Framing the Scientific Opportunities on

Harmful Algal Blooms and California Fisheries

Scientific Insights, Recommendations and Guidance for California

Developed by a working group of the Ocean Protection Council Science Advisory Team and California Ocean Science Trust

OCTOBER 2016

About the Contributors and Planning Team

California Ocean Science Trust

Ocean Science Trust is an independent, non-profit organization that brings together governments, scientists, and citizens to build trust and understanding in ocean and coastal science issues. We empower participation in the decisions that are shaping the future of our oceans. We were established by the California Ocean Resources Stewardship Act to support managers and policymakers with sound science. For more information, visit our website at www.oceansciencetrust.org.

Ocean Protection Council Science Advisory Team Working Group

This report has been approved by the Ocean Protection Council Science Advisory Team (SAT). The purpose of the SAT is to provide scientific advice to California's ocean and coastal state agencies and entities. The work of the Ocean Protection Council Science Advisory Team is managed by California Ocean Science Trust and supported by the California Ocean Protection Council.

Ocean Science Trust convened the "Harmful Algal Blooms and California Fisheries" working group of the SAT at the request of the Interagency Harmful Algal Bloom Task Force. Working group members include Dave Caron (University of Southern California), William Cochlan (San Francisco State University), Raphael Kudela (University of California, Santa Cruz), and Gregg Langlois (California Department of Public Health, retired) (see Appendix A for brief member biographies). Tom Maloney, Ocean Science Trust Executive Director and Science Advisor to the Ocean Protection Council, participated in the workshop and provided a link between the working group and the full SAT. Emily Knight, Ocean Science Trust Program Director, also participated in the workshop and provided staff guidance and support throughout the working group process. For more information about the working group, visit http://www.oceansciencetrust.org/project/harmful-algal-blooms-and-california-fisheries.

Interagency Marine Harmful Algal Bloom Task Force

The Interagency Harmful Algal Bloom Task Force (Task Force) was established by the Ocean Protection Council in early 2016. Task Force members include Sonke Mastrup (California Department of Fish and Wildlife), Susan Ashcraft (California Fish and Game Commission), Patrick Kennelly (California Department of Public Health), Susan Klasing (Office of Environmental Health Hazard Assessment), Valerie Termini (California Fish and Game Commission), and Jennifer Phillips (California Ocean Protection Council). During the winter of 2016-17, the Task Force will help guide the working group in developing a longer term management document about what information and investments are needed to better predict and plan for future events. The Task Force will also review and update standard operating procedures that will be utilized by the agencies responsible for oversight of public health and fisheries.

Acknowledgements

Funding was provided by the California Ocean Protection Council. In addition to members of the Task Force and SAT working group, Ocean Science Trust would like to thank the following individuals for informing this report: Vera Trainer, Robert Dickey, Pete Kalvass, Jerry Borchert, Kimberly Selkoe, Carrie Pomeroy, Carrie Culver, Joe Tyburczy, Kathi Lefebvre, and Stacey Degrasse.

Contacts

Errin Ramanujam, Senior Scientist, errin.ramanujam@oceansciencetrust.org
Hayley Carter, Program Scientist, hayley.carter@oceansciencetrust.org

Citation: *Framing the Science Around Harmful Algal Blooms and California Fisheries: Scientific Insights, Recommendations and Guidance for California*. 2016. California Ocean Science Trust, Oakland, CA.

Cover image credits: background image (Monterey harbor) - Blok 70, creative commons; circle inset left (research cruise) - Cochlan Ecophysiology Lab, RTC-SFSU; circle inset middle (*Pseudo-nitzschia australis*) - Charles Wingert, Cochlan Ecophysiology Lab, RTC-SFSU; circle inset right (Pillar Point Harbor, Half Moon Bay) - Sheraz Sadiq, creative commons.

California Ocean Protection Council OPC-SAT Science Advisory Team

CALIFORNIA OCEAN SCIENCE TRUST

CALIFORNIA OCEAN PROTECTION COUNCIL

Funding provided by the California Ocean Protection Council

Table of Contents

About this Document

This report is meant to provide a "menu" of scientifically robust options for consideration by California's public health and natural resource management agencies and the State Legislature. It will inform conversations about next steps to address harmful algal blooms (HABs) and their impacts on fisheries and coastal communities, as well as a second phase of the "Harmful Algal Blooms and California Fisheries" SAT working group to be convened by Ocean Science Trust in 2017. It is our intent that the recommendations contained here also stimulate independent research efforts, partnerships, and funding opportunities for HAB-related science.

This report was developed in response to the 2015-16 domoic acid event on the U.S. West Coast that impacted major California fisheries. Given climate-induced changing ocean conditions and the increasing threat of HABs to coastal economies, California aims to strengthen its seafood biotoxin sampling and phytoplankton monitoring programs, as well as advance our understanding of and ability to predict HAB events and their impacts on fisheries.

In response to this event, California Ocean Science Trust convened a four-member working group of the Ocean Protection Council Science Advisory Team (SAT) (see Appendix A) at the request of the Ocean Protection Council and the Interagency Marine Harmful Algal Bloom Task Force (Task Force). On June 27, 2016, Ocean Science Trust led a workshop (see Appendix B) with working group members to begin addressing these topics:

- State of the science on West Coast HABs
- Guidance on strengthening existing HAB and biotoxin monitoring in California
- Information needs and gaps between government actions and scientific understanding
- State and federal agency resource needs to accommodate incorporation of greater scientific understanding and capacity

This report, developed by working group members in partnership with Ocean Science Trust, is a summary of high-level messages from workshop discussions, conversations with individual working group members, and consultation with additional experts. This work is complementary to a "Frequently Asked Questions" document released by Ocean Science Trust in early August 2016[1].

The goals of this working group were to:

- *Reflect on our current understanding of HABs in light of the 2015-16 domoic acid event.*
- *Identify primary science needs to better understand HABs and minimize impacts.*
- *Provide initial scientific insights for improving monitoring and responding to HAB events that capitalize on the State's existing research and monitoring programs.*
- *Provide a starting point for identifying priority focal areas for the next phase of the "HABs and California Fisheries" working group and other science based opportunities as we prepare for future toxic bloom events in California.*

Throughout this document, the 2015-16 domoic acid event is used as an example for understanding, learning from, and elucidating three principal perspectives on HABs:

1. ocean conditions that contributed to such a toxic *Pseudo-nitzschia* bloom event;
2. major science gaps about HAB events and their impact on marine fauna and fishing communities; and
3. the successes and shortcomings of our current HAB monitoring and response network (e.g., human health, fishery management, sustainability of monitoring efforts and response, etc.).

This report highlights several key characteristics of the 2015 *Pseudo-nitzschia* bloom as representative of a particularly high-impact HAB event, and provides science recommendations to support California agencies in making decisions about monitoring and responding to HAB events in the future.

[1] See *Frequently Asked Questions: Harmful Algal Blooms and California Fisheries, Developed in Response to the 2015-2016 Domoic Acid Event* (California Ocean Science Trust, 2016), available at: http://www.oceansciencetrust.org/wp-content/uploads/2016/09/HABs-and-CA-Fisheries-FAQ-8.5.16.pdf

I. Lessons Learned from the 2015-16 Domoic Acid Event

Background

In the spring and summer of 2015, an unprecedented HAB dominated by the toxigenic diatom *Pseudo-nitzschia australis*[1] (also referred to here as *P. australis*) stretched from Santa Barbara, California to southeastern Alaska. The bloom impacted major commercial and recreational fisheries in California in 2015 and 2016, including Dungeness crab and rock crab, and led to multiple and prolonged fishery closures and health advisories. The bloom resulted in some of the highest concentrations of the neurotoxin domoic acid ever observed in California seafood. Given the extensive geographic range and longevity of the bloom, the levels of toxicity observed in multiple marine species, and the socioeconomic impacts to California's fishing industry, this event was unprecedented from a scientific, human health, and natural resource management perspective. .

Phytoplankton growth and biomass accumulation (i.e., blooms) is a complex interplay of temperature, nutrient and light availability, and interactions with other organisms such as zooplankton grazers and bacteria. Scientists are still working to understand the environmental drivers of HABs, including when events occur, physiological responses of phytoplankton, and the oceanographic conditions that lead to highly toxic bloom events rather than benign phytoplankton blooms (Anderson et al., 2015). While research on HABs in coastal California has primarily focused on *Pseudo-nitzschia* species, there are numerous other toxic and harmful algae and cyanobacteria including the dinoflagellates *Alexandrium, Dinophysis, Cochlodinium, Gonyaulax, Protoceratium, A. sanguinea*, the raphidophyte *H. akashiwo*, and the cyanobacteria *Microcystis* (from coastal freshwater sources) that also pose a potential threat to ecosystems here (Anderson et al., 2015). Although many of these species produce biotoxins at low levels under normal conditions, there is limited scientific understanding of the physiological processes that lead to the production of significantly elevated levels of toxin. For toxigenic diatoms like *Pseudo-nitzschia*, it is becoming clear that the environmental factors that promote cellular growth leading to such blooms are not necessarily the same as those that control biotoxin production (i.e., whether more toxin is present due to high biomass blooms vs. more toxin produced per individual cell). Research is underway to unravel these relationships, and determine which are ecologically significant in the development of toxic blooms in natural marine ecosystems.

[1] *Pseudo-nitzschia* is a marine planktonic diatom genus that includes many individual species, some of which are capable of producing the neurotoxin domoic acid (e.g., *Pseudo-nitzchia australis*, also referred to here as *P. australis*).

Reflecting Back

The causes of the 2015-16 domoic acid event are consistent with climate change, though much is still unknown about the environmental conditions that lead to toxic bloom events.

The 2015 bloom was a consequence of a series of abnormal ocean conditions in the Pacific Ocean, including a large mass of warm water that developed in the North East Pacific Ocean during 2013–2014, named "The Blob" (Bond et al., 2015), combined with warm water driven by El Niño (Figure 1). High levels of domoic acid accumulated in the food web (McCabe et al., 2016) and the benthic environment, leading to very toxic marine organisms months after the toxic phytoplankton bloom dissipated. For example, some species like razor clams in Humboldt and Del Norte, California remained above the Food and Drug Administration's (FDA) action level[2] more than one year after the initial bloom event.

Temperature linkage

Oddly, *Pseudo-nitzschia* is not typically a "warm water" harmful algal species. It has generally been a spring (and sometimes fall) bloomer on the West Coast fueled by cooler, recently upwelled nutrient-rich waters (e.g., Schnetzer et al., 2013; Trainer et al., 2009 a,b). However, based on this most

[2] Action levels represent limits at which FDA will regard the food product "adulterated"; and subject to enforcement action.

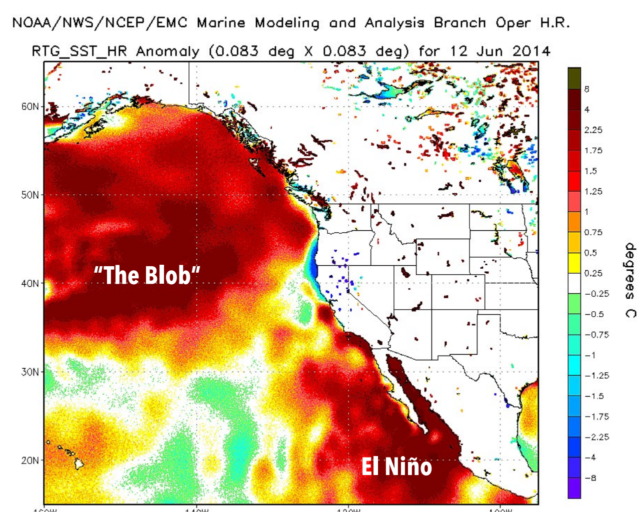


Figure 1. The 2015 *P. australis* bloom event was a consequence of a large mass of warm water termed "the blob" and warm water driven by El Niño.

Credit: NOAA/NWS/NCEP/EMC Marine Modeling and Analysis Branch recent event, there appears to be a correlation between the warm water blob, *P. australis* growth, and elevated domoic acid levels (McCabe et al., 2016). Temperature allowed these cells to grow quickly, and both outcompete non-toxic phytoplankton and even other *Pseudo-nitzschia* species. The toxic bloom did not develop in regions of southern California (south of Ventura County), which were likely too warm to support *P. australis* growth. The development of the bloom in the Pacific Northwest was likely due in part to the anomalously warm waters, which brought that region closer to "typical" conditions in northern and central California.

As far as whether we can we expect more toxic blooms during warmer years, it is difficult to predict which species are likely to occur based on temperature alone. Phytoplankton, including toxin-producing species, each have optimum temperature ranges that are conducive to blooms (see Lewitus et al., 2012 for a review of "Harmful algal blooms along the North American west coast region: History, trends, causes, and impacts"). However, warming sea surface temperatures globally and off California's coast (Figure 2) are projected to expand the seasonal period over which most phytoplankton can grow (based on the relationship of increasing temperature associated with intrinsic growth rates), potentially enhancing the risk of exposure to and negative impacts from dangerous toxins from species capable of biotoxin production (Moore et al., 2008). A warmer Eastern Pacific with localized upwelling is predicted to statistically increase the chance of more large-scale bloom events in the future.

Upwelling and nutrient linkage

Generally, coastal phytoplankton blooms are supported by seasonal upwelling, driven by winds that force deep, nutrient-rich, cool water to the surface ocean. These nutrients fuel phytoplankton growth (the base of the marine food web), which drives the biodiversity and rich fisheries along the U.S. West Coast. Despite warm temperatures, upwelling continued in 2014 and 2015, potentially providing nutrients that stimulated the toxic bloom. However, nutrient dynamics during the course of the 2015-16 bloom are not well understood given the lack of in situ measurements, and little is known about the variance in phytoplankton species' ability to acquire these nutrients. Thus, HABs that occur in upwelling centers like California cannot be easily characterized using simple relationships (Kudela et al., 2010). The link between nutrients, upwelling, climate variability, and toxic blooms is complicated, and remains an area of debate and a research need (Rykaczewski and Dunne, 2010; Kudela et al., 2010).

Ocean acidification

While the 2015-16 bloom has not been directly linked to CO_2-induced ocean acidification, changes in seawater carbonate chemistry and the resultant reduction in pH due to the increase in the partial pressure of CO_2 (pCO_2) also are likely to influence phytoplankton species assemblages and possibly even toxin production in diatoms. Our understanding of the potential impacts of ocean acidification on HAB species is severely limited, and based on relatively few laboratory studies, many of which are contradictory.

Some studies in *Pseudo-nitzschia* have shown 2-3 fold increases in cellular domoic acid concentrations under reduced pH levels when cultures are nutrient limited (Sun et al., 2011; Tatters et al., 2012), whereas others have reported cellular domoic acid increasing up to 70-fold at elevated pH levels (Lundholm et al., 2004; Trimborn et al., 2008). The relationship between ocean acidity and the growth rate achieved by *Pseudo-nitzschia* species is equally confusing since culture studies have shown that elevated pCO_2 results in either increased (Sun et al., 2011; Tatters et al., 2012), decreased (Lundholm et al., 2004), or no change in growth rate (Cho et al., 2001) depending on the species of *Pseudo-nitzschia* and experimental conditions employed. These effects will need to be verified and extended to other

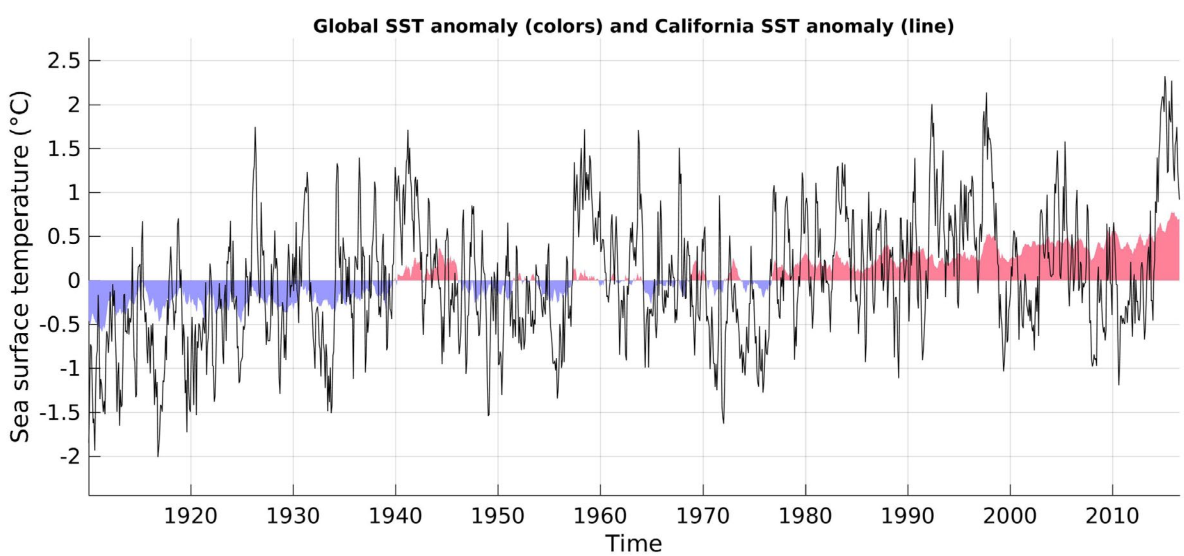


Figure 2. Global and California sea surface temperature (SST) anomalies from 1915 to present. Warmer temperatures may increase the chance of more large-scale bloom events.

Credit: Monique Messie, MBARI

toxigenic HAB organisms, given the complexity of natural ecosystems (Anderson et al., 2015). It is also unknown whether the effects of acidification and temperature are synergistic or antagonistic. In other words, do warming and acidification work together to enhance toxicity, or do these environmental stressors work against each other to reduce toxin production?

Main Lessons Learned

California was successful in protecting human health, but the socioeconomic impacts were considerable.

From a human health perspective, the various state agencies involved in California's fishery and biotoxin management successfully prevented human illness[3] due to the elevated levels of domoic acid that entered the marine food web in 2015-16. The California Department of Public Health (CDPH), the California Department of Fish and Wildlife (CDFW), and independent scientists throughout the State, were able to detect and track bloom progression and toxin transport, and communicate across the appropriate agencies to protect the health and safety of seafood consumers. However, from a socioeconomic perspective, California's commercial crab fishing industry was hit incredibly hard. The direct economic impact from commercial closures was estimated at approximately $30 million for the Dungeness and rock crab fisheries, in addition to the substantial but unquantified impacts to other commercial, recreational, and aquaculture shellfish and finfish fisheries. Alleviating these impacts should be considered in any future research and monitoring efforts (see Recommendation 1).

With blooms likely to become more common in the future, the scientific community can help.

As harmful phytoplankton blooms are expected to become more common in an era of global change, science can play a valuable role in helping decision-makers develop innovative science-based strategies. While even the best scientific models cannot predict the future with certainty, there are opportunities to advance our understanding of HABs and add resources to increase the capacity of the State's existing monitoring program to better track future HAB events and potentially minimize socioeconomic impacts.

[3] No cases of amnesic shellfish poisoning were officially confirmed during the 2015-16 domoic acid event.

Scientific Insights to Prepare for Future HAB Events

California fishing industries and state agencies should expect and prepare for more unusual bloom events along our coastline.

There is mounting scientific evidence that the effects of HABs on public health, marine and freshwater ecosystems, economies, and human social structures are worsening. It is generally accepted that HABs are increasing in frequency, magnitude, intensity, and duration in all aquatic environments on a global scale and along the U.S. West Coast (Moore et al., 2008). Eutrophication (excessive nutrients that lead to dense algal growth and subsequent oxygen declines), increasing sea surface temperatures, ballast water dispersal, and improved monitoring (i.e., greater detection due to better/more monitoring) are the most cited factors for the increased frequency of reported blooms. However, the links are poorly understood. For example, we do not yet understand what causes a HAB species to begin producing a toxin, as well as their various responses to environmental factors (e.g. cellular growth rate and toxicity). We do not yet fully understand the response of phytoplankton species to their environment, regardless of whether the stressors are natural or man-made.

Given the multi-year picture of oceanographic conditions of the California current, scientists suggest that it is very likely HAB events that have negative consequences for coastal communities will occur more frequently off the coast of California. It is impossible to predict with certainty whether future blooms will be of the same magnitude, which algal species or toxins will dominate, when and where a toxic bloom will occur, or which harvested species will be impacted. Therefore a scientifically robust approach that utilizes monitoring, empirical data, predictive modeling, and research is needed (and discussed further below).

Any monitoring and biotoxin program should be scalable and have the flexibility to track and respond to an array of biotoxins, HAB species, and fishery impacts.

The major difficulty in managing for HABs is the breadth of species, life histories, ecosystems and impacts involved (Anderson et al., 2015). Off the Pacific Coast of North America, there are many different harmful algal species capable of producing different toxins, and they often respond to somewhat different environmental drivers (Lewitus et al., 2012). Investing in or developing a monitoring program focused too narrowly on one species of phytoplankton, a single toxin, or single fishery may result in being caught off guard for a future event. This is especially true with climate change, which disrupts historical patterns and can lead to emergence of new problem species. Because of this, California needs to develop a balanced research and monitoring approach that is cost-effective while also broad enough to capture the unpredictable nature of HAB events under changing ocean conditions (see Recommendation 1).

Working group members all agreed that CDPH Marine Biotoxin Monitoring Program and Phytoplankton Monitoring Program and CDFW have a robust framework in place to build upon as it can allow for enhanced HAB research and monitoring efforts. The 2015-16 event helped identify where additional capacity is needed. California's biotoxin monitoring and response programs have been historically focused on commercial and recreational bivalve shellfish, and not offshore fisheries. CDPH currently maintains a baseline monitoring program for phytoplankton and shellfish toxins, increasing that effort when toxin-producers or toxins are detected. For non-bivalve shellfish and finfish, massive toxicity events in California have been sporadic in the past. Thus, comprehensive comprehensive biotoxin monitoring plans for every commercial and recreational species have not been developed or funded. As these events increase in frequency and distribution, and potentially impact more fisheries, California will likely have to expand proactive sampling programs for offshore fisheries (as opposed to reactive testing once an event has occurred). Important considerations for the State include which additional fisheries should be sampled, when and how frequently fishery sampling occurs, how samples are obtained, and how these additional efforts are funded. An initial understanding of the differences in toxin accumulation and depuration rates is needed and could inform these efforts. Additional offshore phytoplankton sampling and oceanographic mooring stations could also serve as early warnings of potential HAB conditions developing in a specific region (Frolov et al., 2013). An expanded monitoring program should also consider linkages to predictive modeling efforts.

Innovative HAB monitoring and management programs in other regions are models for California to consider moving forward.

Given that HABs are ubiquitous across the globe, there are many regions that have developed innovative ways to monitor and manage their impacts. New Zealand's monitoring program is funded by the shellfish industry and incorporates the use of tools that allow for rapid algal species identification. Florida has the most comprehensive HAB monitoring program in the Gulf of Mexico, deploying underwater vehicles to map blooms, and using satellite imagery to measure bloom extent and distribution. Lastly, on the West Coast, Washington State's Olympic Region Harmful Algal Bloom (ORHAB) partnership program is funded by a surcharge on recreational shellfish licenses, and incorporates federal and state agencies, tribal governments, industry, academic institutions and NGOs. These programs can serve as excellent models as California considers building on its existing programs and identifying funding sources to do so.

Consistent funding for HAB research and monitoring is needed to better prepare and respond to future events.

In general, monitoring and HAB research are not well funded globally. By necessity, the standard approach most regions have taken is to characterize the effects of a massive bloom after it has already manifested. As such, there are major gaps in our understanding of basic physiological characteristics and environmental drivers of key toxin-producing species, let alone how they respond to climate change and other stressors. This has made it very difficult to identify the myriad factors that lead to blooms. There is a need for proactive strategies to be implemented if California wishes to better understand the causes of HABs and the means to mitigate their impacts. These empirical data are needed to deepen our understanding of what happens within a HAB event. Understanding the ecology of these events can feed into predictive modeling, elucidate how HABs move through the environment, and help to identify when a fishery might be re-opened.

Currently, there are no dedicated, long-term state, federal or private funding sources for either HAB research or monitoring in California. As HAB events occur, limited state funding is provided by a redirection of General Funds from other programs to cover the necessary activities conducted by CDPH. NOAA'S Ecology and Oceanography of HABs (ECOHAB) is a federal program that funds research to understand the causes and impacts of HABs and associated biotoxins. However, they are not capable of supporting long-term monitoring efforts and programs. Therefore the funds for stable monitoring often come from state sources (e.g. the legislature, bonds, etc.). In addition, independent scientists are limited in their ability to support biotoxin monitoring and research due to the short-term nature of most grants and funding cycles, and are often only able to reactively redirect resources to sample when an event has already begun.

California requires consistent funding streams for HAB-related work in order to develop a robust monitoring program that supports public health and natural resource management. By partnering and investing across the tate and federal government, non-governmental organizations, and academia, we can be in a better position to predict, plan for, respond to, and learn from the next HAB event. Importantly, HAB research, monitoring, and prediction does not need to be separated from other state interests. For example, many of the monitoring and modeling approaches used for ocean acidification could also benefit HAB programs, and vice versa. Other regions, including New Zealand and Florida, have invested in dedicated centers for biotoxin research that are driven by regulatory and industry needs. In California, it will be important to draw from these models and understand how we can bring existing and new resources together.

II. Scientific Recommendations and Guidance

In this section, we provide recommendations followed by a list of associated considerations, needs and/or potential options where science could play a role in advancing next step for California. These items arose during discussions at the July 27, 2016 working group workshop (see Appendix B) and conversations with fishermen, state and federal decision-makers, and other academic experts. The recommendations and guidance focus on how best to capitalize upon the State's existing programs, as well as existing academic research and monitoring efforts. While these recommendations and science needs are not exhaustive, they provide a good starting point to scope the next phase of the "Harmful Algal Blooms and California Fisheries" working group, which aims to assist California in developing more effective short- and long-term HAB response planning. Additionally, these recommendations can serve as a starting point to support California in prioritizing research needs.

Recommendation 1: Continue to build out a robust, cost-effective, and flexible monitoring program that can be responsive to future HAB events, and that considers impacted communities.

Concern is growing about potential HAB impacts to non-bivalve species (e.g., California spiny lobster). Managing our vast number of fishery and aquaculture species necessitates a continued response based upon our knowledge of toxin accumulation/depuration rates in different species, including toxin partitioning in different tissues (e.g., leg, claw, and viscera), as well as species' ecology. For example, management response for a localized mussel event is and should be very different than for anchovies. As California considers expanding existing research and monitoring, there is also a need to consider HAB research focused on protecting not only environmental systems and public health, but also the economies and communities around them (Bauer et al. 2006). Management must continue to be flexible to better determine and characterize regional impacts, especially in years where HAB events affect only a small region or portion of a fishery. During peak events, additional resources need to be allocated for effective response and management. In order to avoid the "boom and bust" scenario of HAB resource allocation, California should identify and fund a number of agreed-upon long-term needs and deliverables that the State and other entities could focus on when not participating in active response. These data also facilitate improved modeling, since it is as important to sample at bloom initiation and during non-toxic events to improve our fundamental knowledge of HAB dynamics and translate this information into effective monitoring and modeling.

California's public health and natural resource management agencies, as well as groups like California Harmful Algal Bloom Monitoring and Alert Program (HABMAP) already have excellent long-term data sets, and are programs that could be built upon by adding nutrient monitoring and offshore sampling stations. Given capacity and budgetary limitations, the State should continue to explore innovative techniques to monitor phytoplankton and biotoxins, including expanding the role of CDPH's highly functional citizen science program.

As changing ocean conditions lead to new and unusual events, California should ensure that future monitoring efforts consider new and emerging biotoxin-producing species (e.g., diarrhetic shellfish poisoning, azaspiracid poisoning, and marine accumulation of freshwater toxins).

Science considerations, needs, and/or potential options:

- *Consider partnering to expand monitoring outside of fishing seasons to give advanced notice of any potential fishery closures and allow industry to prepare.*
- *Ensure any new monitoring plans and research take into account the full breadth of known HAB species which may be present or begin to show up in California fished species.*
- *Develop scientific guidance and/or standards for sampling and monitoring biotoxins in an array of harvested species.*
- *Explore opportunities to incorporate (and provide resources for) industry involvement in long-term monitoring efforts.*
- *Promote the development of innovative techniques for monitoring phytoplankton and advance the state of the science (e.g., improve early detection of offshore and subsurface blooms, implement reliable tracking tools, etc.).*
- *Explore funding streams and mechanisms as utilized in other countries' and states' programs for inclusion in a California monitoring plan.*
- *Leverage existing research and monitoring efforts or ongoing cruises to collect HAB-related data (e.g., yearly CalCOFI fishery cruises, NOAA groundfish surveys) at under- or non-sampled regions or areas.*

- *Explore opportunities to expand the number of accredited laboratories able to process seafood and environmental samples for toxin analyses; ensure consistent funding of programs that process samples in non-accredited labs in order to inform State monitoring efforts and for predictive purposes.*
- *Evaluate potential field-based monitoring tools and work towards validation of the most promising tools for the various seafood tissue matrices.*
- *Advance understanding of the socioeconomic impacts related to HAB events and understand the potential tradeoffs between human health protection and socioeconomic impacts.*
- *Collect additional physical environmental data (temperature, salinity, pH, nutrients) in areas where phytoplankton and seafood are sampled to further our knowledge of how these toxins and species move through and respond to their environment (this could be done at small set of primary sites as a pilot test).*
- *Add phytoplankton and toxin sampling to programs that already measure temperature, salinity, pH, and nutrients in areas where phytoplankton and seafood are not currently being sampled.*
- *Continue to explore creative options to fill monitoring gaps in areas that are difficult to sample (e.g., North Coast, offshore).*
- *Explore the boundary between marine and freshwater HABs, and other emerging species and toxins.*

Recommendation 2: Pursue efforts to better understand offshore bloom dynamics and bloom timelines.

Many bloom events begin offshore, then are brought nearshore via upwelling, downwelling, or other oceanic processes. Sampling offshore for phytoplankton and potentially fished species will (a.) provide more information about how blooms move and spread, (b.) bolster the predictive model capabilities, and (c.) potentially provide an early warning that an event is occurring offshore before it moves to the coast. Offshore monitoring will become increasingly important with the development of offshore aquaculture facilities.

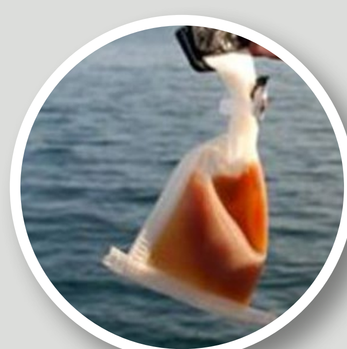
Science considerations, needs, and/or potential options:

- *Explore cost-effective options to expand offshore data collection and monitoring.*
- *In order to facilitate early detection, determine how far offshore monitoring must extend, and how frequently sampling must take place.*
- *Explore the role of Solid Phase Adsorption Toxin Tracking (SPATT) (MacKenzie et al., 2004) for detection of toxin (presence/absence) in areas where frequent data collection is not feasible, or where opportunistic sampling (e.g. existing research vessels) provides value-added toxin measurements (Box 2).*
- *Leverage external partnerships and opportunities to conduct offshore monitoring (e.g., existing research cruises, citizen science/industry partnerships, future offshore aquaculture facilities).*

Box 2. The role of SPATT in the detection of harmful algal bloom toxins

Solid Phase Adsorption Toxin Tracking (SPATT) can be used to monitor toxin levels in seawater. SPATT was first proposed for HAB monitoring by MacKenzie et al. (2004), who developed this passive sampling device by placing SPATT resin, which binds an array of lipophilic algal toxins, within a polyester mesh bag. Over the last several years University of California Santa Cruz researchers have been further developing and applying SPATT for HAB detection in both marine and freshwater environments. Their results indicate that the sensitivity of this system is extremely high, which greatly facilitates source-tracking efforts.

While this method is cost-effective and useful for presence-absence information, it is not highly quantitative if the State is considering a robust offshore monitoring program. Before implementation, the reliability of this method should be ground-truthed with offshore monitoring observations.



Source: San Francisco Estuary Institute

Recommendation 3: Advance predictive modeling tools and better link models and model outputs to monitoring and management.

Modeling and other predictive tools have the potential to assist public health and natural resource agencies with making decisions about where best to invest limited resources. These tools should be used as part of an "ensemble" approach alongside monitoring and sampling efforts. The combination of information from these various sources can help with identifying trends and inflection points that can inform decision-making. For example, models can help interpret limited direct sampling (e.g., provide information about why the bloom is there, and the spatial-temporal extent of the bloom), as well as predict seasons, years, or locations that would be highly favorable for HAB events. The prediction of a toxic year could trigger an early warning for fishing communities as well as prompt a ramp-up in monitoring for seafood species in locations where blooms are predicted to occur. This type of approach is not only cost effective, but could be linked to a tiered monitoring approach, in which sampling of additional species (beyond standard baseline monitoring) is "triggered" by model predictions before a toxic event occurs.

Modeling is only as good as the information that feeds into it, thus modeling, empirical data collection, and monitoring must go hand-in-hand and advance collectively. Additional key information is needed to improve the predictive capabilities of the model, including better offshore data, as well as additional ecophysiological information on the key toxin-producing phytoplankton species. These HAB models rely on operational oceanographic models, which must also be maintained and improved.

For *Pseudo-nitzschia*, California and federal partners have invested in a C-HARM predictive model led by Drs. Clarissa Anderson at the Southern California Coastal Ocean Observing System (SCCOOS) and Raphael Kudela at UC Santa Cruz in collaboration with Central and Northern California Ocean Observing System (CeNCOOS). This model produces predictive nowcasts and forecasts of *Pseudo-nitzschia* blooms and domoic acid probabilities along the California coast. This model can help the State prepare for and respond to HAB events, as well as provide information about bloom sources, triggers, trajectories, duration and toxicity . Recent assessment of the model (Anderson et al., 2016) shows that it is most useful for assessing regional patterns, such as the incidence of marine mammal strandings, and is much less accurate at predicting individual locations, where the existing CDPH Volunteer Monitoring Program excels. This model is still under development and could benefit greatly from an array of environmental and physiological data as well as ground truthing to improve its reliability and effectiveness. The model is currently based on statistical probabilities; the next generation of model would ideally incorporate HAB organisms directly into numerical ocean models. The level of understanding necessary to make these coupled models would improve both our ability to predict HAB events and our understanding of what triggers these events. Taken together, models combined with direct measurements (both existing and proposed) provide more information than either alone.

Science considerations, needs, and/or potential options:

- *Continue to ground-truth and test the C-HARM domoic acid statistical model to assess the accuracy of predictions.*
- *Advance ecophysiology studies of HAB species in order to improve model predictions, including development of embedded physiological models within existing oceanographic numerical models.*
- *Explore modeling efforts that can forecast additional HAB species and toxins as well as the feasibility, cost, and timeline for development.*
- *Scope and develop predictive tools that meet the most pressing needs of state managers and the fishing industry.*
- *Better understand key oceanographic drivers of toxic blooms to inform modeling efforts.*

Recommendation 4: Improve basic understanding of the ecophysiology of marine HAB species.

There is a lack of basic understanding of the ecology and physiology of most HAB species. The majority of our knowledge is related to abiotic factors that are known to impact the development of a bloom, such as temperature, salinity, and nutrients. Much less is known about how these environmental factors interact to regulate growth and/or toxin production by HAB species, or the competitive relationship between HAB and co-occurring non-HAB species. Scientists understand the growth and toxin production of many important HAB species in a singular manner – single species, single toxin, and single stressor. However, for modern stressors associated with climatic change, this approach fails to provide adequate knowledge on the linkages between what we currently know about HABs and what can be expected concerning future ocean conditions, and the outcome of competition by toxigenic species (c.f. review by Wells et al., 2015). The complexity of multiple stressors (such as increasing acidification and warming together) need to be assessed for HAB species to establish ecologically realistic predictions on their response(s) to environmental change. We also know very little about top-down control (grazing impacts on HAB by metazoans), which could add significantly to our understanding of bloom development and their natural demise. Mortality losses have proven to be an important factor in other modeling efforts of HAB bloom dynamics.

If we understood more about the ecophysiology of the species and the interaction of environmental stressors, scientists could incorporate these variables into predictive models (e.g., the C-HARM model above, or next-generation models) to improve predictions about where and when to monitor. This type of research could enhance the predictive capabilities of CDPH and CDFW to issue warnings to fishermen, communities, and consumers of toxin-contaminated seafood in the environment.

Science considerations, needs, and/or potential options:

- *Promote research on HAB species responses to basic abiotic environmental factors, such as changes in carbonate chemistry (ocean acidification), temperature, and salinity. Identify factors which promote toxin production in toxin-producing species such as* P. australis, *and their relationship with factors that enhance the growth of these HAB species to determine how they differ*
- *Advance understanding of how HAB species outcompete non-toxic phytoplankton and the conditions under which this occurs.*
- *Advance understanding of loss processes, and how they contribute to our knowledge of bloom formation and demise.*
- *Focus research on the impacts of multiple stressors on the growth and toxicity of key HAB species.*
- *Determine why HABs develop consistently in certain locations; identifying the physical and chemical factors associated with these natural marine areas that 'promote' HABs.*

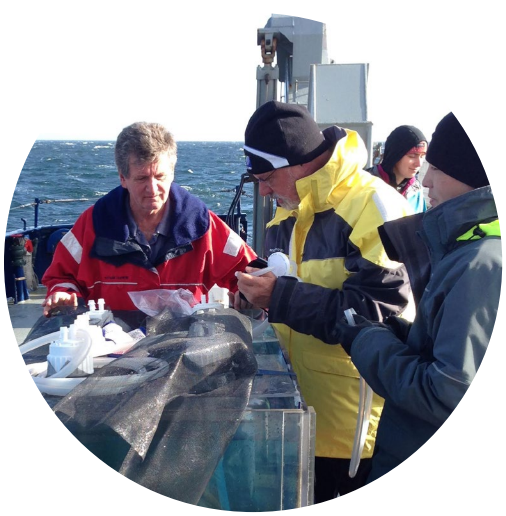


Photo credit: Cochlan Ecophysiology Lab, RTC-SFSU

Recommendation 5: Improve understanding of how biotoxins move through food webs.

A better understanding of how toxins move through food webs could bolster predictive capabilities. Knowing the time lag between toxin detected in the water column and when it enters the tissue of particular fished species could give the fishing community more time to prepare in advance of a closure. Scientists are already working to develop this link for domoic acid in California (Figure 3). Work is still needed to determine how information like this could be utilized to inform fishing efforts and the fishing industry.

Very little is known about the rate at which various seafood species will cleanse themselves of domoic acid or other marine toxins from their tissue. Also known as depuration, much of our knowledge about the rates at which this process occurs is based on limited laboratory studies, and may not represent typical coastal ocean conditions. The toxicity data gathered during the 2015-16 event might be useful in this regard, but is complicated by the possibility that crab and lobster continued to ingest more toxin via prey species long after the bloom had subsided. Nonetheless, this type of information could be utilized to predict when the tissue of fished species may begin to show levels above the acceptable FDA action levels and the length of time it can be expected to persist, which can ultimately inform how long a fishery must remain closed. The modeling component to this work is currently under development. The feasibility of depurating crab and lobster by relocating them outside the bloom area has never been explored, but may warrant consideration by CDFW and industry experts. There is also a need to evaluate the cost effectiveness of other marketing strategies during an extended domoic acid event. Research is needed to determine if there is a higher, secondary threshold for domoic acid in crab viscera below which the crab meat remains at acceptable levels. This secondary threshold may allow implementation of an evisceration order where only cleaned crab bodies or legs and claws could be marketed.

Science considerations, needs, and/or potential options:

- *Conduct research into the differences in toxin accumulation and depuration rates in key species, toxin partitioning in different tissue types, and biotransformation of toxins for some species.*
- *Improve understanding of toxin dynamics in the benthos and sediments.*
- *Gain knowledge on the time lag between toxin detected in the water column and when it enters organism tissue.*
- *Investigate locations where HABs first develop.*
- *Gain insight into the movement of key harvested species in relation to location of toxic blooms and toxin accumulation.*

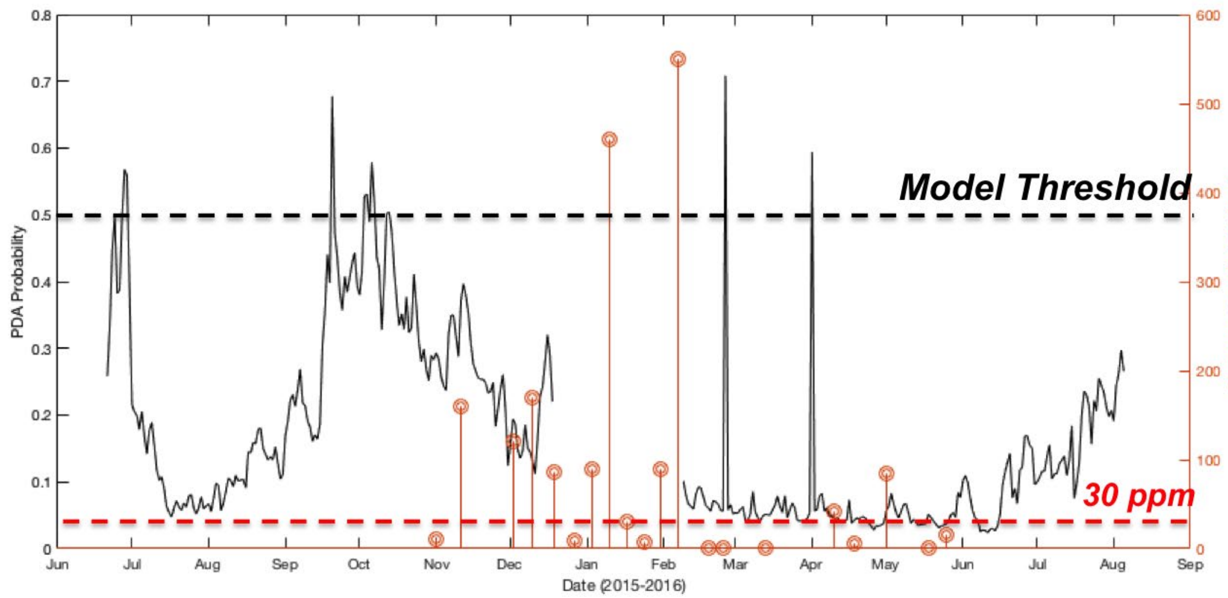


Figure 3. The C-HARM model from June 2015 - August 2016 depicting particulate domoic acid (PDA) probability in the water column off Santa Barbara (in black) overlaid with maximum domoic acid detected in CDFW crab samples (in orange) for CDFW Block 710. The 30 ppm FDA action level in crab viscera is represented by the dashed red line. The model domoic acid spikes lead crab toxicity spikes by about one month.

Credit: R. Kudela, UCSC

Recommendation 6: Advance research on the relationship between HABs and human health.

Additional elements below were brought up during the course of the working group process related to human health that did not fall under the above categories, and may be valuable for California to pursue.

Science considerations, needs, and/or potential options:

- *Improve understanding of the long-term effects of chronic human exposure to low levels of toxin (Box 3).*
- *Analyze data on toxin exposure and health impacts from during an advisory when potentially contaminated seafood was in circulation.*
- *Explore the toxin exposure risk among subsistence fishing communities.*

BOX 3. Chronic low level exposure of domoic acid in humans

With regards to domoic acid, it is not known whether repeated exposure over several days, months or years to low-levels has health consequences. Researchers have explored the short- and long-term effects of high-level domoic acid exposure in sea lions, but little is known about the effects of repeated low-level exposure.* A study in zebrafish showed that repeated, low-level exposure caused increased sensitivity to domoic acid and affected cellular function in the brain, even though the fish looked outwardly healthy. There are still significant gaps in knowledge of the health effects of repeated low-level exposure in mammals (K. Lefebvre, personal communication). Ongoing studies are underway to identify health impacts of chronic low level domoic acid exposure in laboratory mammalian model species and human populations that are known to consume low levels of domoic acid on a regular basis.

**Note: High level exposure refers to levels that cause outward signs of toxicity such as seizures, confusion, and disorientation. Low level exposure refers to levels below those that cause the outward signs of toxicity.*

Next Steps

This document provides a "menu" of scientific options for State and Federal agencies, foundations, the fishing industry, and community members to consider. It is important to note that not all of the options and recommendations captured in this report need to be completed before action can be taken. Rather, this menu presents scientifically rigorous and realistic options based on our current knowledge. Managers and stakeholders should work together to align their priority questions and needs to the options contained in this report.

This report is also meant to serve as the starting place for the State Legislature, Task Force, fishermen, scientists, and funders to work together to determine their most immediate needs and when science can help them meet those needs. To that end, a second phase of the "Harmful Algal Blooms and California Fisheries" working group, convened by California Ocean Science Trust and supported by the California Ocean Protection Council, will expand and address some of the key recommendations encompassed in this report.Ocean Science Trust will continue to engage with these audiences and other community members to determine topic areas the long-term working group should tackle in 2017.

For more resources on HABs off California and the U.S. West Coast, see box 4. For additional questions about this work and next steps, contact Errin Ramanujam (errin.ramanujam@oceansciencetrust.org), Senior Scientist, California Ocean Science Trust.

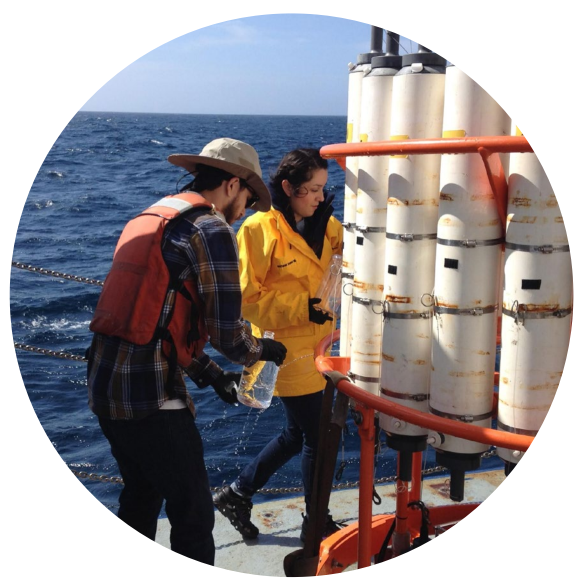


Photo credits: Cochlan Ecophysiology Lab, RTC-SFSU

Box 4: Additional Resources on Harmful Algal Blooms Off California and the U.S. West Coast:

Frequently Asked Questions

A Primer on California Marine Harmful Algal Blooms (McGaraghan, Kudela and Negrey) - http://fisheries.legislature.ca.gov/sites/fisheries.legislature.ca.gov/files/u8/Primer%20on%20HAB%20westcoast.pdf

Domoic Acid: Frequently Asked Questions (California Department of Public Health) - https://www.cdph.ca.gov/pubsforms/Documents/fdbSSdaFAQ.pdf

Frequently Asked Questions: Harmful Algal Blooms and California Fisheries, Developed in Response to the 2015-2016 Domoic Acid Event (California Ocean Science Trust, 2016) - http://www.oceansciencetrust.org/wp-content/uploads/2016/09/HABs-and-CA-Fisheries-FAQ-8.5.16.pdf

Natural Biotoxins in California Crabs: Domoic Acid, Frequently Asked Questions on Human Health, Fishery Closures, and Biotoxins in Crabs (California Sea Grant, 2016) - https://caseagrant.ucsd.edu/sites/default/files/Biotoxins-SU16-FAQ-v2.pdf

Government

California Department of Fish and WIldlife, Health Advisories for California Finfish, Shellfish and Crustaceans - https://www.wildlife.ca.gov/Fishing/Ocean/Health-Advisories

California Department of Public Health, Marine Biotoxin Monitoring Program - https://www.cdph.ca.gov/HealthInfo/environhealth/water/Pages/MarineBiotoxinMonitoring.aspx

California Department of Public Health, Phytoplankton Monitoring Program - https://www.cdph.ca.gov/HealthInfo/environhealth/water/Pages/phytoplanktonmonitoringprogram.aspx

California State Senate, Joint Committee on Fisheries and Aquaculture - http://fisheries.legislature.ca.gov/committeehome

National Center for Coastal Ocean Science, Ecology and Oceanography of HABs (ECOHAB) - https://coastalscience.noaa.gov/research/habs/ecohab

National Center for Coastal Ocean Science Phytoplankton Monitorin Network - https://products.coastalscience.noaa.gov/pmn/

Modeling, Monitoring and Alert Networks

CeNCOOS C-HARM *Pseudo-nitzschia* Model - http://www.cencoos.org/data/models/habs

Monterey Bay Harmful Algal Bloom Portal - http://oceandatacenter.ucsc.edu/MBHAB/

California Harmful Algal Bloom Monitoring and Alert Network - www.HABMAP.info

Online Informational Resources

Woods Hole Oceanographic Institute "Harmful Algae" - http://www.whoi.edu/redtide/home

Phytoplankton Identification Gallery - http://oceandatacenter.ucsc.edu/PhytoGallery/

References

Anderson, C.R., R.M. Kudela, M. Kahru, Y. Chao, L.K. Rosenfeld, F.L. Bahr, D.M. Anderson, T.A. Norris. 2016. Initial skill assessment of the California Harmful Algae Risk Mapping (C-HARM) system. Harmful Algae, doi:10.1016/j.hal.2016.08.006.

Anderson, C.R., Moore, S.K., Tomlinson, M.C., Silke, J. and Cusack, C.K., 2015. Living with harmful algal blooms in a changing world: strategies for modeling and mitigating their effects in coastal marine ecosystems. Coastal and Marine Hazards, Risks, and Disasters. Elsevier BV, Amsterdam, pp.495-561.

Bauer, M., ed. 2006. Harmful Algal Research and Response: A Human Dimensions Strategy. National Office for Marine Biotoxins and Harmful Algal Blooms, Woods Hole Oceanographic Institution, Woods Hole, MA, 58 pp.

Bond, N.A., Cronin, M.F., Freeland, H., Mantua. A. 2015. Causes and impacts of the 2014 warm anomaly in the NE Pacific. Geophys. Res. Lett. 42: 3414-3420, doi:10.1002/2015GL063306.

Cho, E.S., Kotaki, Y., Park, J.G. 2001. The comparison between toxic *Pseudo-nitzschia multiseries* (Hasle) Hasle and non-toxic *P. pungens* (Grunow) Hasle isolated from Jinhae Bay, Korea. Algae 16: 275–285.

Frolov, S., Kudela, R.M. and Bellingham, J.G., 2013. Monitoring of harmful algal blooms in the era of diminishing resources: a case study of the U.S. West Coast. Harmful Algae, 21, pp.1-12.

Kudela, R.M., Seeyave, S. and Cochlan, W.P., 2010. The role of nutrients in regulation and promotion of harmful algal blooms in upwelling systems. Progress in Oceanography, 85(1), pp.122-135.

Lewitus, A.J., Horner, R.A., Caron, D.A., Garcia-Mendoza, E., Hickey, B.M., Hunter, M., Huppert, D.D., Kudela, R.M., Langlois, G.W., Largier, J.L. and Lessard, E.J., 2012. Harmful algal blooms along the North American west coast region: History, trends, causes, and impacts. Harmful Algae, 19, pp.133-159.

Lundholm, N., Hansen, P.J., Kotaki, Y. 2004. Effect of pH on growth and domoic acid production by potentially toxic diatoms of the genera *Pseudo-nitzschia* and *Nitzschia*. Mar. Ecol. Progr. Ser. 273: 1-15.

MacKenzie, L., Beuzenberg, V., Holland, P., McNabb, P. and Selwood, A., 2004. Solid phase adsorption toxin tracking (SPATT): a new monitoring tool that simulates the biotoxin contamination of filter feeding bivalves. Toxicon, 44(8), pp.901-918.

McCabe, R.M., Hickey, B.M., Kudela, R.M., Lefebvre, K.A., Adams, N.G., Bill, B.D., Gulland, F., Thomson, R.E., Cochlan, W.P. and Trainer, V.L., 2016. An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions. Geophysical Research Letters.

Moore, S.K., Trainer, V.L., Mantua, N.J., Parker, M.S., Laws, E.A., Backer, L.C. and Fleming, L.E., 2008. Impacts of climate variability and future climate change on harmful algal blooms and human health. Environmental Health,7(2), p.1.

Rykaczewski, R.R. and Dunne, J.P., 2010. Enhanced nutrient supply to the California Current Ecosystem with global warming and increased stratification in an earth system model. Geophysical Research Letters, 37(21).

Schnetzer, A., Jones, B.H., Schaffner, R.A., Cetinic, I, Fitzspatrick, E., Miller, P.E., Seubert, E.L., Caron, D.A. 2013. Coastal upwelling linked to toxic Pseudo-nitzschia australis blooms in Los Angeles coastal waters, 2005–2007. J. Plankton Res. 35: 1080–1092.

Sun, J., Hutchins, D.A., Feng, Y., Seubert, E.L., Caron, D.A., Fu, F.-X. 2011. Effects of changing pCO_2 and phosphate availability on domoic acid production and physiology of the marine harmful bloom diatom *Pseudo-nitzschia multiseries*. Limnol. Oceanogr. 56: 829-840.

Tatters, A.O., Fu, F.-X., Hutchins, D.A. 2012. High CO2 and silicate limitation synergistically increase the toxicity of *Pseudo-nitzschia fraudulenta*. PloS ONE 7: e32116.

Trainer, V.L., B.M. Hickey, E.J. Lessard, W.P. Cochlan, C.G. Trick, M.L. Wells, A. MacFadyen, and S. Moore. 2009a. Variability of *Pseudo-nitzschia* and domoic acid in the Juan de Fuca Eddy region and its adjacent shelves. Limnol. Oceanogr. 54: 289-308.

Trainer, V.L., M.L. Wells, W.P. Cochlan, C.G. Trick, B.D. Bill, K.A. Baugh, B. F. Beall, J.Herndon, and N. Lundholm. 2009b. An ecological study of a massive bloom of toxigenic *Pseudo-nitzschia cuspidata* off the Washington State coast. Limnol. Oceanogr. 54: 1461-1474.

Trimborn, S., Lundholm, N., Thoms, S., Richter, K.-U., Krock, B., Hansen P.J., Rost, B. 2008. Inorganic carbon acquisition in potentially toxic and non-toxic diatoms: the effect of pH-induced changes in seawater carbonate chemistry. Physiol. Plant. 133: 92-105.

Wells, M.L., Trainer, V.L., Smayda, T.J., Karlson, B.S.O., Trick, C.G., Kudela, R.M., Ishikawa, A., Bernard, S., Wulff, A., Anderson, D.M., Cochlan, W.P. 2015. Harmful algal blooms and climate change: Learning from the past and present to forecast the future. Harmful Algae 49: 68-93.

Appendix A: Working Group Membership

The Ocean Protection Council Science Advisory Team (SAT) working group on "Harmful Algal Blooms and California Fisheries" was established in June 2016 by soliciting nominations from SAT members and the Task Force. Working group members have experience in ecology and physiology of phytoplankton, biological oceanography, biotoxins, and modeling. Membership also included an agency scientist (now retired) with intimate knowledge of the State's current HAB sampling and biotoxin testing protocols. Ocean Science Trust Executive Director and Science Advisor Tom Maloney served as the Ocean Protection Council Science Advisory Team liaison.

Working Group Members

Dave Caron

Professor of Biological Sciences, University of Southern California

Dr. Caron's research focuses on marine and freshwater microbial ecology, with emphasis on the trophic relationships between protists (microalgae and protozoa) and other planktonic and benthic microorganisms. Recent research programs have focused on the distribution, feeding ecology, respiration and nutrient regeneration of bacterivorous and herbivorous protozoa, the ecology of harmful algae, the physiology of Antarctic protists, feeding and growth of phagotrophic (mixotrophic) microalgae, and the development of molecular biological approaches for studying the ecology of free-living microorganisms.

William Cochlan

Senior Research Scientist, Romberg Tiburon Center for Environmental Studies, San Francisco State University

Dr. Cochlan currently heads a biological oceanography/marine microbial ecology research laboratory at the Romberg Tiburon Center, San Francisco State University. His research is centered on the utilization and dynamics of macro- and micro-nutrients, and their effects on marine phytoplankton and heterotrophic bacteria in coastal and oceanic environments. His ocean acidification and HAB research projects are laboratory and field-based efforts and include the study of fish-killing flagellates in the Salish Sea, and toxigenic diatoms in the Pacific Northwest and California. He has been directly involved in the development of HAB and seafood safety training programs in a number of developing countries including the Republic of Philippines, Indonesia and Guatemala.

Raphael Kudela

Professor, Ocean Sciences Department, University of California, Santa Cruz

Dr. Kudela is a phytoplankton ecologist who seeks to understand the fundamental question: what controls phytoplankton growth and distribution in the ocean. More specifically, how do the multiple interactions of light, macro- and micronutrients and phytoplankton physiology determine the rates, processes, and patterns we observe in the marine environment? His approach is to combine a suite of 3 tools: (1) remotely sensed data from moorings and satellites in combination with biological models; (2) novel bio-optical methods assaying phytoplankton physiology; and (3) the refinement of stable and radio-tracer isotopes.

Gregg Langlois

Senior Environmental Scientist (ret.), California Department of Public Health

Dr. Langlois managed the State's Marine Biotoxin Monitoring Program for 25 years and has supervised the Preharvest Shellfish Program for 18 years. He developed a statewide volunteer-based phytoplankton monitoring program and incorporated routine testing for domoic acid into the shellfish monitoring program following the 1991 *Pseudo-nitzschia* bloom in Monterey Bay. Gregg has worked closely with researchers at U.C. Santa Cruz and the shellfish aquaculture industry in the evaluation of field-based toxin screening kits, incorporating this tool into the routine monitoring of shellfish growing areas that are in a high risk region for domoic acid.

Ocean Protection Council Science Advisory Team Liaison

Tom Maloney

Executive Director, Ocean Science Trust and Science Advisor, California Ocean Protection Council

As Executive Director of California Ocean Science Trust, Tom brings deep experience with environmental issues affecting the West Coast, including natural resource management and conservation planning. Throughout his career, Tom has led the protection of working lands, collaborating with citizen scientists and partnering with a wide variety of interests on conservation plans for ecosystem restoration in terrestrial and aquatic environments across the United States. Tom also serves as Science Advisor to the California Ocean Protection Council, and is a member of the Ocean Protection Council Science Advisory Team.

Appendix B: Working Group Workshop Agenda

WORKSHOP AGENDA

Harmful Algal Blooms and California Fisheries: Science Advisory Team Working Group

10:00 AM - 5:00 PM
Monday, June 27, 2016
2201 Broadway, Second Floor Conference Room, Oakland, CA

Attendees

Working group Members: Dave Caron, William Cochlan, Raphe Kudela, Gregg Langlois
Ocean Science Trust: Hayley Carter, Emily Knight, Tom Maloney, Errin Ramanujam
Ocean Protection Council: Jenn Phillips (afternoon)
Remote Participants: Vera Trainer, Robert Dickey (afternoon)

Workshop Goals

- Clarify the State's existing HAB and biotoxin monitoring procedures
- Gather information about what is being monitored and by whom (independent and state supported)
- Gather information about independent scientific programs, tools, science that could be linked to State needs
- Begin conversation about how to better bridge the gap between science being conducted and science needed by the State
- Set up initial, science-based, questions to be addressed in advane of and following the August 10 legislative hearing

Agenda

9:30 AM	**Coffee and pastries**
10:00 AM - 10:20 AM	**Introductions and Overview of Project Scope & Goals for workshop** Errin Ramanujam and Hayley Carter, Ocean Science Trust
10:20 AM - 12:00 PM	**OPC-SAT Working Group Discussion: State of the Independent Science on West Coast HABs** This group will begin to lay out the capacity already within the scientific community and how they are thinking about HAB events along the coast of California. We will begin by focusing the discussion on the following questions: • **State of the science:** What is our current understanding of harmful algal blooms, biotoxins, and species responses given changing ocean conditions? • **Overview of independent monitoring programs, tools, and networks:** What are the current academic monitoring programs, tools, data sets and online networks/portals that the State might want to know about or draw from? • **Horizon scanning:** What are the emerging toxins and HAB species, as well as other impacted species or habitats that the State should be thinking about going forward? • **Developing a comprehensive HAB monitoring network:** In an ideal world, how would the State be monitoring, studying, managing, and responding to HAB events? What science is needed to support that ideal world?
12:00 PM - 12:30 PM	**Lunch Break**
12:30 PM - 12:40 PM	**Morning Recap - revisiting goals and scope** Errin Ramanujam and Hayley Carter
12:40 PM - 1:30 PM	**Overview of the State's existing HAB and Biotoxin Programs** Gregg Langlois, California Department of Public Health, Interagency HAB Task Force We will hear about the current HAB and biotoxin monitoring and methodologies employed by the State. This presentation and discussion will allow us to better understand how the State is currently thinking about HAB events and monitoring.

Funding provided by the California Ocean Protection Council

1:30 PM - 3:00 PM **Leveraging Independent Science to Support the State**

Moderator: Errin Ramanujam

Taking the morning's discussion about the status of the science from within the scientific community and the previous discussion about what California is monitoring currently, we will begin exploring how we can better link and bridge the gap between independent science and the needs of California state managers.

Addressing gaps between government and science

- What are current knowledge gaps in the State's existing HAB and biotoxin monitoring programs?
- How do we better link innovative research to support State needs?
- What scientific tools, information, or capacity is needed to better address management needs?
- Where should the State focus limited resources?

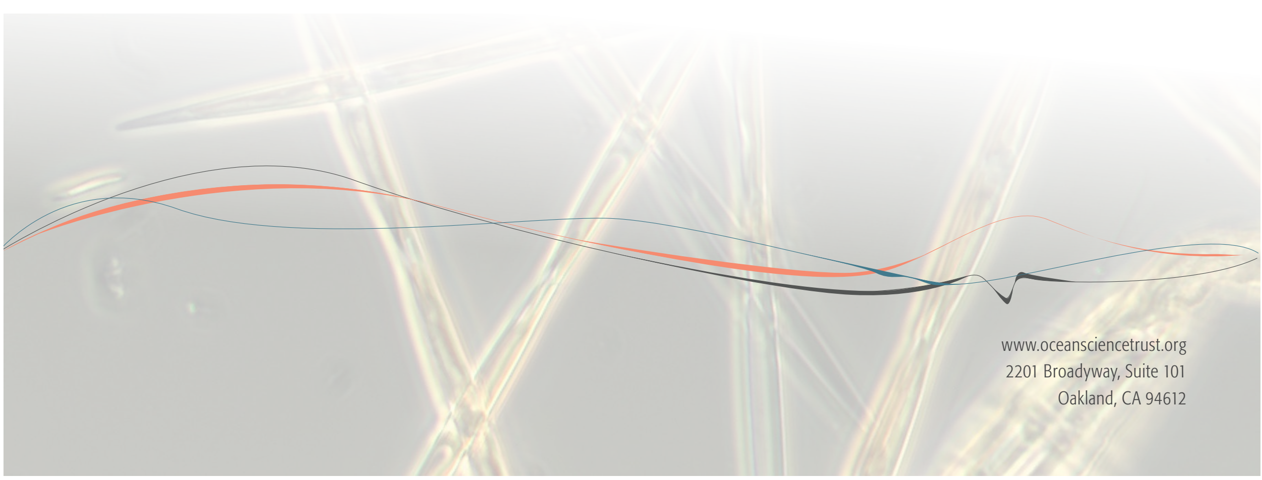
Moving away from being reactionary: Predictive modeling efforts

- What does that allow us to do that you can't do now?
- How can the state use this information?
- What are the knowledge gaps and science needs?
- How do current modeling efforts consider additional stressors of interest to the region, such as ocean acidification and hypoxia?

3:00 PM - 5:00 PM **Reporting out: Project Deliverables (short term) and Next Steps (longer-term)**

Based on the discussions earlier, we will use the last portion of the day to begin to take pen to paper and draft any scientific responses to FAQ questions, determine if there are others this group can address, and outline a long-term working group scope. We will also discuss immediate next steps for the following:

- Presentation: August 10 Joint Committee on Fisheries and Aquaculture hearing
- "Frequently Asked Questions" science communication product
- Final report



California Ocean Science Trust
2201 Broadway, Suite 101
Oakland, CA 94612
www.oceansciencetrust.org