our understanding, posing new questions, and dealing with uncertainty, experience shows that there will be greater acceptance of science-based solutions in the long run. Treating the community with respect and bringing them along on the journey from the start is much more effective than dropping highly developed technical solutions on the community that are not understood and trusted.

Putting ownership and control in the hands of managing authorities will be important as will supporting them to secure the budget to invest. Part of this is an evolution in thinking about what constitutes green infrastructure – from 'build it and they will come', to 'manage it and they will come.' Community organizations such as the Chamber of Commerce or the tourism board or a sailing or fishing club can influence elected officials to act by expressing that HABs are hurting my business, my restaurant, my marina, my aquaculture business, etc. Providing them with information, knowledge, and understanding is crucial to empowering these entities to act.

It was, however, again noted that whereas HAB control has been made a priority and backed with investment in some U.S. states (New York, Ohio, Florida), these are the exception rather than the rule and such efforts have not scaled up to a national strategy. Regional pilots were proposed as one approach to scaling up. Relating HABs to issues that resonate at the local level (e.g. pet fatalities) has also been found to be effective.

The right messaging is key to success

The tourism sector is opposed to negative messaging. What frustrates that sector is not knowing the exact impacts and how long the bloom is going to last. While additional observations and monitoring are needed, the HAB community needs to engage better with tourism officials to understand what information, products, and services are needed to support their efforts. Moving to control and explaining how and when these technologies can be used to mitigate the impact of a HAB event could help to spur innovation and use of control methodologies.

Open Session

The last session provided an opportunity for open dialogue including both the panelists and the observers. Two additional topics were discussed:

> Education and advancement of control technologies. Observers introduced the International Society of Automation and offered that the society is having its international instrument control systems meeting in Orlando this fall, which could be an opportunity to present HAB control technologies to a wider audience.

> Integration of pest management as it is used in terrestrial agriculture. Has this been considered for HABs? It is, for example, being used successfully to control Crown of Thorns starfish on the Great Barrier Reef in Australia. It was recognized that there needs to be stronger engagement with other national agriculture and food agencies, and a broader focus on clean, safe water initiatives and more holistic clean-up efforts.

Potential Pathways Forward

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

- **Develop greater public awareness and understanding of control technologies:** This can begin with a collection of cases where HAB control methods have effectively been used. Meeting with key groups, such as Economic Development Agencies, Tourism Boards, and Trade Associations, early in the process is fundamental so these groups understand the significant science that underpins the control methodologies.

- **Commission Cost-Benefit studies of control compared to response:** There is a lack of market studies on the benefits of HAB control in general. Studies are needed to cross-compare different types of control methods, including comparisons to settings where no controls are used. Studies are also needed to compare costs of employing control methods external to an aquaculture farm or treatment plant to respond to efforts either after a bloom in the case of the farm or within a treatment plant.

- **Discussions with the Insurance Sector:** Recommend small convenings with the appropriate global insurance corporations to establish favorable cost structures to incentivize control methodologies.

- **Work with permitters to understand and in the future streamline regulations:** Support efforts such as the United States HABs-CIT, which is working on developing materials to identify and navigate permitting requirements.

- **Develop decision trees on when and how to employ HAB controls:** This can be modeled after the decision tree for HAB monitoring and control developed for freshwater - https://hcb-2.itrcweb.org/

Appendix 1: Participants

Sector	Affiliation	Name
Public/USA	National Oceanic and Atmospheric Administration (NOAA)	Sean Corson
Public/USA	U.S. Army Corps of Engineers (USACE)	Mandy Michalsen
Public/USA	National Oceanic and Atmospheric Administration (NOAA)	Nia Rene
Public/Japan	Public Works Research Institute, National Research and Development Agency	Nobuharu Inaba
Public/China	Key Laboratory of Marine Ecology and Environment Science, Institute of Oceanology, Chinese Academy of Sciences (CAS)	Isaac Yongquan Yuan
Public/Canada	Fisheries & Oceans Canada (DFO)	Cynthia McKenzie
GOOS	Gulf of Mexico Coastal Ocean Observing System (GCOOS)	Barb Kirkpatrick
Industry/NGO	Mote Marine Laboratory	Kevin Claridge
Industry	EutroPHIX	Alexis Fisher
Industry	Akvafuture Salmon Ltd.	Dean Trethewey
Industry	GreenWater Services	Al George
Industry	BlueGreen Water Technologies	Jessica Frost
Academia	Ohio State University	Heather Raymond
Academia	Woods Hole Oceanographic Institution (WHOI)	Don Anderson
Academia	University of Maryland Center for Environmental Science at the Institute of Marine and Environmental Technology (IMET)	Al Place
Academia	School of Marine and Atmospheric Sciences, Stony Brook University, New York State Center for Clean Water Technology	Christopher J. Gobler

Appendix 2: Use Case

Dialogues with Industry - Harmful Algal Blooms

Use Case for Dialogue 2: Advancing Control Technologies

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 3.

Background and Scope

Our first two *Dialogues* explored ways to increase engagement of private sector partners to help meet the need for sustained HAB data, observational networks and downstream delivery of actionable data information including forecasts to mitigate impacts across an expanding number of social and economic sectors. Control is another aspect of the societal response to HABs that merits greater engagement with the private sector. HAB Control strategies directly kill HAB cells and/or destroy their toxins, physically remove cells and/or toxins from the water column, and/or limit cell growth and proliferation. There are well documented cases of millions of dollars of economic loss due to HABs. From October 2017 to January 2019, a large and prolonged red tide event caused respiratory distress and displaced recreational activities along Florida's Gulf coast, heavily impacting the tourist sector. NOAA, National Centers for Coastal Ocean Sciences funded researchers now estimate that the loss to tourism-related businesses during the 2018 Florida red tide bloom was $2.7 billion USD[3]. In Florida, HABs, like other disruptive events weather events, can affect other parts of the economy such as the convention business in inland areas such as Orlando which generates approximately $3.9 billion in economic impact for the Central Florida economy each year.

[3] https://www.sciencedirect.com/science/article/pii/S0301479723025999.

When a senior individual in the Florida tourism industry was asked about HABs and the need for monitoring, that individual responded stating that Florida does not need another "season" (like Hurricane) to deal with, we need the HABs to be dealt with before they affect the coastal waters. The estimated total economic impact (including direct, indirect and induced effects) of the 2018 red tide event resulting from the shock to the Airbnb market corresponded to $318 million. Additionally, 2,876 jobs were lost state-wide.[4]

Despite a few notable successes (e.g., China, Korea, Japan) and advances in promising new approaches to controlling HABs in coastal marine and estuarine waters and in large freshwater basins, these markets lag significantly behind similar sectors for controlling algae in small and enclosed freshwater bodies, land-based aquaculture, and potentially related sectors such as control of pests in agriculture, silviculture. The market for HAB control in freshwater systems is generally more mature than in marine environments. In contrast, marine HAB control remains in a more nascent stage, with fewer commercially viable solutions due to factors including the complexity of open-water environments, varying jurisdictional regulations, and the scale of interventions required.

This dialogue will draw on experiences and perspectives from representatives from more mature control industries as well as from global leaders working to bring new control technologies suitable for larger scale ocean or freshwater applications to market. Discussions will explore drivers and complexities unique to the global HAB problem and a range of scientific, technological, regulatory, and societal factors that have slowed efforts to establish a new market for HAB control at larger geographic scales.

Scientific issues include efforts to determine the effectiveness, scalability, and environmental safety. Transitioning raises technological questions such as how to license, produce, transport, store and deploy treatments which speaks to a need for greater. Societal concerns may include concern for ecological and environmental risks to control methods. Finally, engagement across to those industry sectors directly affected by HABs will be necessary to accelerate the implementation of control methods in marine and coastal waters.

Support from HAB impacted industry, private and public sectors (a.k.a Stakeholders) is particularly important in advancing control technologies and an expanded market for HAB control. Further, efforts to educate the public and managers are key to building awareness of the expanding global HABs problem, efforts to accelerate the number of potential control solutions (e.g., a US example is the HAB Control Technologies Incubator (HAB-CTI) and may be needed to garner support for acceptance and deployment of the technology. In its early stage, HAB-CTI is focused on identifying and educating stakeholders are the existing technologies. There is an annual $1M competition for seed funding, with assistance in permitting/regulatory requirements with resource list, contact, and available technologies by regions/species/habitat. As the Clearing House matures, the goal is to help companies within the HAB control sector accelerate transition and commercialization of technologies.

Regulations and permitting for research are not specifically highlighted during this dialogue as there have been advancements in understanding what accountability is required and research processes have been adjusted to meet these requirements. However, it is anticipated that this topic will be discussed in the context of the issues that businesses have encountered.

[4]Economic Impacts of 2018 Florida Red Tide: Airbnb Losses and Beyond - NCCOS - National Centers for Coastal Ocean Science: https://doi.org/10.1177/13548166211068276;

Dialogues Outcome

The goal of the *Dialogues* is an awareness of where the global community is going regarding standing up services for HAB control and support for an expanded market for HAB control solutions at larger geographic scales. Opportunities for greater industry involvement and new public-private partnerships will be explored.

The deliverable from the *Dialogues* is a set of actionable recommendations to be acted upon by those globally engaged in responding to HABs and their impacts through the HAB data, observational networks and downstream delivery of actionable data information including forecasts to mitigate impacts across an expanding number of social and economic sectors.

Format of Dialogue 3

Dialogue 3 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 market use cases; landscape of control technologies innovations; and public/private partnership - strategies for implementation. 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 I - Market Use Cases

There is limited data on understanding the global market size for implementing control of HABs. The markets are likely to be regional and, based on the type of HAB organism(s) or toxin involved, will require different technology. The important discussion during the Dialogue is to focus globally on identifying the potential markets and perceptions of those potential markets. To further identify gaps in this knowledge and recommend a path forward to closing the gaps in understanding market demand. While the impact of HABs events can be economically devastating, the focus has been on the observing, monitoring, and taking steps to reduce the impact of the events. Steps for the aquaculture industry can be delays in harvesting, for the beach going community closure of a beach, and water treatment in areas that are sources for drinking water.

Within the United States, surveys by NOAA have indicated that stakeholders are interested in control methods but have significant questions on impacts and utilities of the methods. Experiences from other parts of the world vary with some impacted areas where HABs control methods are routinely implemented.

Who should implement these control methods, the public or private sector, or a combination of the two? Should this be implemented by governments, or end user sector (e.g., aquaculture, desalination, ballast water management) or adjunct sectors such as tourism (through potential tourism fees). Are there incentives (e.g., insurance, access to financial capital, risk management requirements) that currently drive the adoption of HAB control, which could provide a model for expansion in other sectors. One example, from Blue Life Hub, describes the role of insurance in Algeria's aquaculture industry. A notable quote from that example, "Insurance safeguards aquaculture operations and plays a crucial role in enabling farmers to access traditional financial markets."[5]

[5] https://www.bluelifehub.com/2024/06/14/the-crucial-role-of-insurance-in-aquaculture-and-an-example-from-algeria/

There is a lack of data on the return on investment for implementation of control methods. For example, it is not known whether HAB control would be considered an incentive or a barrier for aquaculture from an insurance perspective.

Discussion Topics

1. What is the market demand?

2. Where is this demand coming from?

3. What are the best methods for coordinating with impacted industries, understanding the market from their perspectives, and sharing possible solutions?

4. From the industry's perspective what are some arguments you have used to advance the need for control methodology?

5. Are there sufficient market reports that will appeal to the commercial community in HAB control technology? If not, what specific reports are needed?

6. Should efforts to define markets for freshwater and marine\open water control recognize this difference? If so, are there any benefits to representing separate efforts as part of a larger initiative?

7. Are there specific incentives or disincentives for certain HAB impacted global marine systems or large lake "business" sectors (e.g., shellfish, salmon, desalination, drinking water, recreation, etc.) to support HAB control?

8. Considering HABs broadly defined includes phytoplankton that can harm farmed stocks or disrupt aquaculture operations, is there a market for related HAB control approaches?

9. What level of monitoring should be required or recommended before, during, and after a permitted or registered treatment to ensure safe and effective HAB control, and how might this shape the development of the market?

Section II - Landscape of Control Technology Innovations

Some of the more promising strategies include the use of ozone nanobubbles for destruction of cells and toxins, clay flocculation for aggregation and settling of HAB cells and absorption of their toxins, and the use of bacteria or bacterial exudates, or viruses to selectively control and/or suppress HAB growth within the plankton community. Clay flocculation has been used for more than two decades to control numerous blooms in Asia over scales of tens to hundreds of kilometers; however, it has not been accepted for use globally. In the United States' only ozone and clay flocculation have been tested in limited controlled field trials.6 Each of the methods has pros and cons and will work differently on the type of HAB organism or toxin. This Dialogue is not focused on the technical merits of a particular method, but the overall issues associated with implementing HAB control technologies.

As much of this technology is being developed outside of national agencies by commercial companies there are opportunities for the public sector to partner with the private sector. Within the United States, for example the Cooperative Research and Development Agreement (CRADA) and Small Business Innovation Research (SBIR) processes are available, as is a control technology incubator program. Are there other programs globally that can accelerate this technological development? How can the private sector, with experience in more mature control markets, be engaged to more quickly accelerate the transition of promising research methods into applications for larger geographic areas?

The apparent lack of programs for independent third-party evaluation of emerging HAB control technologies is a challenge to the adoption of solutions by stakeholders. There needs to be both test beds for evaluating performance of HAB control prototypes, as well as for fully validating technologies in relevant and actual real-world environments. Perhaps this could be an expanded role for the US HAB Control Technologies Incubator and Clearing House. Another approach could be adapted from the successful (albeit recently sunsetted) Alliance for Coastal Technologies 'technology evaluation' model, and there may be other international examples to draw from.

Discussion Topics

1. What (if any) shortcomings do industry partners see in the development and implementation of HAB control technologies?

2. What are the barriers for commercialization?

3. Besides US-HCTI Are there other examples of programs globally that can accelerate HAB control technologies to market?

4. Are there existing test beds for evaluating prototypes and/or programs for independent third-party evaluation of technology performance in a relevant or real-world environment? If not, how best to address this critical need?

5. From the industry's perspective what are the licensing, permitting and approval processes requirements that must be considered in transitioning control technologies to application.

6. What are the solutions to enable testing?

7. What are issues with transfer, storage, deployment of various chemical control methods?

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

Section III - Public/Private Partnership - Strategies for Implementation

There has been a steadily increasing demand for HAB control solutions. The hesitation is based on technology and where it is applied. There is an educational need for control strategies in general, asking the public what information they need to be more comfortable with deploying this in their region. In discussions the United States has conducted, the sentiment of the public has been open - they would rather see something done than fail than do anything.

There are often unique educational challenges and negative public perceptions which can differ by type of control methodology. For example, treatments can sometimes produce short-lived murky water or produce a visible color change. or orange-colored but have no other adverse effects. Educating stakeholders to understand and accept such treatments is one element. In the case of "ozone" overcoming public perception that ozone is an atmospheric pollutant that contributes to negative human health outcomes, crop damage, and increased smog. However, what is being employed in the water is completely different. This requires different skills such as a social component for outreach to convince stakeholders that the positives outweigh the negatives. This presents an opportunity for public/private partnership that can be influential in accelerating the acceptance of control methods by soliciting concerns and developing robust methods to alley those concerns.

Since HABs have known impacts on aquaculture, water production (e.g., desalination plants), ballast water management, and tourism, how can economic development organizations, tourism boards, and trade associations be approached and engaged to accelerate the acceptance and use of control methodologies? What types of financial tools (e.g. insurance) or policies can be utilized to incentivize public\private partnerships to advance new technologies and stimulate new private sector entrants to adopt technologies.

Stakeholder engagement and understanding the socioeconomic value is key to implementing these controls. Various workshops are held in association with specific demonstrations but how can these be scaled to national, regional, and global scales to grow the nascent control efforts.

Discussion Topics

1. What is the role of policy and regulations? Can exceptions be identified and applied in the case of certain HAB control methods?

2. How can other communities, e.g., tourism boards, economic development organizations, etc., become involved in accelerating the testing and use of control mechanisms?

3. What are the adverse public perceptions and how do you mitigate those perceptions?

4. How can public and private sectors collaborate to develop and implement sustainable strategies for addressing Sargassum proliferation, and what are key factors for success in these partnerships?

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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Advancing Control Technologies

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