Harmful Algae 8 (2009) 291–298

Contents lists available at ScienceDirect

Harmful Algae

journal homepage: www.elsevier.com/locate/hal

A shift in the dominant toxin-producing algal species in central California alters phycotoxins in food webs

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ARTICLE INFO

Article history:
Received 30 January 2008

Accepted 1 July 2008

Keywords:
Alexandrium
Domoic acid
Food web
Paralytic shellfish poisoning toxins
Phytoplankton shift
Pseudo-nitzschia

ABSTRACT

In California, the toxic algal species of primary concern are the dinoflagellate *Alexandrium catenella* and members of the pennate diatom genus *Pseudo-nitzschia*, both producers of potent neurotoxins that are capable of sickening and killing marine life and humans. During the summer of 2004 in Monterey Bay, we observed a change in the taxonomic structure of the phytoplankton community—the typically diatom-dominated community shifted to a red tide, dinoflagellate-dominated community. Here we use a 6-year time series (2000–2006) to show how the abundance of the dominant harmful algal bloom (HAB) species in the Bay up to that point, *Pseudo-nitzschia*, significantly declined during the dinoflagellate-dominated interval, while two genera of toxic dinoflagellates, *Alexandrium* and *Dinophysis*, became the predominant toxin producers. This change represents a shift from a genus of toxin producers that typically dominates the community during a toxic bloom, to HAB taxa that are generally only minor components of the community in a toxic event. This change in the local HAB species was also reflected in the toxins present in higher trophic levels. Despite the small contribution of *A. catenella* to the overall phytoplankton community, the increase in the presence of this species in Monterey Bay was associated with an increase in the presence of paralytic shellfish poisoning (PSP) toxins in sentinel shellfish and clupeoid fish. This report provides the first evidence that PSP toxins are present in California's pelagic food web, as PSP toxins were detected in both northern anchovies (*Engraulis mordax*) and Pacific sardines (*Sardinops sagax*). Another interesting observation from our data is the co-occurrence of DA and PSP toxins in both planktivorous fish and sentinel shellfish. We also provide evidence, based on the statewide biotoxin monitoring program, that this increase in the frequency and abundance of PSP events related to *A. catenella* occurred not just in Monterey Bay, but also in other coastal regions of California. Our results demonstrate that changes in the taxonomic structure of the phytoplankton community influences the nature of the algal toxins that move through local food webs and also emphasizes the importance of monitoring for the full suite of toxic algae, rather than just one genus or species.

1. Introduction

California has a long-standing history of toxic phytoplankton blooms that date back to the early 1900s (Meyer et al., 1928). In the past, the toxic species of primary concern has been the dinoflagellate *Alexandrium catenella*, producer of a suite of highly toxic compounds referred to as paralytic shellfish poisoning (PSP) toxins, and human deaths related to PSP can be traced back over a century. After a major PSP outbreak in 1927, the California Department of Public Health (CDPH) recognized the continuing threat to shellfish consumers and initiated a statewide marine biotoxin monitoring program (Price et al., 1991). Since the inception of the monitoring program, over 500 human illnesses and 39 deaths have been reported, that last of which occurred in the 1980s (Price et al., 1991). Interestingly, and despite its routine presence in California, PSP toxins have not been associated with any marine animal mortality events, as occurs in other regions afflicted by PSP (Geraci et al., 1989; Reyero et al., 1999; White, 1981). Aside from shellfish, sand crabs (*Emerita analoga*) are the only other organisms in which PSP toxins have been reported in California (Bretz et al., 2002).

More recently, members of the diatom genus *Pseudo-nitzschia* were discovered to be problematic on the US west coast, when two

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doi:10.1016/j.hal.2008.07.001

species, *Pseudo-nitzschia australis* and *P. multiseries*, were linked to the production of domoic acid (DA) in 1991. The event that led to this discovery involved the death of hundreds of brown pelicans (*Pelecanus occidentalis*) in Monterey Bay, CA (Fritz et al., 1992; Work et al., 1993). Since then, repeated DA poisoning events throughout central and southern California have resulted in the closure of commercial fisheries and the deaths of hundreds of pinnipeds and cetaceans (Langlois, 2003, 2004; Scholin et al., 2000). Many potential vectors of DA to secondary predators have been identified (Bargu et al., 2002; Goldberg, 2003; Powell et al., 2002; Wekell et al., 1994), but planktivorous fish, such as northern anchovies (*Engraulis mordax*) and Pacific sardines (*Sardinops sagax*), are the most frequent vector implicated in animal mortalities in this region (Lefebvre et al., 1999; Scholin et al., 2000; Work et al., 1993). To date, there have not been any incidences of human illness related to DA in California, likely the result of prompt inclusion of DA monitoring by CDPH into the statewide biotoxin monitoring program.

In addition to these well-known taxa, two genera known to be toxic in other regions are present in California coastal waters. *Dinophysis* species such as *D. fortii*, *D. acuminata* and *D. rotundata*, globally recognized as producers of diarrhetic shellfish poisoning (DSP) toxins (Hallegraeff, 1993), are routinely present along our coastline. In addition, DSP toxins have been detected in surface water samples (Weber, 2000) and a recent study has confirmed for the first time the presence of low levels of DSP toxins in mussels from Monterey Bay (Sutherland, 2008). Another potentially problematic dinoflagellate, *Cochlodinium*, has become more frequent in central California (Curtiss et al., 2008), causing visible red tides and attracting the attention of the media. The presence of this alga has raised concerns, as members of this genus have caused fish mortalities in the coastal Pacific waters of Mexico, Central America, Canada and Asia (Garate-Lizarraga et al., 2004; Kim et al., 1999; Lara et al., 2004; Vargas-Montero et al., 2006; Whyte et al., 2001). There have not yet been any published reports of human illnesses or animal mortality events caused by *Dinophysis* or *Cochlodinium* in California, though there is unpublished circumstantial evidence that a recent bloom of *Cochlodinium* caused mass shellfish mortalities (G. Langlois pers. commun.).

The coastal upwelling region of Monterey Bay, the focal point of this study, supports a rich and diverse marine ecosystem and is valued not only economically for its fisheries, but also for its importance to marine wildlife. The primary production level in Monterey Bay differs significantly in the three well-described hydrographic "seasons" of the Bay (Bolin and Abbott, 1963; Breaker and Broenkow, 1994) and is usually highest during the diatom-dominated spring to summer "upwelling season" (Bolin and Abbott, 1963). In contrast, periods of dinoflagellate dominance are thought to be temporary and associated with intrusions of more nutrient-depleted, offshore waters as can occur during the oceanic and Davidson Current "seasons" (Bolin and Abbott, 1963; Garrison, 1979). The seasonal high productivity that characterizes this region is particularly important to the variety of resident and migratory animals, such as sea birds, marine mammals and turtles, that depend on this area as a feeding ground (Benson et al., 2007; Croll et al., 2005; Hyrenbach et al., 2006; Yen et al., 2004). Given that a major prey item for many of these predatory animals is planktivorous fish, exposure to algal toxins may be common, given the efficiency with which these fish vector toxins (Lefebvre et al., 1999; Scholin et al., 2000).

As part of our ongoing work in Monterey Bay monitoring the phytoplankton community (especially harmful algal bloom [HAB] taxa) and examining the presence of algal toxins in marine food webs, we observed an unexpected shift in the phytoplankton community. This shift was characterized by the unusual dominance of dinoflagellates in this typically diatom-dominated system. As such, in this study we compare the taxonomic structure of the phytoplankton community before and after this change in the dominant flora of Monterey Bay using samples collected over a 6-year period, with particular attention paid to toxin-producing taxa and the presence of DA and PSP toxins in the food web.

2. Materials and methods

2.1. Field sampling

2.1.1. Water sample collection

From January 2000 to December 2006 weekly surface water samples were collected using a bucket at 2 sites within Monterey Bay, CA: nearshore at the Santa Cruz wharf (SCW) (36.95 N, 122.02 W) and offshore at the Monterey Bay Aquarium Research Institute's M1 mooring (36.75 N, 122.02 W). SCW water samples were immediately transported to the lab for processing, while M1 samples were collected midday aboard the *R/V Pt. Lobos*, stored in a dark cooler, and transported to the lab for processing approximately 6 h after collection. The three best known toxin-producing species in Monterey Bay, *P. australis*, *P. multiseries* and *A. catenella*, were identified and enumerated on an epifluorescent compound microscope (Zeiss Axio Imager) using whole-cell oligonucleotide probes as described in Miller and Scholin (1998, 2000) and Scholin (1994). *P. australis* and *P. multiseries* densities are summed and presented as "toxic *Pseudo-nitzschia*." At SCW, net plankton samples, used for phytoplankton community assessments, were collected with a 20-μm mesh net hauled through the upper 3 m of the water column. Using live net tow material viewed under a dissecting microscope (Olympus SZH Stereozoom) and magnified 64×, the relative abundance (present, common or dominant) of the most commonly observed genera of dinoflagellates and diatoms were recorded. Aliquots of both water and net tow samples were preserved in 4% formalin for archival purposes.

2.1.2. Fish and shellfish collection

Northern anchovies (*E. mordax*) and Pacific sardines (*S. sagax*) caught commercially within Monterey Bay were collected opportunistically from the landings of local fishing boats during periods of elevated cell densities between January 2003 and December 2005. Freshly caught fish were collected dockside, packaged whole and promptly placed in a −20 °C freezer until processing. In preparation for toxin analysis, slightly thawed fish were dissected and the viscera of multiple specimens from each species were pooled and homogenized to provide one representative sample per sampling day. The species and quantity of fish varied based on the day's catch and ranged from 8 to 90 individuals for anchovies and 4 to 34 individuals for sardines. Aliquots of homogenized viscera were placed in 50 ml conical tubes and frozen for later DA and PSP toxin analysis.

Shellfish samples were collected as part of the statewide CDPH marine biotoxin monitoring program. Since our nearshore site, SCW, is not in close proximity to accessible shellfish beds, mussels (*Mytilus californianus*) were harvested from a rocky intertidal beach north of Santa Cruz (Davenport Landing; 37.02 N, 122.21 W), placed in mesh bags (ca. 30 mussels) and suspended from the wharf a minimum of 7 days before collection. Each week one mesh bag of SCW mussels were shucked, homogenized using a standard kitchen blender, frozen at −20 °C and shipped to CDPH for toxin assay. Data were also used from shellfish samples gathered statewide, including intermittently elsewhere in Santa Cruz County, and submitted by the CDPH volunteer network. CDPH analyzes all submitted shellfish samples for PSP toxins, whereas samples are only analyzed for DA when *Pseudo-nitzschia* (all