

HARMFUL ALGAL BLOOMS

UNIVERSITY OF SOUTHERN CALIFORNIA SEA GRANT
FUNDED RESEARCH RESULTS
2012—2018

KEY FINDINGS

- **A Warmer Climate and More Acidic Ocean Can Increase Bloom Toxicity**
Warming waters and increased carbon dioxide (ocean acidification) can increase the toxicity of harmful algal blooms, especially under conditions of low nutrient availability.
- **Environmental Conditions Interact to Affect Toxicity**
The toxicity of harmful algal blooms depends upon interactions among environmental variables influenced by natural and human processes such as temperature, carbon dioxide, solar radiation and nutrients such as nitrogen and silicate.
- **Freshwater Toxins Can Spread to the Coast**
Toxins from harmful algal blooms in freshwater environments (cyanotoxins) can spread from the watershed into coastal waters at the land-sea interface.

ABOUT THIS REPORT

This report synthesizes and summarizes results from published USC Sea Grant research on harmful algal blooms funded between 2012-2018. It is part of a series of reports reviewing published research funded by USC Sea Grant, grouped by major ocean and watershed-focused research themes.

This research report series aims to provide California stakeholders and policy makers with key findings on ocean issues to assist in decision-making at the local and state levels. Further, it serves to increase science literacy for broader audiences.

Increasing local and regional understanding of globally-relevant scientific issues can improve the management of stressors on California's coastal and marine environments and ensure the longevity of our valuable coastal ecosystems, economies and resources.

ABOUT USC SEA GRANT

The University of Southern California (USC) Sea Grant is one of 34 programs within the National Oceanic and Atmospheric Administration (NOAA) National Sea Grant Program. This national network of university-based programs across coastal and Great Lakes states involves more than 300 institutions nationwide in research, education and the transfer of technology regarding coastal, marine and Great Lakes issues. USC Sea Grant is housed at the University of Southern California in Los Angeles, CA and focuses on solving problems of the Urban Ocean in greater Los Angeles while recognizing opportunities for coastal commerce, recreation and improving the quality of life in coastal regions such as Southern California.

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Cover Photo:

Aerial of Scripps Pier in La Jolla, CA, taken from 450 meters (1,500 feet) during a *Tetraselmis* sp. bloom. Photo credit: Eddie Kisfaludy / Scripps Institution of Oceanography (Flickr).



Harmful algal blooms: why care?

While aquatic microorganisms are invisible to the naked eye, their impact on our planet is immense. Marine and freshwater phytoplankton (microalgae) play critical roles in the functioning of aquatic ecosystems worldwide by providing energy at the base of food webs, producing oxygen, absorbing carbon dioxide, and cycling nutrients. However, some species have the capacity to produce potent toxins that adversely affect organisms that consume them (FIG. 1). Harmful algal blooms (HABs) – described as the proliferation of microalgae that are toxic and/or deplete oxygen in the water column as they decompose – can detrimentally impact marine life, water quality, recreation, and fisheries.

Extending across the last decade, USC Sea Grant actively supports research projects that aim to characterize the ecological causes and consequences of HABs in freshwater and marine environments in Southern California, as well as to understand how these blooms are affected by simultaneous environmental changes such as a warmer climate and more acidic ocean. The information described in this report represents key findings on these topics, synthesized from USC Sea Grant-funded research results from 2012-2018.

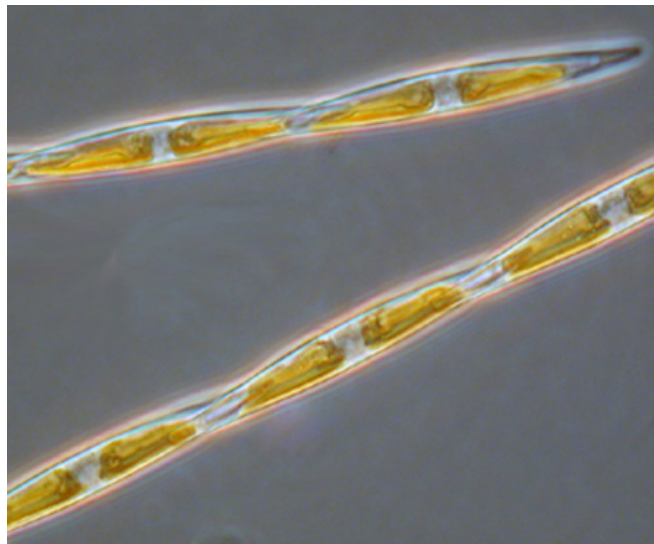


Figure 1: Cells of *Pseudo-nitzschia*, a toxic domoic acid-producing algae. SOURCE: DR. ROZALIND JESTER, FLORIDA SOUTHWESTERN STATE COLLEGE

Nature produces harmful toxins

Toxic algal blooms in both freshwater and marine ecosystems are caused by a multitude of phytoplankton species. Coastal California has a history of experiencing HABs caused by species that produce potent neurotoxins, including saxitoxins and domoic acid (FIG. 2). These blooms often contaminate shellfish and seafood, which can result in paralytic and amnesic shellfish poisoning upon consumption. Furthermore, multiple toxic algal species can exist in one location — a variety of toxins have been detected simultaneously at sites along the coast of Southern California (Smith et al., 2019). These toxins can negatively impact marine life by bioaccumulating into food webs, causing mortality of larger predators like marine mammals and sea birds.

A suite of environmental factors can stimulate HABs; most prominently nutrient enrichment (Howard et al., 2014). Nutrient levels in waters can increase naturally through ocean upwelling, as well as through land-based human sources such as sewage outfalls and runoff from storms and agriculture (Smith et al., 2018). In addition to impacts on marine environments, nutrient enrichment can also cause harmful algal blooms in freshwater environments, usually associated with blue-green algae (cyanobacteria) that produce toxins that can be harmful to the liver when ingested.

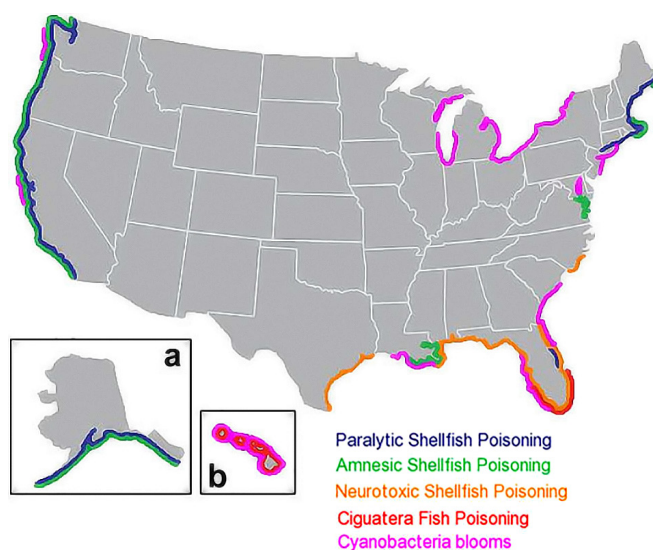


Figure 2: Distribution of regional issues and illnesses associated with HABs along U.S. coastlines, including (a) Alaska and (b) Hawaii. ADAPTED FROM CARON ET AL. 2010

Anthropogenic stressors increase HAB toxicity

While HAB events can occur naturally, their likelihood can also be influenced by anthropogenic stressors. Such stressors on oceans include increasing acidification, stratification and hypoxia, warming temperatures, and changing nutrient availability, all which have large implications for the ecology of marine microorganisms (Capone and Hutchins 2013; Stauffer et al., 2013; Hutchins and Fu 2017; Spackeen et al., 2017).

Further, these stressors can impact marine ecosystems, either individually or by interacting with each other. In particular, increasing levels of atmospheric carbon dioxide (CO_2) cause ocean warming and acidification, which may in turn increase the frequency and toxicity of harmful algal blooms (Fu et al., 2012). Additionally, higher CO_2 levels in combination with low nutrient availability (such as phosphate and silicate) have been found to shift species composition in phytoplankton communities and increase toxicity of some species known to cause shellfish poisoning such as the saxitoxin-producing *Alexandrium catenella* (Tatters et al., 2013c; Tatters et al., 2013b) and the domoic acid-producing *Pseudo-nitzschia fraudulenta* (FIG. 3; Tatters et al., 2012).

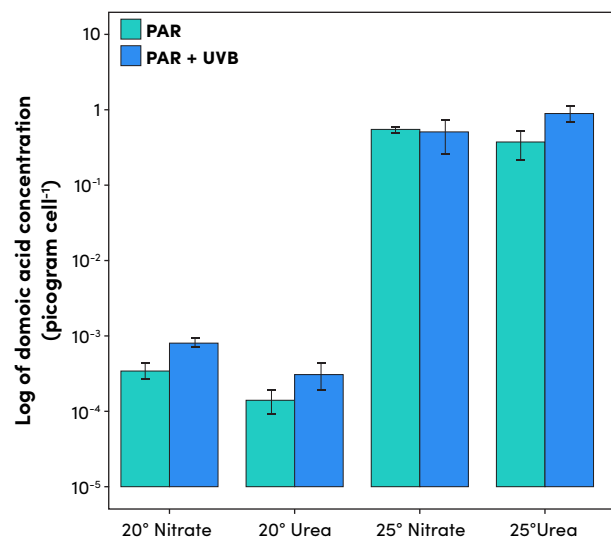
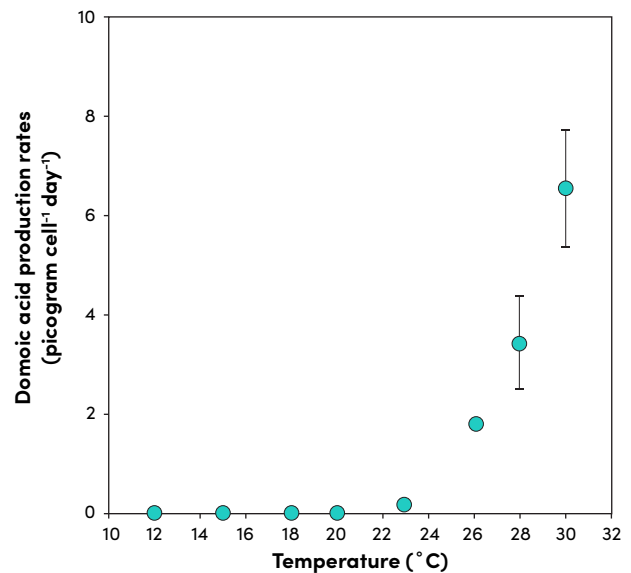
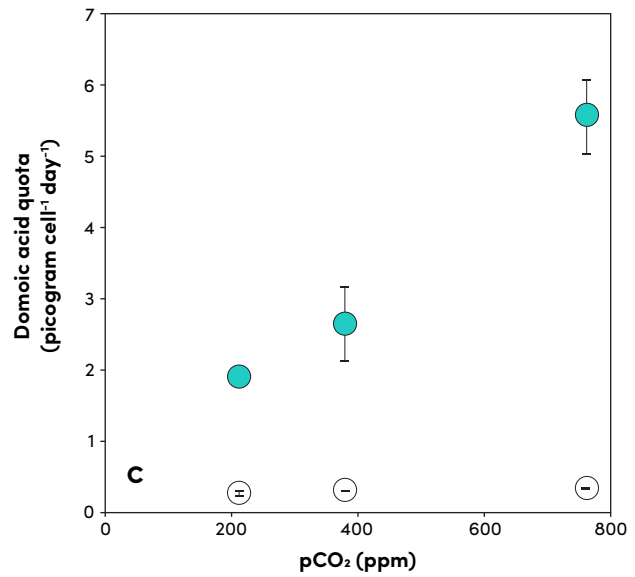
Moreover, warming ocean temperatures can increase the abundance and toxicity of additional species in the genus *Pseudo-nitzschia* (FIG. 4; Zhu et al., 2017), especially when combined with elevated CO_2 (Tatters et al., 2018). Interactions between CO_2 , increasing temperatures, and nutrient availability are thus likely to increase the frequency and toxicity of harmful algal blooms by shifting species composition of phytoplankton communities (Tatters et al., 2013a; Tatters et al., 2018) and impacting toxin production.

Preliminary findings of a multi-stressor study on the impacts of nitrogen, temperature, and solar radiation on domoic acid production show that the combination of warming, UVB exposure, and urea multiplicatively enhance *Pseudo-nitzschia* toxicity, and that warming is the primary driver of increased toxicity (FIG. 5; Kelly, Hutchins & Fu, unpublished results).

Figure 3: (top) The abundance of a Southern California domoic acid-producing *Pseudo-nitzschia* species grown in the lab over a range of seawater CO_2 concentrations. The species were grown under low (blue) and high (white) silicate conditions. ADAPTED FROM TATTERS ET AL. 2012

Figure 4: (middle) Domoic acid production rates of a Southern California *Pseudo-nitzschia* species, grown across a range of temperatures (12–30 °C). ADAPTED FROM ZHU ET AL. 2017

Figure 5: (bottom) Log domoic acid concentration per *Pseudo-nitzschia* cell in a multiple stressor experiment including two temperatures (20 °C and 25 °C), two nitrogen sources (nitrate and urea), and two types of solar radiation exposure (Photosynthetically Active Radiation (PAR) plus Ultraviolet Radiation (UVB)). SOURCE: KELLY, HUTCHINS AND FU, UNPUBLISHED RESULTS



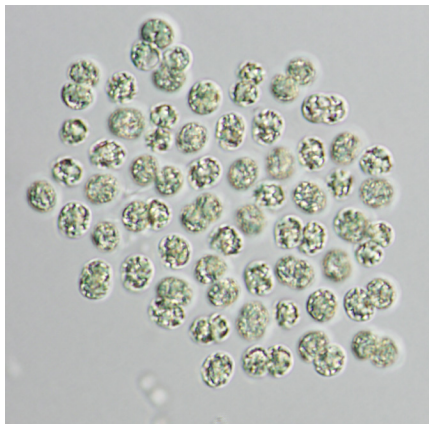
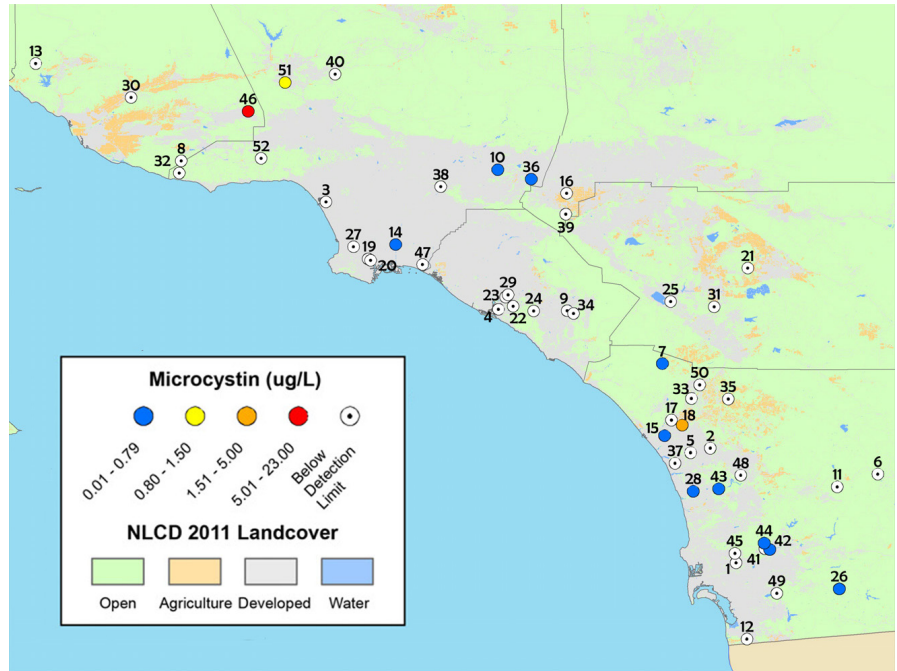
Freshwater toxins enter coastal waters at the land-sea interface

Warming has also been linked to increases in toxin-producing harmful algal blooms in freshwater environments (FIG. 6), which can then be transported from inland watersheds into coastal environments at the land-sea interface. Multiple co-occurring freshwater algal toxins produced by blue-green algae, or cyanobacteria (cyanotoxins such as microcystins; FIG. 7), were documented and detected in lakes, lagoons, creeks and estuaries with connectivity to the Pacific Ocean in Southern California, and were even detected in coastal shellfish tissues (FIG. 8; Howard et al., 2017; Tatters et al., 2017; Tatters et al., 2019). Thus, watersheds can be a source of cyanotoxins to marine and estuarine environments, indicating a need for monitoring programs at the land-sea interface, including monitoring of freshwater algal toxins in seafood (Tatters et al., 2019).

Figure 6: (bottom right) A boat wades through a bloom of toxic cyanobacteria (blue-green algae) in the Copco Reservoir in California. SOURCE: DAVID MCLAIN/ALAMY

Figure 7: (bottom left) A colony of *Microcystis aeruginosa*, a common freshwater cyanobacterial species and producer of the toxin microcystin. SOURCE: BARRY H. ROSEN, USGS

Figure 8: (top) Map of microcystin concentrations detected from samples in a spring wetlands assessment between 2011-2013. The yellow, orange and red circles indicate microcystin levels that exceed CA recreational health thresholds. ADAPTED FROM HOWARD ET AL. 2017



Research, monitoring and management: the key to mitigating HAB impacts in a changing environment

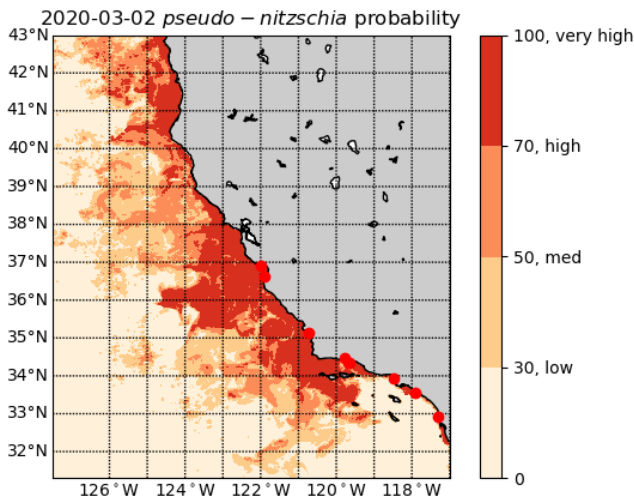


Figure 9: This map from California-Harmful Algae Risk Mapping (C-HARM) displays the probability that the abundance of toxin-producing species of the diatom *Pseudo-nitzschia* in coastal waters is at or above the “bloom” threshold of 10,000 cells per liter on a given day. These probabilities are calculated using predictive models that are valuable tools for forecasting HAB events based on environmental and remote sensing data. SOURCE: CENTRAL AND NORTHERN CALIFORNIA OCEAN OBSERVING SYSTEM (CENCOOS)



Figure 10: A sign in Kern County, CA warns recreational users of lakes with high levels of toxic algae to avoid recreation and contact with the water due to public health concerns. Issuing warnings to communicate HAB risks is an important management measure for reducing harmful health impacts to the public. SOURCE: KERN VALLEY SUN

Harmful algal blooms have dire consequences for aquatic ecosystems and food webs, as well as for human health and the economy. Understanding the species and environmental factors associated with HABs is critical for developing effective monitoring (FIG. 9) and management (FIG. 10) tools in order to reduce negative impacts on fisheries, recreation, and public health.

Ongoing research projects supported by Ocean Protection Council (OPC) Proposition 84 and USC Sea Grant (described on page 8, in the section ‘Ongoing or New Sea Grant Funded Research’) show promising preliminary findings (FIG. 5; Kelly, Hutchins & Fu, unpublished results). In addition, two ongoing projects aim to advance technologies for rapid detection of marine harmful algal blooms using genetic tools (p. 8). These critical technological advancements will provide stakeholders, resource managers and the aquaculture industry with the ability to cost effectively and predictively detect various HAB species that impact shellfish, marine mammals and birds. As detection tools and data become more readily available, predictive models for HABs will be more reliable, resulting in improved management and response to these events.

The research findings presented in this report, in addition to ongoing and new research (p. 8), will contribute valuable information and emerging tools that support regional knowledge and management of HAB causality and toxicity. Additionally, integrating and continuously updating global change predictions for HAB occurrence and toxicity into models will improve the ability to accurately forecast and respond to HAB events in a changing environment, providing decision-makers and managers with the best science available to manage fisheries, recreation, and water quality.

COMPLETED SEA GRANT-FUNDED RESEARCH

This report was developed using research results from USC Sea Grant funded HAB projects between 2012 and 2018. These results can assist government agencies and fisheries to better predict and prepare for HABs under changing environmental conditions, as well as to better understand the transport of toxins across freshwater to marine environments. An overview of these projects and associated principal investigators (PIs) is provided below.

Resolving the annual pattern of algal toxins in coastal waters off Los Angeles

2012–14, PIs: David Caron and Astrid Schnetzer (USC)

This project documented abundance dynamics for the most toxic Southern California HAB species (*Pseudo-nitzschia* and *Alexandrium*) inside the Los Angeles Harbor, at Newport Pier, in Redondo Beach Harbor, and at Wrigley Pier on Catalina Island. This task was accomplished by employing species-specific state-of-the-art molecular approaches for identification and enumeration in concert with newly-developed toxin detection methods. The same molecular approaches were used to analyze archived samples to test for differences in the frequency and duration of toxicity events inside the Los Angeles Harbor compared to the adjacent San Pedro Channel.

Will a warmer, more acidic ocean lead to increased *Pseudo-Nitzschia* bloom toxicity in the Southern California bight?

2012–14, PIs: David Hutchins and Feixue Fu (USC)

While anthropogenic enrichment of the ocean with CO₂ (i.e., ocean acidification) could greatly exacerbate the already substantial damage that HABs do to commercially important species ranging from shellfish to finfish, little is known about how the toxicity of *Pseudo-nitzschia* species will be affected by increasing CO₂ in combination with other concurrent climate change variables, such as sea surface warming and changes in nutrient supplies and light fields. This pilot project examined domoic acid production by cultured and natural populations of local *Pseudo-nitzschia* species under simulated future ocean conditions of temperature, CO₂ (pH), irradiance, and nutrient availability.

Trophic transfer of domoic acid in food webs of the future greenhouse coastal ocean

2014–16, PIs: David Hutchins and Feixue Fu (USC)

Previous USC Sea Grant-supported work showed that both warming ocean temperatures and ocean acidification can greatly increase the toxicity of local *Pseudo-nitzschia* species. Enhanced toxin levels in diatom prey cells may in turn result in higher domoic acid levels in the planktonic and benthic grazers that eat them, and ultimately end up in valuable harvested resources such as mussels, oysters, squid, and fish. The objectives of this project were to examine the interactive effects of warming and CO₂ on local *Pseudo-nitzschia* growth and toxin production, with special reference to the effects of the 2015 warming event in California that produced toxic blooms leading to multi-million dollar impacts on local marine ecosystems and fisheries resources.

Documenting multiple phycotoxins in coastal ecosystems of the California coast

2016–18, PIs: David Caron, Eric Webb, Avery Tatters (USC)

The confluence of freshwater and marine ecosystems along the coast of Southern California can be affected by multiple toxins (referred to as phycotoxins) of either freshwater or marine origin. This research focused on determining the extent of known or presently-undocumented phycotoxins in Southern Californian coastal waters and estuarine ecosystems, identifying the origin of these toxins, obtaining a greater understanding of their “hot spots” within this region, establishing the basic physiological tolerances (temperature, salinity) of these species and their effects on toxin production, and providing information for the development of future monitoring practices.

ONGOING OR NEW SEA GRANT-FUNDED RESEARCH (2018–2022)

A brief overview of ongoing or new USC Sea Grant and Ocean Protection Council (OPC) Proposition 84 funded HAB research projects is provided below. Although this report does not include research findings from all of these projects, they utilize cutting-edge science to address complex questions about HAB occurrence and detection.

Advancing portable detection capabilities of harmful algal bloom species in California waters

2018–21, OPC Prop 84 Funding, PIs: Holly Bowers and Jason Smith (Moss Landing Marine Laboratories)

We now have the ability to vastly improve the efficiency of detecting HAB species through new handheld technology that provides rapid and specific analyses from locations ranging from shore-side to ship deployments. The principal investigators were recently awarded such a device (the Freedom4) through a competitive award from Ubiquitome, New Zealand with the goal of improving HAB detection in the field. The flexibility of established, portable genetic detection technology would greatly enhance sampling efforts on relevant temporal and spatial scales toward overcoming challenges inherent to field monitoring. Moreover, the Freedom4 platform will support future efforts outlined in the OPC recommendations: advancing HAB predictive models, improving the understanding of HAB ecophysiology, and linking HAB events to human health.

Multiple stressors and toxic *Pseudo-nitzschia* blooms in California waters: understanding the complex interactive impacts of nutrients, temperature, and carbonate chemistry

2018–21, OPC Prop 84 Funding, PIs: David Hutchins and Feixue Fu (USC)

Despite our growing knowledge about the impacts of each of these single factors on toxicity, little is known about how projected simultaneous future changes in nutrients, temperature, and carbonate chemistry will together affect domoic acid levels in California coastal food webs. This project will experimentally test the effects of relevant projected levels of these three critical controlling factors using multi-stressor studies with *Pseudo-nitzschia* cultures isolated from California waters, and with local natural phyto-

plankton communities containing toxic *Pseudo-nitzschia* species. The project will be specifically designed to inform a new generation of domoic acid forecasting HAB models incorporating quantitative, mechanistic knowledge of climate change multiple stressor interactions. The aim is to generate a set of informed predictions of how future environmental conditions may influence damaging toxic *Pseudo-nitzschia* blooms, as our coastal ocean ecosystems continue to respond to ever-increasing human populations and a changing climate.

Design and development of a universal genetic assay to monitor and predict toxic *Pseudo-nitzschia* planktonic blooms

2020–22, PIs: Bradley Moore (Scripps Institution of Oceanography) and Andrew Allen (Scripps Institution of Oceanography and J. Craig Venter Institute)

Accurate predictive monitoring tools are lacking for blooms of the globally distributed diatom genus *Pseudo-nitzschia* that produces the neurotoxin domoic acid (DA). This project aims to develop predictive monitoring approaches by detecting domoic acid biosynthesis genes (dab genes) associated with toxin production in three *Pseudo-nitzschia* species with varying levels of toxin production. The goal is to develop a universal genetic assay to reliably detect dab genes and apply this knowledge to create a commercial detection kit that can be used for monitoring. This technology presents a predictive, rapid, and low-cost method to identify dab genes of high-toxin producing *Pseudo-nitzschia* in the environment prior to toxin production. Moreover, this new DA monitoring strategy would complement existing direct detection methodology to better inform and protect coastal communities and economies by predicting the extent of HABs in areas of likely production before they actually begin.

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