Harmful Algal Bloom Control in California Coastal Waters: January 12-13, 2026 Workshop Proceedings

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Executive Summary

Harmful algal bloom (HAB) impacts have increased in frequency and severity in California coastal waters; while naturally occurring, both global climate change and local anthropogenic factors are exacerbating this problem. The State of California is supporting scientific studies to determine where control of nutrient pollution could be effective in preventing or alleviating the problem. However, given that implementing nutrient controls take time and would not address the naturally occurring conditions that favor HABs, the State is interested in management strategies to control HABs and mitigate their impacts in the near-term. To investigate options, a two-day workshop was convened to 1) evaluate the current state of HAB control and mitigation, 2) identify investments that could be made now that would start to reduce HAB effects in the next year, and 3) determine what strategic research investments would have a high likelihood of providing implementable tools that reduce HAB effects within five years. The workshop brought together 21 HAB experts, coastal water quality managers, and practitioners representing impacted sectors, including marine mammal strandings, fisheries, and aquaculture.

The workshop discussion first focused first on HAB where control measures, with investigation, had potential feasibility. Control measures were discussed in relation to key HAB impact pathways: 1) aquaculture, 2) marine mammal health, and 3) commercial and recreational fishery management. When HAB control measures were not feasible, discussions focused on enhancements or improvements to HAB mitigation efforts that might help to reduce impacts. The workshop also discussed improvements in monitoring, which are necessary to support HAB prevention, control and mitigation efforts.

Workshop Findings and Recommendations

#1 HAB control strategies have the potential to be effective to limit impacts to aquaculture

HAB control technologies, include physical, chemical, or biological approaches to stop, suppress, or alter blooms through the removal or inactivation of algal cells or toxins. These technologies are in routine application internationally but are not widely employed in the US where regulations are a formidable barrier to trialing new technologies. The trials on control technologies that have occurred in other U.S. states have generally targeted HAB species that are not relevant to California’s most significant HAB impacts.

Experts identified three HAB control strategies that are potentially viable for lessening effects on bivalve aquaculture which have a well-defined and limited spatial footprint and often occur

in enclosed or semi-enclosed locations. In particular, they identified application of clay and the co-culture of seaweed and bivalves as the most likely to be successful. Another strategy worth evaluating involves sediment capping or disturbance to limit the emergence of germinated cells from dormant cysts in bottom sediments. However, these technologies will require at least five years of investment to document their efficacy in controlling HAB species endemic to California. Those studies will include a combination of lab studies with California HAB species, field trials, and monitoring of HAB bloom initiation and transport dynamics, and documentation of HAB cysts in sediments at aquaculture sites, in order to fine tune control strategies, address regulatory requirements, and document and minimize unintended ecological consequences. Finally, investments in HAB forecasting (seasonal and weekly) would improve readiness to implement control technologies at a local scale.

#2 HAB control strategies are unlikely to resolve bloom impacts on marine mammals, commercial and recreational fisheries in California

Workshop participants agreed that HAB control technologies are not viable to meaningfully reduce HAB effects on marine mammal strandings, and commercial and recreational fisheries. The bioaccumulation of HAB toxins of these species occurs over large geographic areas and the spatial scale of potential control technologies is too limited to have a meaningful effect on these applications. Instead, the State should focus on mitigation measures and steps that can support long-term prevention (i.e., nutrient control).

#3 Mitigation approaches can meaningfully reduce HAB impacts for multiple uses

There are many steps that can be taken now that will lessen the impacts of HABs, while the State continues to investigate where prevention measures such as nutrient management will be effective to prevent or alleviate HABs. Participants recommended specific mitigation steps dependent on the impact pathway:

Marine Mammal Stranding. Experts identified many steps that can be taken to 1) increase the success of wildlife rehabilitation efforts, 2) assess the long-term efficacy of treatment of HAB-related illness in wildlife, and 3) reduce the frequency of unsafe interactions between intoxicated animals and the public. These include a range of activities such as:

- Developing updated HAB specific treatment protocols based on lessons learned through the last 4 years of HAB events, including developing case guidelines to better triage animals that are likely to survive and those that need humane euthanasia.

- Developing the systems to expand operational rescue and rehabilitation capacity during large scale events, which includes developing systems to conduct rescues more quickly and/or deploy trained staff to manage public interactions with the animal, expand the spatial capacity of rehabilitation centers during events (e.g., overflow hospital space), increase the number of trained staff who can assist with treatment, and safe, cost effective management of animal remains.

- Enhancing data collection and management capacity for marine mammal rehabilitation centers. This includes streamlining data entry and management of animal treatment records and developing the capacity to track long term patient success following rehabilitation from HAB related illness (e.g., tagging released animals).

Commercial and Recreational Fisheries. The State of California has established a comprehensive framework to manage public health risks associated with HAB toxins across commercial and recreational fisheries. However, the breadth of fished species and diversity of HAB toxins, combined with the increasing frequency and severity of HAB events, make comprehensive monitoring along California's 1,000-mile coastline increasingly challenging. Workshop discussions focused specifically on two categories of fisheries use: recreational bivalve harvesting and commercial and recreational crustacean fisheries. Participants agreed that current bloom control technologies are unlikely to reduce the number of advisories and closures affecting these fisheries. Instead, discussions centered on two complementary priorities: strengthening tissue monitoring systems to ensure continued public health protection as HAB events intensify, and pursuing targeted research to evaluate whether the duration or scope of advisories and closures could be reduced where possible to preserve recreational and commercial harvesting opportunities. Participants identified a suite of investments to strengthen public health toxin testing and reduce economic disruption for fishing communities, including:

- Developing pathways to sample fisheries that lack systematic testing programs and are currently only opportunistically monitored for HAB toxins, such as rock crab, spiny lobster, and selected finfish species.

- Establishing certified testing protocols for paralytic shellfish toxins in crustacean tissues, as this toxin is not routinely monitored in these species.

- Expanding the monitoring of the Dungeness crab fishery to include in season tissue testing and integrate it with environmental monitoring to better characterize habitat-scale risk in northern California.

- Conducting mapping of recreational bivalve harvest areas, conducting human consumption studies, expanding volunteer-based tissue monitoring, and evaluating rapid toxin screening tools to determine whether advisories could be limited to specific species, locations, or use patterns while still protecting human health.

#4 Strategic monitoring enhancements are needed to support control and mitigation goals

Implementation of the recommended control and mitigation strategies require improved environmental monitoring and forecasting; participants noted that such investments would also support long-term HAB prevention measures such as nutrient management. The experts identified the following investments as ones that will most improve those systems:

- Conducting modeling and field-based studies to identify bloom initiation locations to streamline offshore monitoring efforts to better develop early warning capacity.

- Conducting environmental monitoring for HAB toxins offshore and in sediments to better guide tissue toxin efforts and enhance early warning capabilities. Monitoring efforts could be expanded through a combination of coordinated community science and local agency monitoring efforts.

- Conducting enhanced testing of marine mammal samples collected during HAB stranding events to inform updates to rehabilitation and release protocols.

- Enhancing and maintaining marine mammal stock assessments and pup counts of impacted species to more accurately quantify the impacts of HAB related stranding events on these populations.

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INTRODUCTION

The frequency and severity of harmful algal bloom (HAB) impacts have increased in California coastal waters. In recent years, domoic acid–producing *Pseudo-nitzschia* blooms have caused repeated marine mammal mortality events, extended shellfish harvest closures, and disruptions to commercial and recreational fisheries. Furthermore, advisories and closures for both recreational and commercial fisheries are common from paralytic shellfish toxins produced by *Alexandrium.* Emergent HAB issues such as red tides caused by other dinoflagellate and raphidophyte species have also caused largescale wildlife mortality events in recent years. Together, these impacts have heightened concern among resource managers, Tribes, and coastal communities and there is a collective desire to take more measures to minimize HAB impacts.

Holistic management of HABs along California's coast relies on a toolbox designed to address blooms from multiple angles, ranging from long-term risk reduction to short-term response. These tools fall into four broad categories: **monitoring, prevention, mitigation**, and **control**. Each plays a distinct role, operates on different timeline horizons, and carries different levels of scientific certainty and management readiness.

***Monitoring: tools and systems to detect bloom events*.** Monitoring is the most mature and well-established component of California's HAB management strategy. A coordinated network of state, federal, academic, and regional programs along the coast has provided nearly 20 years of routine surveillance of bloom occurrence, toxin presence, and environmental conditions. These efforts support early detection of blooms, inform public health protection decisions, and underpin wildlife response efforts. Monitoring efforts have evolved significantly over the past decade as new HAB issues and technologies emerged. These changes have included incorporating pier-based sampling, automated imaging technologies, satellite observations, model-based forecasts, and monitoring for an expanding list of HAB toxins and taxa. Together, these tools enable California to track bloom development to assess HAB risks to key stakeholders. However, monitoring alone does not prevent blooms or reduce their impacts once they occur. Furthermore, despite these long-term monitoring efforts, numerous gaps persist in spatial and temporal coverage.

***Prevention: reducing long-term HAB risks*.** While HAB can occur due to naturally occurring environmental conditions, human activities in watersheds and coastal habitats, such as nutrient pollution, hydromodification, and physical habitat alteration, can widen the window of opportunity for HABs. Prevention focuses on addressing underlying drivers in order to reduce the likelihood, frequency, or severity of HABs. Prevention approaches typically include management of anthropogenic sources of nutrients and watershed and coastal habitat restoration to reduce the conditions favorable to blooms. While prevention is a critical component of HAB management, these management actions take significant time and economic investments to implement. Even after prevention measures have been taken, HABs will likely still occur. As a result, effective and feasible prevention strategies must operate alongside other management strategies, such as mitigation and control.

Mitigation: limiting impacts when blooms occur. Mitigation strategies aim to reduce the ecological, economic, and public health consequences of a HAB event, but do not alter the bloom itself. In California, there are multiple HAB mitigation systems in place including fishery advisories and closures, marine wildlife rescue and rehabilitation networks, and aquaculture management actions. Monitoring underpins these activities. Mitigation efforts are essential for protecting human health and wildlife but are inherently reactive. Impacts still occur and can be substantial. Mitigation effectiveness is tied to the timeliness and accuracy of monitoring and forecasting systems.

***Control: stopping a bloom that is occurring*.** HAB control refers to actions and technologies intended to stop, suppress, or alter blooms by removing or disabling algal cells or toxins once a bloom is underway. In California's open coastal waters, HAB control remains largely unexplored and untested. The dynamic nature of marine systems, coupled with concerns about ecological risk, scalability, and regulatory feasibility, has limited the application of control technologies to date.

Workshop Goals, Structure and Summary

The State is interested in expanding its HAB management and response toolbox to better address the growing frequency and severity of HAB events along California's coast. To explore whether HAB control technologies could play a role in this toolbox, a two-day workshop was convened with four primary goals: (1) evaluate the current state of HAB control research; (2) identify where HAB control technologies may be a logistically, economically, and ecologically responsible option for managing HAB impacts or where mitigation approaches may be more effective; (3) identify near-term investments that could begin to reduce HAB impacts within approximately one year, and (4) determine strategic research investments most likely to yield implementable tools within five years. The workshop brought together 21 HAB experts, coastal water quality managers, and practitioners representing key impacted uses, including marine mammal response, aquaculture, and commercial and recreational fisheries (see Appendix 1 for list of invited attendees).

The workshop was structured to move from shared information exchange to focused expert deliberation (see Appendix 2 for the agenda). The first day of the workshop was open to in-person and virtual attendance by interested members of the public. The morning session consisted of expert presentations designed to establish a common foundation across participants. Presentations included overviews of California's dominant HAB species and impact pathways, the current state of HAB monitoring, prevention, and mitigation, and the range of physical, chemical, and biological control approaches that have been explored both in the U.S. and internationally in coastal ecosystems. These presentations highlighted lessons learned, emphasizing both successful applications and the ecological, regulatory, and logistical impediments that have limited broader adoption. Control presentations emphasized that while there is strong societal interest in HAB control technologies, progress in this area has been constrained by significant regulatory, scientific, and practical challenges. Federal pesticide and food safety requirements restrict which control technologies can be tested or deployed in marine waters, increasing development time and cost. This inadvertently results in a limited toolkit of existing technologies. Presentations underscored that most HAB control technologies are in the early stages of research, which follows a tiered framework that progresses from laboratory and small-scale testing (Tier 1), to controlled mesocosm or semi-enclosed field studies (Tier 2), and only then to larger field trials (Tier 3) once efficacy, safety, and feasibility are demonstrated. Very few control studies to date have focused on HAB species most relevant to California, such as *Pseudo-nitzschia* (see Appendix 3 for a full summary).

Afternoon sessions on the first day shifted from control concepts to the pathways through which HABs impact key coastal uses and the mitigation strategies currently employed to manage those impacts. Presentations highlighted how HAB impacts manifest differently across marine mammals, aquaculture, and commercial and recreational fisheries. Presentations discussed how HABs affect marine mammals primarily through bioaccumulation of algal toxins in prey, leading to acute neurological illness, mass stranding events, and long-term health effects that require rapid, resource-intensive response. In aquaculture systems, HAB toxins accumulate in shellfish, triggering harvest closures that protect public health but result in substantial economic losses for growers. For commercial and recreational fisheries, HAB toxins necessitate advisories, closures, or delayed seasonal openings to protect public health, however these protective health measures lead to economic, cultural, and social impacts that can persist well beyond the bloom itself. Presentations across these impact pathways outlined the current management approaches to minimize HAB impacts to human and wildlife health and considered suitability of potential control technologies for each use case.

The second day of the workshop transitioned to facilitated breakout discussions with invited experts organized around key HAB-impacted uses: marine mammals, bivalve aquaculture, and commercial and recreational fisheries. Breakout groups were intentionally composed to include expertise in both HAB control technologies and the relevant management, response, or regulatory context for each use. To promote consistency and comparability across groups, all deliberations followed a common framework that asked participants to: (1) assess the current state of HAB control and mitigation for their assigned use; (2) identify near-term investments that could begin to reduce impacts within approximately one year; and (3) prioritize strategic research investments most likely to yield implementable tools within a five-year timeframe. This approach was designed to distinguish immediate capacity-building opportunities from longer-term research and development pathways.

Where bloom control was determined to be infeasible or unlikely to provide meaningful benefit, discussions focused on opportunities to reduce impacts by strengthening HAB mitigation and monitoring efforts. Participants emphasized the foundational role of monitoring and forecasting in supporting both mitigation and any future consideration of control, and identified opportunities to refine testing, coordination, and decision-making to better align management actions with risk. Comparatively less time was spent on HAB prevention, as the State understands the importance of and has already begun investing in studies to quantify the efficacy of nutrient management to alleviate or prevent the impacts of eutrophication, including toxic HABs. The workshop concluded with report-back sessions and facilitated synthesis discussions that compared findings across use cases and identified cross-cutting themes.

Workshop Findings and Recommendations

The large spatial scale and dynamic nature of coastal blooms, combined with deployment and infrastructure limitations, make many control strategies challenging to implement effectively. Therefore, the selection of the technology needs to consider both the ecology of the specific HAB target and the pathways of impacts. The dynamics of the most prevalent HAB issue in California, domoic acid producing *Pseudo-nitzschia* blooms, pose several key challenges for control applications. These blooms often are geographically expansive and commonly develop offshore. They are shaped by regional oceanographic processes such as upwelling, stratification, and alongshore transport, allowing toxic conditions to emerge far from bloom initiation areas. In many cases, *Pseudo-nitzschia* occurs in thin, subsurface layers that are patchy, transient, and difficult to detect or access, complicating the timing and application of potential control actions. Beyond *Pseudo-nitzschia,* blooms that are associated with the production of paralytic shellfish toxins, typically caused by *Alexandrium*, are also large in scale and even less well characterized, which further complicates selection of bloom control options. Lack of characterization (i.e., understanding underlying bloom mechanisms and dynamics) makes it similarly challenging for other emerging HAB issues. These principles underpinned the discussion and findings of the workshop participants, who ultimately developed a series of four findings and corresponding recommendations related to these findings.

#1. HAB control strategies have the potential to be effective to limit impacts to aquaculture.

Bivalve aquaculture was identified as a setting where targeted HAB control strategies may be feasible, warranting focused research and pilot-scale evaluation. These operations are a unique use case that have a limited and well-defined spatial footprint, and existing monitoring and regulatory frameworks that make them suitable candidates for control measures. Experts noted that these same conditions suitable for potential HAB control measures may also be present in selected recreational bivalve harvest locations, particularly in enclosed bays and estuaries. As a result, three potential technologies were identified as having the greatest likelihood of success of minimizing HAB impacts on aquaculture: clay, seaweed and bivalve co-culture, and sediment disturbance/burial of HAB seed sources (i.e., cysts), depending on the local characteristics and type of bloom. For each of these methods, a variety of research needs were identified as necessary before considering implementation of any of these approaches on a large scale (e.g., Tier 3 deployment). Experts identified a variety of Tier 1 and Tier 2 research activities to evaluate efficacy, feasibility, and risk before any consideration of pilot deployment. Experts also noted that site specific environmental and bloom characterizations are also needed to inform efficacy evaluations. Any control measures would need to comply with aquaculture licensing, permitting and public health testing requirements. Lastly, socioeconomic evaluations are needed to weigh the value of the resource against the cost of the control actions.

Clay-based approaches involve the application of fine mineral particles to the water column to physically remove HAB cells through flocculation and sedimentation. When dispersed, clay particles bind to algal cells, forming aggregates that sink out of the water column and reduce cell concentrations and, in some cases, associated toxin levels. These approaches may be suited for aquaculture because growing areas are spatially well defined, hydrodynamics are relatively constrained, and operations already occur under intensive monitoring and regulatory oversight. Additionally, this approach has been deployed at large scales (up to 100 km^2) internationally, particularly for surface-forming blooms, and has demonstrated the ability to rapidly reduce algal abundance with minimal environmental concerns. Most efficacy data are derived from non-California HAB species and relatively confined systems; however, little is known about how clay performs against dominant California taxa, including *Pseudo-nitzschia*. Key uncertainties include whether clay removal reduces toxin presence or primarily redistributes toxins to sediments, how dosing strategies perform under varying depths and mixing regimes, and the potential impacts of repeated applications on benthic communities. Participants emphasized that any evaluation of clay-based approaches would require Tier 1 laboratory studies of FIFRA-and FFDCA-compliant clay formulations against multiple HAB taxa relevant to California aquaculture. These studies would need to assess cell removal efficiency, dosing requirements, and toxin fate under simplified conditions. Acute toxicity testing would also need to be conducted to screen for potential non-target organismal effects and to inform regulatory requirements.

Seaweed and bivalve co-culture represent a biological approach that integrates macroalgae alongside shellfish to suppress HABs and reduce toxin exposure through a combination of ecological mechanisms. Conceptually, macroalgae may reduce HAB impacts by competing for nutrients, altering local water chemistry, or releasing allelopathic compounds that inhibit algal growth. Published small-scale laboratory and mesocosm studies (Tier 1 &2) presented during the workshop demonstrated promising reductions in HAB cell densities and, in some cases, reduced toxin accumulation in shellfish, even under conditions of water exchange. These results suggest potential applicability in managed aquaculture environments where spatial boundaries and operational controls are well defined. However, responses appear to be species-specific (for both HAB species and macroalgae) and context-dependent, and the relative importance of nutrient competition, allelopathy, and physicochemical modification remains unresolved. It may also take days to weeks for impacts on HAB species to become evident, so this is not a short-term strategy. Thus, Tier 1 laboratory studies using relevant HAB and seaweed species are needed to inform if similar results are observed for the most commonly cultured bivalve species in California. Additional research is also needed to assess the consistency of performance across seasons and sites, operational feasibility for growers, and potential tradeoffs for cultured species and surrounding ecosystems. Participants emphasized that sustained monitoring of HAB dynamics, shellfish tissue toxins, and water chemistry would be essential to evaluate both effectiveness and reliability.

Sediment disturbance or burial is based on the premise of disrupting benthic life stages or reservoirs that may contribute to bloom initiation or persistence, such as resting cysts or cells that accumulate in sediments. This approach is specific to cyst- or spore-forming HAB taxa such as *Alexandrium, Lingulodinium,* and perhaps *Heterosigma.* This approach may involve physical disturbance, sediment removal, or burial to reduce the availability of viable propagules that can seed future blooms in enclosed or semi-enclosed systems. Conceptually, sediment-based interventions may be most relevant in embayments with aquaculture where local sediment processes are suspected to play a role in recurrent HAB dynamics. However, empirical evidence for efficacy remains limited, and the relationship between sediment reservoirs and subsequent bloom development is not well resolved. In particular, investigations of cyst beds in California are sparse. Participants noted that in some settings sediment disturbance could reduce viable cyst reservoirs, if present, while in others it could resuspend nutrients or cells and potentially exacerbate bloom conditions. Potential benefits must therefore be weighed against risks associated with habitat disturbance and unintended ecological effects. As a result, sediment-focused approaches would require careful, site-specific evaluation supported by sediment monitoring, cyst mapping, and pilot-scale testing (Tier 1 & Tier 2) before being considered viable control tools.

#2. HAB control strategies are unlikely to resolve bloom impacts on marine mammals, commercial and recreational fisheries in California.

Due to the nature of domoic acid-producing *Pseudo-nitzschia* blooms and other blooms that occur along California's open coast, workshop participants agreed that HAB control technologies are not viable to meaningfully reduce HAB effects on marine mammal strandings or for commercial and recreational fisheries. HAB toxins enter marine mammals and key fishery species through bioaccumulation in the food web, as prey organisms consume toxic algae and transfer toxins to higher trophic levels. Since this process occurs over broad geographic areas, the spatial footprint of available HAB control technologies is too limited to reliably reduce exposure for these uses. The most ambitious HAB control efforts globally have been ~100 km^2, and most California *Pseudo-nitzschia* blooms cover significantly larger areas.

An additional challenge for the use of control technologies for these use cases is that current monitoring and forecasting systems, while effective for early warning and impact response, generally lack the spatial and temporal resolution needed to consistently identify bloom initiation points with sufficient lead time to guide control efforts. By the time toxic conditions are detected, blooms are often already widespread or in decline, reducing the potential effectiveness of intervention. Participants also emphasized that *Pseudo-nitzschia* species are common and ecologically important components of the California Current System, with toxin production occurring episodically in response to environmental conditions. This raises concern that non-selective (e.g., against non-toxin producing *Pseudo-nitzschia*) control actions could disrupt broader ecosystem processes or food-web dynamics, contributing to uncertainty and caution around applying HAB control technologies in open coastal systems.

Together, these constraints explain why workshop participants concluded that bloom-scale control of *Pseudo-nitzschia* is unlikely to meaningfully reduce HAB impacts on marine mammals or fisheries in California's open coastal waters. Instead, participants highlighted that effort should focus on mitigation measures (see below) while investigations into long-term prevention (i.e., nutrient control) are ongoing.

#3. Mitigation approaches can meaningfully reduce HAB impacts for multiple uses.

Marine mammal rescue, rehabilitation and assessments can be strategically enhanced to further reduce HAB impacts

Experts agreed that there are no feasible bloom control technologies available now or likely to emerge within the next five years that would meaningfully reduce the number of marine mammals affected by HABs or the frequency of stranding events. Instead, discussions emphasized that improving outcomes for marine mammals will depend on strengthening response, rehabilitation, and post-release assessment systems that are already under significant strain during HAB events. HAB-related strandings differ from other stranding causes in both scale and severity: exposure can occur rapidly and simultaneously across wide geographic areas, often resulting in sudden surges of neurologically impaired animals that overwhelm existing response capacity. These events can coincide with peak tourism or recreation seasons, compounding public safety challenges and increasing demands on responders.

Participants described how HAB-intoxicated animals often present with acute neurological symptoms such as seizures, disorientation, abnormal aggression, and impaired mobility, requiring intensive veterinary care, specialized facilities, and extended treatment timelines. These clinical presentations raise responder safety concerns and require additional staff training, specialized equipment, and controlled environments to protect both personnel and the public. During large events, rehabilitation centers must balance competing priorities, including animal welfare, staff safety, resource limitations, and ethical considerations around treatment intensity and duration. The cumulative toll of prolonged or repeated HAB events also contributes to responder fatigue, emotional strain, and burnout across the stranding network.

A key near-term opportunity identified by participants is the development of updated, HAB-specific treatment and triage protocols informed by lessons learned during recent large-scale events. While the past four years have generated substantial clinical experience, treatment approaches, triage thresholds, and decision-making criteria remain variable across organizations. Standardized protocols could support more consistent care, enable earlier and more informed triage decisions, and help distinguish animals likely to recover from those with low likelihood of survival. Such guidance would improve animal welfare outcomes while ensuring that limited resources are allocated effectively during surge conditions.

Participants also highlighted the need to expand operational rescue and rehabilitation capacity to better accommodate the scale and pace of HAB-related strandings. Unlike isolated incidents, HAB events often require rapid, system-wide scaling of operations, including faster rescue deployment, expanded staffing for animal care and public interaction management, and increased treatment space. Suggested actions include developing plans for temporary or overflow treatment facilities, establishing agreements to share space and personnel across organizations, and increasing the pool of trained responders who can be mobilized quickly during events. Managing animal remains during large mortality events was identified as an additional logistical and emotional challenge, underscoring the need for respectful, efficient, and cost-effective approaches to carcass disposal that reduce strain on response teams.

Finally, participants emphasized that limitations in data collection and management constrain both real-time response and long-term assessment. During active events, managing case data is challenging due to limited staff. Lack of data sharing and data loss can hinder situational awareness, coordination, and communication across the stranding network. Over the longer term, limited capacity to track post-release outcomes leaves uncertainty about treatment success, chronic neurological effects, and population-level consequences of HAB exposure. Enhancing data infrastructure, including streamlined data entry, interoperable databases, and post-release monitoring such as tagging, would strengthen evaluation of rehabilitation outcomes and improve understanding of the long-term impacts of HAB-related illness. Together, these investments represent practical, near-term opportunities to improve marine mammal response and recovery in the absence of viable bloom control options.

To address these challenges, participants proposed a series of targeted workshops focused on strengthening coordination, standardizing practices, and expanding response capacity across the marine mammal stranding network. One proposed workshop would bring together stranding and wildlife health experts to refine HAB-specific field response and rehabilitation protocols, improve triage guidance, assess hospital and overflow capacity, and develop approaches for increasing trained volunteer support during large events. This forum would also support coordination around sample collection, drug handling, data management, and post-release tagging, and help establish a community of practice to share lessons learned across organizations. A second, broader workshop would focus on multi-sector coordination and resource management, with the goal of strengthening data exchange, expanding response and treatment capacity, identifying infrastructure and fundraising needs, and aligning research priorities related to HAB impacts on marine mammal populations. Together, these workshops were viewed as practical, near-term investments to sustain and strengthen the stranding network’s ability to respond effectively to HAB events.

HAB impacts to commercial and recreational fisheries are best managed via mitigation through strategic monitoring program enhancements.

As with marine mammals, workshop participants agreed that there are no feasible bloom control technologies available now or likely to emerge within the next five years that would meaningfully reduce the number of fishery advisories, closures, or opening delays associated with HABs. Discussions of fisheries impacts focused specifically on two categories of use: recreational bivalve harvesting and commercial and recreational crustacean fisheries. In both cases, HAB toxins bioaccumulate through food webs over broad geographic areas and across multiple trophic levels, far exceeding the spatial scale at which bloom control technologies could be applied effectively. Instead, discussions focused on two complementary priorities: enhancements to tissue monitoring systems to ensure continued public health protection if HAB events intensify, and investigate opportunities to minimize the duration, geographic extent, or scope of advisories, closures, and opening delays where possible to preserve recreational and commercial harvesting opportunities.

Participants described how HAB-related advisories and closures affect fisheries in different but overlapping ways. For recreational bivalve harvesting, which encompasses multiple bivalve species across the state, HAB events can result in loss of access to culturally and socially important activities, with impacts often felt most by coastal communities and subsistence users. For crustacean fisheries, HAB-related management actions can lead to substantial economic losses, market disruption, and operational uncertainty. Participants noted that these impacts vary regionally based on the dominant fisheries and monitoring systems in place. North of Point Conception, the Dungeness crab fishery is the primary crustacean fishery and is supported by a systematic pre-season biotoxin testing program that informs season openings and delays. South of Point Conception, crustacean fisheries are comprised of rock crab and spiny lobster, for which no comparable systematic testing program exists, and monitoring relies largely on voluntary sample submissions.

Participants emphasized that the most effective pathway to minimize fishery impacts lies in ensuring public health remains protected from exposure to HAB toxins. For crustacean fisheries, participants noted that a systematic testing framework already exists for the Dungeness crab fishery through coordinated pre-season tissue testing, which provides an established foundation for managing HAB-related risk in much of northern and central California. In contrast, comparable routine testing programs do not currently exist for rock crab and spiny lobster fisheries in southern California, where monitoring relies largely on voluntary or opportunistic sample submissions. This approach could become strained during repeated, large bloom events. Participants therefore identified the need to develop analogous testing pathways for these fisheries, potentially through expanded industry partnerships or engagement of recreational-sector volunteers, to improve situational awareness during HAB events and support management decisions. In addition, participants recommended establishment of certified testing protocols for paralytic shellfish toxins in crustacean tissues, as these toxins are not routinely monitored in crustaceans despite their relevance to public health and fishery management.

Additional recommendations focused on targeted research activities to evaluate whether more spatially and temporally refined fishery management actions during HAB events could still maintain robust public health protections. For crustacean fisheries, participants discussed expanding the Dungeness crab monitoring program to include in-season tissue testing to better characterize how toxin levels vary across management areas. Participants also emphasized integrating tissue testing with environmental monitoring to develop a more complete, habitat-based view of exposure risk by linking crab toxin data with bloom development, oceanographic conditions, and toxin dynamics. Environmental monitoring capacity was noted to be more limited in many northern California regions where the Dungeness crab fishery operates, underscoring the importance of strategically expanding and integrating monitoring efforts in these areas.

For the recreational bivalve fishery, participants identified several research activities aimed at evaluating whether advisories could be limited to specific species or smaller geographic ranges. These included mapping recreational bivalve harvest areas and conducting consumption studies to better understand where harvesting occurs and which species are most commonly consumed, especially by tribal communities or subsistence fishers. Better characterizing the toxin depuration characteristics of important species for consumption was also identified as a useful step to support these evaluations. Participants also discussed expanding the existing volunteer-based bivalve tissue monitoring to support these efforts to broaden the breadth of species tested or to target specific beaches. Lastly, participants discussed investigating the inclusion of emerging rapid toxin testing kits into the volunteer program to assist CDPH with initial sample screening.

#4 Strategic monitoring enhancements are needed to support control and mitigation goals.

Across all use cases, experts emphasized that the effectiveness of both HAB control and mitigation strategies is fundamentally dependent on several strategic enhancements in environmental monitoring and forecasting. Monitoring and forecasting underpin California's HAB management system, linking early detection, public health protection, wildlife response, aquaculture operations, and fisheries management. Without sufficient spatial coverage, temporal resolution, and integration across data streams, even well-designed mitigation or control strategies cannot be implemented effectively or evaluated reliably. Strengthening these systems was therefore viewed not as a standalone investment, but as a prerequisite for improving outcomes across all HAB-impacted uses. Participants also noted that such investments would also support evaluation of the efficacy of long-term HAB prevention measures such as nutrient management.

A priority investment identified by participants is the integration of modeling and field-based studies to better identify where *Pseudo-nitzschia* blooms initiate and how they are transported into nearshore environments. Improved understanding of bloom initiation locations and transport pathways would allow offshore monitoring efforts to be more strategically focused, increasing the likelihood of detecting blooms early enough to support meaningful early warning. Participants noted that many HAB impacts manifest nearshore even when bloom initiation occurs offshore, creating a disconnect between where blooms form and where impacts are observed. Addressing this offshore–nearshore linkage would improve forecasting skill and help managers anticipate downstream impacts to wildlife, fisheries, and aquaculture.

Participants also emphasized the need to expand environmental monitoring for HAB toxins beyond traditional nearshore sampling to include offshore waters and sediments. Offshore toxin monitoring could improve understanding of exposure pathways and inform tissue toxin testing programs by providing earlier indicators of risk, while sediment monitoring could help clarify the role benthic domoic acid reservoirs in bloom recurrence and persistence. It could also characterize the distribution cysts of *Alexandrium* cysts and the potential role of cyst beds in paralytic shellfish toxin distributions.

Experts stressed that expanding monitoring capacity does not require building entirely new programs, but rather strengthening coordination and support for existing efforts. Community-based science monitoring programs, including trained volunteers, Tribal monitoring initiatives, shellfish growers, port-based observers, and local agency partners, already provide valuable observations of water quality and wildlife behavior. When supported with standardized HAB collection protocols, training, and quality assurance, these efforts can substantially increase spatial and temporal coverage. Participants emphasized the importance of integrating these observations into centralized data systems and maintaining clear feedback loops, so contributors understand how their data inform early warning, management decisions, and public communication.

Enhanced analysis of marine mammal samples collected during HAB-related stranding events was identified as another important investment. More comprehensive testing of tissues and fluids from stranded animals would improve understanding of exposure severity, toxin persistence, and recovery trajectories, and directly inform updates to rehabilitation and release protocols. Participants also noted the value of linking rehabilitation data with environmental monitoring and bloom forecasts to improve understanding of exposure thresholds and clinical outcomes. Over time, this feedback could strengthen both clinical response and early warning systems by clarifying which bloom characteristics pose the greatest risk to marine mammals.

Finally, participants highlighted the importance of maintaining and enhancing marine mammal stock assessments and pup counts for species frequently impacted by HABs. Robust population data are essential for accurately quantifying the demographic impacts of HAB-related strandings and distinguishing episodic mortality events from longer-term population trends. Improved population-scale information would also help identify sub-lethal and reproductive impacts that may not be immediately apparent during stranding events, providing critical context for evaluating cumulative HAB effects alongside other environmental stressors.

Appendix 1. Invited Workshop Participants

Don Anderson (WHOI)

Clarissa Anderson (SCCOOS, UCSD)

Taylor Armstrong (UMCES)

Dave Bader (MMCC)

Holly Bowers (MLML)

Kevin Claridge (Mote Marine Labs)

Alissa Deming (PMMC)

Christina Grant (CDPH)

Ali Hossain (CDPH)

Christy Juhasz (CDFW)

Kyla Kelly (OPC)

Hannah Kempf (SWRCB)

Raphael Kudela (UCSC)

Alle Lie (SCCWRP)

Shannon Murphy (OEHHA)

Melissa Peacock (Northwest Indian College)

Allen Place (UMCES)

Ellen Preece (CA DWR)

Jayme Smith (SCCWRP)

Beckye Stanton (OEHHA)

Martha Sutula (SCCWRP)

Steve Weisberg (SCCWRP)

Appendix 2. Workshop Agenda

Day One: Public In person at Orange County Sanitation Board Room and online as a webinar, January 12, 2026

10:00 am Introduction:

- Goal, agenda, and key products: Steve Weisberg, SCCWRP
- Management Motivation: Kyla Kelly, OPC
- Framing the problem: CA coastal HAB problems, overview of uses impacted, mitigation framing and needs: Jayme Smith, SCCWRP

10:30 am Controlling HABs in marine waters: concepts, status, and future prospects: Don Anderson, WHOI

11:00 am Short-term HAB mitigation: US HABs Incubator (HAB-CTI) and relevant research: Allen R. Place & Taylor Armstrong, UMCES

11:20 am Short-term HAB mitigation: Research and implementation of control technologies in Florida waters: Kevin Claridge, Mote Marine Lab

11:40 am Audience Q&A

12:00 pm Lunch

1:00 pm Controlling Impacts to the Use: Marine Mammal Stranding

- Dave Bader, LA Marine Mammal Care Center
- Alissa Deming, Pacific Marine Mammal Care Center

1:45 pm Controlling Impacts to the Use: Aquaculture

- Christina Grant, California Department of Public Health

2:30 pm Break

2:45 pm Controlling Impacts to the Use: Fisheries/Recreation

- Christy Juhasz, California Department of Fish and Wildlife
- Misty Peacock, Northwest Indian College

3:30 pm HAB Detection and Forecasting

Clarissa Anderson, SCCOOS

4:00 pm Audience Comments: Attendees will be asked about other use cases or technologies

4:30 pm Adjourn public portion of meeting

Day Two: Invited expert working group at SCCWRP's Medium Conference Room, January 13, 2026

9:00 am Reflections from day 1 and charge for the day: Steve Weisberg

9:15 am Three simultaneous breakout sessions, all answering the same questions:

a) What control actions are ready to be implemented now?

B) What actions are most worthy of investment towards future implementation?

Breakout group 1: Marine Mammals Use Case

Breakout group 2: Fisheries/Recreation Use Case

Breakout group 3: Aquaculture

11:15 am Report out from breakout groups

Noon: Lunch

1:00 pm Return to breakout groups to add specificity to their recommendations

2:30 pm Break

3:00 pm Return to plenary for final report out

4:00 Final reflections and next steps: Steve Weisberg

4:30 pm Adjourn

Appendix 2. Expanded Summary of Expert Presentations

Session 1: HAB Control Technologies

HAB control research in marine waters has historically lagged behind advancements in monitoring, forecasting, and impact response, despite persistent public and management interest in these types of interventions. Although interest in HAB control has increased over the past two decades, marine applications still represent a small fraction of HAB research globally, underscoring that this remains an emerging and highly constrained field, particularly for open coastal systems.

HAB control research in the U.S. follows a tiered framework. Tiered evaluation allows ineffective or risky approaches to be screened out early, reducing ecological risk and wasted investment. This framework begins with laboratory and small-scale tests (Tier 1), progresses to controlled mesocosm or semi-enclosed field experiments (Tier 2), and only advances to larger-scale field trials (Tier 3) when efficacy, environmental safety, and feasibility are demonstrated. This approach reflects both scientific caution and regulatory necessity. Most proposed HAB control technologies are not ready for deployment and are in Tier 1 and Tier 2 stages of research. Only a few technologies to date have reached Tier 3.

Major considerations for advancing HAB control research

Regulatory considerations strongly shape the trajectory of HAB control research in the United States. Under federal law, any chemical added to water to control algae is classified as a pesticide and must comply with the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). In addition, the Federal Food, Drug, and Cosmetic Act (FFDCA) requires assurance that no harmful residues remain in seafood species.

Together, these statutes create barriers to both testing and implementation in marine waters, particularly where fish and shellfish are present. The cost, duration, and complexity of regulatory approval have limited innovation and incentivized the use of specific regulatory ‘minimum risk’ or ‘exempt’ status (FIFRA 25b) compounds, even when potentially more effective options exist. Regulatory feasibility therefore functions as a primary filter determining which HAB control strategies can realistically be pursued.

Beyond scientific and regulatory hurdles, practical considerations can also limit HAB control feasibility. These include the spatial extent and depth of blooms, the volume of water requiring treatment, material and deployment costs, and the availability of infrastructure capable of delivering treatments efficiently. Even modest treatment areas can require large quantities of material and extended deployment times, highlighting the importance of matching technologies to appropriate habitats, species, and management objectives.

Key considerations for control technologies in California

It is unlikely that any one HAB control measure will be broadly applicable across California's open coastal waters. Domoic acid–producing *Pseudo-nitzschia* represents the most prevalent HAB issue affecting California's coastal waters and are a desirable target for potential bloom control actions. Domoic acid–producing *Pseudo-nitzschia* blooms are not a single, uniform phenomenon, instead bloom dynamics differ among California's coastal subregions, indicating that management and potential control strategies are unlikely to be one-size-fits-all. Dozens of *Pseudo-nitzschia* species occur in California waters and are a common members of the phytoplankton community. Only a subset produce domoic acid, and toxin production is not constitutive but instead triggered by specific environmental conditions. Research over the past two decades has identified several of the fundamental drivers that influence *Pseudo-nitzschia* bloom development and toxicity, including coastal upwelling, regional circulation patterns, nutrient enrichment and shifting nutrient ratios, and seasonal to interannual variability in physical conditions. These advances have supported the development of predictive tools and forecasting frameworks, although bloom initiation, toxicity, and duration remain highly variable across regions and events.

Other HAB issues also affect California's coastal waters, including large blooms of dinoflagellates (e.g., *Lingulodinium* and *Akashiwo) and raphidophytes (e.g., Heterosigma)*, paralytic shellfish toxin–producing species such as *Alexandrium*, and the transport of cyanotoxins from inland waters to coastal environments. Compared to *Pseudo-nitzschia*, the understanding of bloom dynamics, toxin triggers, and environmental controls for these HAB types is substantially less advanced, limiting the ability to predict their occurrence and assess the feasibility of management or control actions.

Approaches to HAB Control

HAB control technologies fall into three main categories: physical, chemical, or biological controls. Physical control approaches aim to remove, concentrate, or disrupt algal cells or bloom conditions through mechanical or hydrodynamic means, such as sedimentation, mixing, or physical barriers, and generally seek to reduce cell abundance without relying on chemical toxicity. Chemical control approaches use compounds intended to inhibit algal growth, lyse cells, or neutralize toxins, and can range from naturally derived substances to synthetic formulations, with effectiveness and regulatory feasibility varying widely depending on composition, dosage, and environmental context. Biological control approaches rely on ecological interactions, such as grazing, allelopathy, parasitism, or competition, to suppress HAB populations or reduce toxin transfer through food webs.

Physical approaches include clay-based approaches, which are among the most mature and widely implemented form of marine HAB control globally. These methods involve dispersing fine clay particles into surface waters, where they flocculate algal cells and promote their removal from the water column through sedimentation, thereby reducing cell concentrations and, in some cases, associated toxins. International applications have relied on modified clay formulations deployed repeatedly over large spatial scales, often with limited short-term ecological impacts reported in monitored systems. In the United States, recent efforts in Florida have explored clay-based approaches as part of a broader red tide mitigation program, using clay formulations composed of FIFRA- and FFDCA-compliant materials and integrating clay with other minimum-risk compounds and deployment technologies. Field trials in canals and nearshore settings have demonstrated substantial reductions in *Karenia brevis* cell concentrations, highlighting the potential for clay-based removal in spatially constrained or managed environments when supported by strong monitoring, regulatory coordination, and deployment infrastructure. However, differences in HAB species, coastal oceanography, and regulatory context limit direct transferability to California. Significant uncertainties remain regarding the effectiveness of clay dispersal for California's dominant HAB taxa, particularly *Pseudo-nitzschia*, as well as its feasibility in highly dynamic open coastal systems, where water depth, mixing, sediment resuspension, toxin fate, and food-web interactions may strongly influence both efficacy and ecological outcomes.

Beyond physical disruption via clay, deep-water upwelling or aeration, have proven effective in specific fish farming contexts internationally but rely on site-specific conditions and may be challenging to achieve in open coastal systems.

Biological approaches, such as seaweed co-culture or virus-based control, have demonstrated the ability to suppress certain HAB species under experimental or aquaculture conditions. These approaches may offer environmentally attractive options in confined or managed settings, but their effectiveness in open coastal waters remains uncertain due to dilution, hydrodynamic exchange, and species-specific responses.

Among these biological approaches, seaweed co-culture has received particular attention as a potential HAB mitigation strategy in aquaculture and other managed marine environments. By integrating macroalgae alongside shellfish or finfish, this approach can suppress HAB species through a combination of allelopathic chemical release, competition for dissolved nutrients, and localized modification of water chemistry, including elevated pH. Results presented during the workshop highlighted several small-scale laboratory and mesocosm studies in which macroalgae substantially reduced cell densities of HAB taxa, including *Pseudo-nitzschia*, and in some cases reduced toxin accumulation in bivalves, even under conditions of water exchange. These findings suggest that seaweed co-culture may offer a viable mitigation pathway in controlled or semi-controlled environments. However, observed responses are highly species- and context-dependent, and the mechanisms driving suppression are not fully resolved. In open coastal systems, hydrodynamic exchange may dilute allelopathic compounds and limit effectiveness, and there is limited evidence regarding how dominant California HAB taxa, particularly endemic *Pseudo-nitzschia* strains, would respond at operational scales. Similarly, little work has been done using California relevant seaweed species.

An illustrative example of viral-based HAB control comes from large-scale applications targeting specific dinoflagellate species in shellfish aquaculture systems in East Asia. In this approach, sediments containing high concentrations of naturally occurring, species-specific algal viruses were collected, preserved, and periodically dispersed into affected waters to suppress blooms. Field applications focused on blooms of *Heterocapsa circularisquama*, where monthly spraying of virus-rich sediment over areas on the order of several square kilometers resulted in substantial reductions in target cell densities throughout the bloom season. The effectiveness of this approach relied on strong host specificity, high viral titers, and relatively confined hydrodynamic conditions that allowed sufficient contact between viruses and host cells. While this example demonstrates that viral control can be operationally effective at large spatial scales under certain conditions, its applicability to California would require resolving key uncertainties, including the lack of identified viral agents for dominant California HAB taxa such as *Pseudo-nitzschia*, and differences in coastal circulation and mixing regimes. A clear understanding of ecological risk, food-web interactions, and regulatory feasibility in open coastal environments is also needed.

Chemical control approaches composed of plant-derived or otherwise exempt compounds have shown partial success in laboratory, mesocosm, and limited field trials. However, results are highly species-dependent, and reductions in cell abundance do not always correspond to reductions in toxin concentrations. Cost, delivery logistics, and degradation rates further constrain applicability at scale.

Session 2: California HAB Impacts and Monitoring Systems

HAB related Marine Mammal Stranding Events

HABs sicken marine mammals through exposure to algal toxins that accumulate in their prey. Domoic acid enters the food web when fish and invertebrates consume toxin-producing *Pseudo-nitzschia*, and marine mammals are exposed when they feed on contaminated prey. Domoic acid is a potent neurotoxin that overstimulates nerve cells, leading to seizures, disorientation, abnormal behavior, and, in severe cases, brain damage or death. Exposure can occur rapidly during bloom events and may be acute or chronic, with repeated low-level exposure contributing to long-term neurological and reproductive effects. Because blooms and toxin uptake can occur before obvious surface signs are visible, marine mammals are often affected suddenly and at large scales during HAB events.

Marine mammal rescue and rehabilitation efforts are the primary mechanism in place to mitigate the impacts that HABs cause on marine mammals. HAB stranding response in California is carried out by a coordinated network of trained organizations responsible for detecting strandings, rescuing live animals, conducting triage and medical treatment, collecting biological samples, and documenting causes of illness or mortality. These efforts serve both animal welfare and public health functions, while also providing critical data on ecosystem stressors such as HAB toxins. During HAB events, stranding networks experience sharp increases in the number, geographic extent, and clinical severity of stranding cases, particularly among species that consume toxin-exposed prey. Most commonly, these are California Sea Lions, but can also include whales, dolphins, sea otters, and a variety of other pinniped species. Animals affected by domoic acid frequently present with acute neurological symptoms, including seizures and disorientation, requiring rapid response, intensive veterinary care, and prolonged rehabilitation. HAB-related strandings are especially challenging because exposure can occur quickly and simultaneously across wide areas, often before blooms are fully detected or forecasted. As a result, response efforts must rapidly scale up staffing, facilities, and coordination across agencies, often under significant logistical and resource constraints.

Bivalve Aquaculture

HAB impacts to aquaculture are managed primarily through a precautionary public health framework designed to prevent human illness from shellfish consumption. Marine biotoxins produced by HAB species can accumulate rapidly in bivalve shellfish without visible indicators and are not destroyed by cooking, making early detection and harvest controls essential. As a result, California’s approach to protecting shellfish consumers relies on routine monitoring and rapid management response rather than direct bloom suppression, with oversight provided through the state’s Marine Biotoxin Monitoring Program, implemented by the California Department of Public Health.

Monitoring integrates phytoplankton observations, water sampling, and, most critically, shellfish tissue testing. A statewide network of partners and volunteers collects phytoplankton samples to track the presence of toxin-producing species, while management actions are triggered by measured toxin concentrations in shellfish tissue relative to established health thresholds. Commercial shellfish aquaculture operates under a preharvest control program overseen by the California Department of Public Health, with site-specific sampling requirements that reflect local conditions and toxin history. Sentinel species, such as mussels, are often used as early indicators of risk, and monitoring programs in embayments account for the lag between offshore bloom development and toxin accumulation within growing areas.

Within this regulatory and monitoring context, workshop participants emphasized that any consideration of HAB control technologies for aquaculture must complement and will not replace existing food safety protections. Shellfish harvest decisions would continue to rely on tissue testing and established health thresholds, regardless of whether control approaches are tested or deployed. As a result, potential HAB control strategies were discussed as tools that might, if proven safe and effective, reduce the frequency or severity of toxin accumulation events at specific, well-defined growing sites.

Commercial and Recreational Fisheries

HAB impacts to commercial and recreational fisheries are managed through precautionary public health and fishery management frameworks designed to prevent human exposure to marine biotoxins. Management is a collaborative effort across multiple programs and agencies within the California Department of Public Health (CDPH), California Department of Fish and Wildlife (CDFW) and California Office of Environmental Health Hazard Assessment (OEHHA). A key management challenge is that domoic acid can accumulate in a wide range of fishery species via a variety of mechanisms and uptake and depuration rates vary significantly among managed species meaning toxins may persist in tissues well after blooms dissipate.

The Dungeness crab biotoxin monitoring program is designed to protect public health while supporting timely fishery openings through coordinated pre-season and in-season testing for domoic acid. Sampling is conducted across defined biotoxin management areas, with results used to inform recommendations regarding season openings, delays, closures, and re-openings based on established federal action levels. This spatially explicit approach allows management actions to reflect regional differences in toxin exposure rather than applying coastwide restrictions.

Pre-season testing plays a critical role in determining whether the fishery can open as scheduled, while in-season testing is used to track evolving risk during HAB events and inform adaptive management decisions. Coordination among state agencies, testing laboratories, and industry partners supports sample collection, analysis, and communication of results. Together, these programmatic elements provide a precautionary yet flexible framework that balances consumer safety with the goal of minimizing unnecessary disruption to the Dungeness crab fishery.

Management of recreational bivalve harvest in California is structured around the same core public health principles used for commercial shellfish aquaculture but implemented through advisories rather than preharvest certification. Oversight is provided by the California Department of Public Health, which issues recreational health advisories when marine biotoxins such as domoic acid or paralytic shellfish toxins are detected at levels of concern. Management actions are driven by measured toxin concentrations in shellfish tissue relative to established health thresholds, rather than by visible bloom conditions, reflecting the ability of toxins to accumulate without obvious indicators.

A key programmatic element is the annual statewide mussel quarantine, which prohibits recreational harvest of mussels during historically high-risk months and provides a broad, precautionary layer of protection. Outside the quarantine period, advisories are informed by shellfish tissue testing conducted through a combination of agency sampling and volunteer-based monitoring programs, in which trained partners collect shellfish samples from designated locations to supplement agency coverage. While the overall management approach mirrors that used for bivalve aquaculture, relying on tissue testing, defined health thresholds, and precautionary reopening criteria, the decentralized nature of recreational harvest necessitates broader geographic advisories and a strong emphasis on public communication.

Presentations highlighted how HAB-related advisories and closures affect fisheries in distinct but overlapping ways. For commercial fisheries such as Dungeness crab, domoic acid events can delay season openings, constrain fishing areas, and create uncertainty that affects market timing, fishing effort, and economic viability. While these systems are effective at protecting consumers, HAB events can still result in substantial economic losses when toxin presence persists or expands spatially. Recreational and subsistence fisheries experience additional social, cultural, and food security impacts, including loss of access to traditional harvesting areas, disruption of intergenerational knowledge transfer, and erosion of confidence in when and where seafood is safe to consume. For Tribal communities and subsistence harvesters, these impacts can be particularly acute, as closures and advisories affect not only recreational opportunity but also cultural practices, dietary reliance, and treaty- or tradition-based relationships with coastal resources. Participants emphasized that meaningful engagement with Tribal governments and subsistence communities, along with monitoring approaches that reflect where and how harvesting occurs, is critical to ensuring HAB management strategies equitably protect public health while respecting diverse uses of coastal fisheries.

HAB Monitoring

Workshop presentations emphasized that monitoring is the most mature and foundational component of California's HAB management toolbox, providing the information needed to support public health protection, wildlife response, fishery management, and any future consideration of HAB control. California has invested in a diverse, research-driven monitoring network over the past two decades, including nearshore sampling programs, automated imaging technologies, satellite-based products, and numerical models. Together, these systems provide situational awareness of bloom development, toxin risk, and ecosystem impacts, and form the backbone of early warning and response efforts.

Presentations highlighted that no single monitoring approach is sufficient on its own, given the highly dynamic and spatially heterogeneous nature of HABs along the California coast. Nearshore monitoring programs and pier-based sampling provide long-term continuity and valuable local context but are limited in their ability to detect blooms that initiate offshore or below the surface. High-frequency tools such as the California Imaging FlowCytobot (IFCB) Network have revealed bloom dynamics and alongshore variability that were previously unobservable, including rapid changes in population structure and south-to-north bloom propagation. However, these systems do not directly measure toxins and require substantial investment in maintenance, data processing, and regional calibration. Satellite-based and model-driven products, such as the California Harmful Algae Risk Mapping (C-HARM) system, provide the only synoptic view of offshore bloom and toxin risk and have proven valuable during large marine mammal stranding events, though they are probabilistic in nature and constrained by spatial resolution and data availability.

Presentations emphasized that the strength of California's monitoring enterprise lies in the integration of complementary data streams rather than reliance on any single tool. Efforts to synthesize observations, models, and biological data, such as the HAB Bulletin and the HAB Data Assembly Center, were highlighted as critical for translating complex information into actionable products for managers and responders. At the same time, participants noted that monitoring systems are inherently regional, shaped by legacy observations, local oceanography, and species composition, and that optimal placement of sensors and platforms remains an ongoing challenge. Looking forward, presenters emphasized the need to sustain and enhance monitoring capacity, strengthen cyberinfrastructure, and advance toward food-web–relevant indicators that better link bloom dynamics to ecological and human health outcomes.