A SOUTHERN CALIFORNIA PERSPECTIVE ON HARMFUL ALGAL BLOOMS

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EXTENDED ABSTRACT

Understanding the complexity of harmful algal blooms (HABs) and their impacts on marine resources requires collaborations that overlaps a variety of disciplines, agencies, and regions. Ongoing monitoring efforts by California Department of Public Health (CDPH), the Southern California Coastal Ocean Observing System (SCCOOS) and the Central and Northern Coastal Ocean Observing System (CeNCOOS) provide the basis for evaluating and assessing the potential of marine biotoxins within commercially and recreationally important fisheries along the California coastline. These programs focus efforts on a particular marine resource (CDPH, farmed and recreationally harvested bivalves) or on a specific toxin (domoic acid only for SCCOOS) to meet regulatory requirements or funding shortfalls that constrain sample collection and processing. Since 2001, prevalence and persistence of offshore toxic blooms, particularly of domoic acid, has compounded this problem and additional monitoring efforts are needed to assess potential risks to consumers and inform seafood advisories within the state. Finding opportunities to collaborate with the California Cooperative Oceanic Fisheries Investigations Group (CalCOFI) and the Southwest Fisheries Science Center (SWFSC) can help assess the potential risks to our marine resources and seafood consumers, and provide novel opportunities for data collection and sharing. This presentation is focused on three main points: 1) providing an overview on the HAB monitoring efforts in southern California, 2) discussing the potential impact on California fisheries, and 3) providing input on how CalCOFI and SWFSC can be engaged in HAB monitoring.

HAB Monitoring in California

One of the oldest HAB programs in the U.S. started in 1929 along the California coast to monitor for saxitoxins that can cause illness or death in extreme cases from paralytic shellfish poisoning (PSP). In the 1940s, such monitoring was mandated for the sale of commercial shellfish by the National Shellfish Sanitation Program. By the 1960s, routine coastal monitoring for PSP toxins in shellfish began as a means to protect those recreationally harvesting shellfish. The regulatory alert level for saxitoxins in shellfish is ≥ 80 µg 100 g^{-1} (0.8 ppm). Several dinoflagellate species within the genus *Alexandrium* spp. (formerly *Gonyaulax*) produce PSP toxins.

The CDPH monitoring program was expanded in 1991 to include phytoplankton monitoring (net tow samples) along the coast as a means to provide an early warning of toxic blooms and prioritize shellfish samples for toxin analysis. At this time the program also began routine monitoring for a second biotoxin: domoic acid (DA), a naturally occurring and toxic amino acid that can cause amnesic shellfish poisoning (ASP; Bates et al. 1989). Toxin production has been confirmed in 12 of 30 species of the diatom genus *Pseudo-nitzschia* (Horner et al. 1997; Bates and Trainer 2006). ASP was first recognized in 1987 when three people died and 105 cases of acute poisoning were reported after consuming DA-contaminated blue mussels (*Mytilus edulis*) from Prince Edward Island, Canada (Bates et al. 1989). Along the West Coast of the U.S., human illness or death from ASP has not been reported though numerous cases of large-scale deaths and illnesses of marine mammals and wildlife have occurred since 1991 (Fritz et al. 1992; Work et al. 1993; Lefebvre et al. 1999; Scholin et al. 2000; Bejarano et al. 2008; Fire et al. 2010; Bargu et al. 2012). The regulatory alert level for DA in shellfish is ≥ 20 µg g^{-1} (20 ppm).

The CDPH program standards to protect consumers includes weekly monitoring of marine biotoxins in shellfish and the relative abundance of toxigenic phytoplankton along the coast, posting of annual quarantines from May 1 to October 31 each year, issuing special health advisories as needed for recreationally harvested bivalves, and public education and outreach. The program relies on commercial growers (7 sites) to provide weekly shellfish and plankton samples, and a volunteer network to provide weekly to monthly shellfish samples (70 sites) and plankton samples (115) from coastal stations (1–4 per county). The resulting data are used to regulate shellfish growers, as well as to inform state health advisories about safe consumption of recreationally harvested shellfish when HABs are present. These data, maps and advisories are available at http://www.cdph.ca.gov/healthinfo/environhealth/water/Pages/Shellfish.aspx.

Academic and ocean observing research communities interested in understanding the temporal and spatial scales of HABs, factors which promote HABs, as well as improving the detection and prediction of these events began regular, weekly pier-based HAB monitoring efforts in southern California at one site in 2005 (SIO, La Jolla) and an additional four sites in 2008 (SCCOOS, http://www.sccoos.org/data/habs/index.php). These efforts are focused on all HAB species in California that may pose significant impacts to human health, marine life, marine resources, and the economy including both toxin producing (*Pseudo-nitzschia* spp., *Alexandrium* spp., and *Dinophysis* spp.) and bloom forming species (*Lingulodinium polyedrum*, *Akashiwo sanguinea*, *Prorocentrum* spp. *Cochlodinium* spp., *Phaeocystis* spp., and others). Weekly measurements include HAB species abundance estimates, chlorophyll *a* concentration, temperature, salinity, nutrient concentrations (nitrate, nitrite, phosphate, silicate, and ammonia) and particulate DA concentration. These data are posted weekly to the SCCOOS HAB Web site and shared through the California Harmful Algal Bloom Monitoring and Alert Program (CalHABMAP, http://habmap.info) e-mail list serve, which brings together researchers, marine mammal and wildlife rescue groups, managers, and the general public throughout the state of California.

While coastal monitoring efforts and the CDPH program have been effective at protecting and informing consumers of toxic HABs in coastal areas, these efforts have historically focused on nearshore shellfish resources and not on detection of HABs in offshore waters including areas near the Channel Islands. Additional monitoring is now needed for two primary reasons. First, the prevalence, intensity, and duration of these offshore toxic blooms of *Pseudo-nitzschia* have increased in California over the past decade (CDPH data; Lewitus et al. 2012). As a result, there is a need to monitor commercially and recreationally important species more frequently as they are exposed to higher levels of biotoxins more often and for longer periods of time. Second, these blooms have developed and/or continued offshore, especially in the Santa Barbara Channel (SBC) region, often decoupled from coastal blooms—something not commonly seen in the past. This new pattern in the distribution of toxic blooms now requires that monitoring occur in offshore areas, not just along the coast as is presently done.

The California Sea Grant Extension Program, in collaboration with the CDPH and the California Department of Fish and Wildlife (CDFW) recognized that a more focused and organized offshore monitoring program was critically needed given that 1) toxic offshore blooms are persisting, 2) higher levels of biotoxins may pose more risk to consumers, 3) offshore shellfish and fish samples for biotoxin analysis are obtained haphazardly from recreational and commercial fishermen, rendering useful but incomplete data sets, and 4) the value of a more consistent and reliable offshore monitoring program to better manage offshore fisheries and ensure areas not impacted by HABs are not included in health advisories when another offshore area is impacted by a HAB event. This collaborative effort is looking to expand the CDPH biotoxin monitoring program into offshore areas of southern California (Santa Barbara County to the Mexican border) with funding from the Collaborative Fisheries Research West program. They are seeking volunteers to help with one or more of the sampling tiers; Tier 1, phytoplankton; Tier 2, bivalve shellfish (mussels, oysters, scallops, clams) or filter-feeding finfish (anchovies, sardines); Tier 3, crustacean shellfish (crabs, lobster). Several other organizations (e.g., whale watching, dive and island charters, commercial fishermen, National Park Service) and individuals are joining this effort, but coordinating with additional groups that frequent offshore areas, such as CalCOFI and SWFSC, is of great interest.

Impacts on Fisheries

Biotoxins have been detected in a wide variety of species other than bivalve shellfish including but not limited to pelagic filter-feeding species (Pacific sardines and Northern anchovies), California spiny lobster, crab (Dungeness, rock and pelagic red), Humboldt squid, Market squid, and benthic-feeding groundfish including several commercial and recreationally important species (Pacific halibut, Dover sole, and sanddab); (Wekell et al. 1994; Busse et al. 2006; Vigilant and Silver 2007; Mazzillo et al. 2010). Of particular concern has been the high levels of DA found in samples from California over the last 10 years: 1) mussels from an offshore oil platform that contained 610 ppm of DA; 2) anchovies with 2,300 ppm of DA in viscera; 3) lobster viscera with 1,170 ppm of DA, and several samples with 200–400 ppm of DA; and 4) rock crab containing 300–400 ppm (CDPH data). Toxins are typically concentrated in the viscera (internal organs, digestive glands) and not the body tissue (meat), so thorough cleaning and removal of the viscera in larger species (e.g., crab, scallops) can minimize the risk. However many species (e.g., mussels, oysters, sardines, anchovies) are eaten whole and pose the greatest risk to consumers (Mazzillo et al. 2010). Some individuals and ethnicities may also consume the entire rock scallop, rock crab (crab butter) and lobster (lobster tomalley, pâté, bisque) increasing the risk of exposure to biotoxins and other contaminants.

Importantly, even at high DA concentrations, the preliminary data indicates the meat of the larger crustaceans and game fish remains relatively toxin free even though low concentrations of toxins have been detected in the body tissue (meat) of anchovies (*Engraulis mordax*; Work et al. 1993; Altwein et al. 1995; Lefebvre et al. 2002; Mazzillo et al. 2010), coho salmon (*Oncorhynchus kisutch*; Lefebvre et al. 2007), Dungeness crab (*Cancer magister*; Altwein et al. 1995), mantle of Humboldt squid (*Dosidicus gigas*; Mazzillo et al. 2011) and mantle of octopus (*Octopus vulgaris*; Costa et al. 2004). Overall, these findings are based on a relatively limited number of samples and require more comparative data during HAB events to improve our understanding of the risk exposure to biotoxins for all seafood species.

In general, HABs directly impact California fisheries through the closure of shellfish beds, aquaculture facilities, and even the closure of markets and recreational sport fisheries due to toxin accumulation above regulatory limits and die-offs of natural and farmed fish and shellfish. Almost every year since 2001 CDPH has had to extend the time period of the annual shellfish advisory or issue additional warnings to protect consumers about eating seafood (other than bivalves) such as sardines, anchovies, lobster, and crab that have been found to have biotoxins above the regulatory alert level (20 ppm for DA). The health advisories that have resulted from these findings have impacted commercial fishermen, as some distributors will not buy products coming from the areas under advisory. In most cases, the advisories cover a large area due to a lack of data to pinpoint the location of the bloom and associated affected animals.

Currently, shellfish growers are the most highly regulated in terms of biotoxins, providing the best protection for the consumer, but an equivalent level of monitoring and regulatory oversight for commercial and recreationally important wild-caught fisheries in California does not exist. Ultimately, there are several unanswered questions related to human health impacts of HABs on fisheries. How often are toxins found in offshore populations of shellfish, squid, and finfish? Can one indicator species provide adequate protection to consumers if modes of toxin uptake differ and depuration rates vary for impacted species (bivalves, lobster, crab, squid, and finfish)? Do increased amounts of toxin found in seafood pose a greater risk of acute toxicity to the consumer? Are there human health concerns with chronic exposure to algal biotoxins? These are just a few of the complex questions that need greater attention to protect both the consumer and the seafood industry.

Potential Assistance from CalCOFI

The last goal of this presentation is to provide input on how the CalCOFI and SWFSC groups can be engaged in research and monitoring of HABs. One immediate and cost-saving approach for the offshore monitoring of HABs is to have consistent samples collected during the quarterly CalCOFI cruises and SWFSC fish survey cruises. Sample types consist of water samples (30–100 ml), filtered water samples (400 ml on GF/F filters), net tow samples (20 μm mesh vertical tow), or samples of fish or shellfish (whole or viscera only) and would be analyzed by CDPH and SCCOOS HAB researchers. These samples would be quite beneficial to ongoing research and state monitoring efforts by helping determine HAB species abundance and toxin production in the water and food web at offshore locations on regular intervals. This, in turn, would improve early detection of blooms and increase spatial and temporal data needed to inform health advisories.

Additionally, plankton and hydrographic data sets already being collected by CalCOFI could be reanalyzed to help address HAB related questions. For example, phytoplankton abundance estimates (collected by E. Venrick) and nano- and microplankton biomass and abundance estimates (collected by M. Landry) are currently conducted for some stations and lines throughout the CalCOFI sampling grid. These measurements could also be analyzed to look specifically at HAB species such as *Pseudo-nitzschia* spp., thereby providing information on abundance relative to offshore hydrographic conditions and coastal conditions. More broadly, this increased sampling and analysis of data when combined together would ultimately provide a better understanding of the mechanisms and factors associated with offshore HAB blooms, improve understanding of links with coastal blooms, and potentially improve predictions of HAB events.

Conclusions

Adequate offshore HAB-focused sampling is lacking, hindering the states' ability to provide well-informed seafood health advisories and improve our understanding of the factors related to offshore toxic blooms. Engaging CalCOFI and SWFSC in ongoing HAB monitoring efforts could improve the availability of samples both in space and time thereby helping to identify high-risk areas and improving the resolution of information available to researchers, resource managers, and health regulatory agencies. While some coordination is required, the additional sampling appears to be easily integrated with ongoing activities of CalCOFI and SWFSC. The authors encourage such collaboration, as it would not only increase the knowledge about HABs in California, but it would also enhance the states' ability to provide appropriate seafood health advisories.

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LITERATURE CITED

Altwein, D. M., K. Foster, G. Doose, and R. T. Newton. 1995. The detection and distribution of the marine neurotoxin domoic acid on the Pacific coast of the United States 1991–93. Journal of Shellfish Research 14:217–222.

Bargu, S., T. Goldstein, K. Roberts, C. Li, and F. Gulland. 2012. *Pseudo-nitzschia* blooms, domoic acid, and related California sea lion strandings in Monterey Bay, California. Marine Mammal Science 28:237–253.

Bates, S. S., C. J. Bird, A. S. W. Defreitas, R. Foxall, M. Gilgan, L. A. Hanic, G. R. Johnson, A. W. McCulloch, P. Odense, R. Pocklington, M. A. Quilliam, P. G. Sim, J. C. Smith, D. V. S. Rao, E. C. D. Todd, J. A. Walter, and J. L. C. Wright. 1989. Pennate diatom *Nitzschia-pungens* as the primary source of domoic acid, a toxin in shellfish from Eastern Prince Edward Island, Canada. Canadian Journal of Fisheries and Aquatic Sciences 46:1203–15.

Bates, S. S. and V. L. Trainer. 2006. The ecology of harmful algal blooms. *In*: Ecological Studies, E. Graneli and J. T. Turner, eds. Berlin, Germany: Springer-Verlag Berlin, pp. 81–93.

Bejarano, A. C., F. M. Gulland, T. Goldstein, J. St. Leger, M. Hunter, L. H. Schwacke, F. M. VanDolah, and T. K. Rowles. 2008. Demographics and spatio-temporal signature of the biotoxin domoic acid in California sea lion (*Zalophus californianus*) stranding records. Marine Mammal Science 24:899–912.

Busse, L. B., E. L. Venrick, R. Antrobus, P. E. Miller, V. Vigilant, M. W. Silver, C. Mengelt, L. Mydlarz, and B. B. Prezelin. 2006. Domoic acid in phytoplankton and fish in San Diego, CA, USA. Harmful Algae 5:91–101.

Costa, P. R., R. Rosa, and M. A. M. Sampayo. 2004. Tissue distribution of the amnesic shellfish toxin, domoic acid, in *Octopus vulgaris* from the Portuguese coast. Marine Biology 144:971–76.

Fire, S. E., Z. Wang, M. Berman, G. W. Langlois, S. L. Morton, E. Sekula-Wood, and C. R. Benitez-Nelson. 2010. Trophic transfer of the harmful algal toxin domoic acid as a cause of death in a Minke whale (*Balaenoptera acutorostrata*) stranding in southern California. Aquatic Mammals 36:342–350.

Fritz, L., M. A. Quilliam, J. L. C. Wright, A. M. Beale, and T. M. Work. 1992. An outbreak of domoic acid poisoning attributed to the pennate diatom *Pseudo-nitzschia australis*. Journal of Phycology 28:439–42.

Horner, R. A., D. L. Garrison, and F. G. Plumley. 1997. Harmful algal blooms and red tide problems on the US west coast. Limnology and Oceanography 42:1076–1088.

Lefebvre, K. A., C. L. Powell, M. Busman, C. J. Doucette, P. D. R. Moeller, J. B. Sliver, P. E. Miller, M. P. Hughes, S. Singaram, M. W. Silver, and R. S. Tjeerdema. 1999. Detection of domoic acid in northern anchovies and California sea lions associated with an unusual mortality event. Natural Toxins 7:85–92.

Lefebvre, K. A., M. W. Silver, S. L. Coale, and R. S. Tjeerdema. 2002. Domoic acid in planktivorous fish in relation to toxic *Pseudo-nitzschia* cell densities. Marine Biology 140:625–31.

Lefebvre, K. A., D. P. Noren, I. R. Schultz, S. M. Bogard, J. Wilson, and B. T. L. Eberhart. 2007. Uptake, tissue distribution and excretion of domoic acid after oral exposure in coho salmon (*Oncorhynchus kisutch*). Aquatic Toxicology 81:266–74.

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

Mazzillo, F. F. M., J. C. Field, D. J. Staaf, M. L. Carter, and M. D. Ohman. 2011. A note on the detection of the neurotoxin domoic acid in the beach-stranded *Dosidicus gigas* in the Southern California Bight. California Cooperative Oceanic Fisheries Investigations Reports 52:109–15.

Mazzillo, F. F. M., C. Pomeroy, J. Kuo, P. T. Ramondi, R. Prado, and M. W. Silver. 2010. Angler exposure to domoic acid via consumption of contaminated fishes. Aquatic Biology 9:1–12.

Scholin, C. A., F. Gulland, G. J. Doucette, S. Benson, M. Busman, F. P. Chavez, J. Cordaro, R. DeLong, A. De Vogelaere, J. Harvey, M. Haulena, K. Lefebvre, T. Lipscomb, S. Loscutoff, L. J. Lowenstine, R. Marin, P. E. Miller, W. A. McLellan, P. D. R. Moeller, C. L. Powell, T. Rowles, P. Silvagni, M. Silver, T. Spraker, V. Trainer, and F. M. Van Dolah. 2000. Mortality of sea lions along the central California coast linked to a toxic diatom bloom. Nature 403:80–84.

Vigilant, V. L., and M. W. Silver. 2007. Domoic acid in benthic flatfish on the continental shelf of Monterey Bay, California, USA. Marine Biology 151:2053–2062.

Wekell, J. C., E. J. Gauglitz, H. J. Barnett, C. L. Hatfield, and M. Eklund. 1994. The occurrence of the domoic acid in razor clams (*Siliqua patula*), Dungeness crab (*Cancer magister*) and anchovies (*Engraulis mordax*). Journal of Shellfish Research 13:587–93.

Work, T. M., B. Barr, A. M. Beale, L. Fritz, M. A. Quilliam, and J. L. C. Wright. 1993. Epidemiology of domoic acid poisoning in brown pelicans (*Pelecanus occidentalis*) and Brandt cormorants (P*halacrocorax penicillatus*) in California. Journal of Zoo and Wildlife Medicine 24:54–62.