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Monitoring Oregon Coastal Harmful Algae: Observations and implications of a harmful algal bloom-monitoring project

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A B S T R A C T

The accumulation of domoic acid (DA) and saxitoxins (STX), phycotoxins produced by some species of *Pseudo-nitzschia* and *Alexandrium*, respectively, in coastal food webs are a focus of research on the West Coast of the United States due to the deleterious effects they have on coastal ecosystems and economies. Results are presented from the 2007–2012 Monitoring Oregon Coastal Harmful Algae (MOCHA) project, the Oregon coast's first HAB monitoring and research program. Both historical toxin databases and more detailed case-study observations of individual HAB events are compiled to provide the first detailed overview of HAB occurrence in this region. These results are also presented in the context of informing future HAB monitoring in this and other upwelling regimes affected by STX and DA. A 2009–2010 warming event was associated with the greatest HAB activity during the MOCHA project, including anomalously high sea surface temperatures and shellfish harvesting closures due to STX and DA in 2009 and 2010, respectively. In regards to HAB monitoring, it is shown that (1) razor clams are a more sensitive indicator of DA than mussels; (2) water column concentrations of particulate domoic acid greater than 10^3 ng L^{-1} can be used as a threshold for early-warning of shellfish DA toxicity and (3) approximately bi-weekly, or shorter, monitoring of *Alexandrium* in the surf zone and/or offshore can provide advance notice of STX contamination of shellfish. Both of the latter two metrics gain added value when coupled with local wind stress, a proxy of downwelling/relaxation events that facilitate greater interaction between offshore blooms and shellfish.

1. Introduction

Globally, harmful algal blooms (HAB) are increasing in their frequency, persistence, toxicity, and regional coverage (Anderson et al., 2008; Hallegraeff, 1993; Van Dolah, 2000). Toxigenic HAB events along the West Coast of the United States are no exception and have been a topic of extensive HAB research and monitoring due to the threats they impose on coastal economies, ecosystems, and public health. Two of the major phycotoxins of interest in this region are the water-soluble amino acid domoic acid (DA), produced by some species of the diatom genus *Pseudo-nitzschia*, and a suite of heterocyclic guanidines collectively called saxitoxins (STX) that are produced by certain dinoflagellates, including some species of *Alexandrium* (Horner et al., 1997; Horner, 2001; Van Dolah, 2000). Both STX and DA can accumulate in the marine food web, potentially threatening living marine resources and public health. Human consumption of DA- or STX-contaminated shellfish in sufficient quantities can lead to Amnesic Shellfish Poisoning (ASP) or Paralytic Shellfish Poisoning (PSP), respectively (Picot et al., 2011). Symptoms of these illnesses range from gastrointestinal

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distress to neurological dysfunction and, in rare cases, death. Horner et al. (1997) note that 'it is evident from early records, local native customs and the apparent ability of some native marine animals to distinguish toxic prey items, that PSP has been present on the West Coast for hundreds of years, perhaps longer.' Fryxell et al. (1997) found historical accounts of *Pseudo-nitzschia* on the West Coast, including reports of *Pseudo-nitzschia* in Oregon as early as 1920. Globally, DA and ASP first became a public health concern in 1987 when an outbreak of food-related illness, including three deaths, in Prince Edward Island, Canada were traced to DA in mussels (Bates et al., 1989). On the West Coast of the United States, the first recorded DA event occurred in 1991 when cormorant and pelican deaths were traced to DA in diatoms (Buck et al., 1992). Subsequent research revealed both DA in razor clams on the West Coast of the U.S. (Drum et al., 1993) and the production of DA by *Pseudo-nitzschia* strains isolated from Monterey Bay, California and Coos Bay, Oregon (Garrison et al., 1992; Villac et al., 1993).

The Oregon coast, a key transition zone in West Coast oceanography, has been understudied compared to other regions (Lewitus et al., 2012); although there have been several Master's theses on HAB species in Oregon (Cziesla, 1999; Hughes, 1997; Ohana-Richardson, 2007; Scott, 2007) and a West Coast summit on DA was held at the Oregon Institute of Marine Biology (Wood et al., 1994). In 2007 a collaborative research program termed MOCHA, Monitoring Oregon Coastal Harmful Algae, was the first long-term project (5 years) funded by the National Oceanic and Atmospheric Administration to explore HAB events in this region. The MOCHA project's primary goals included collection of the scientific data necessary to describe both HAB occurrence in Oregon and the ecological mechanisms underlying them and then to use these findings to inform future HAB monitoring.

Harvest restrictions for commercial and recreational harvest of razor clams are costly to the coastal economy of Oregon. In the first known estimate for Oregon, Nosho (1999) determined that full closures in 1991 along the Washington and Oregon coasts resulted in a loss of $23–28 million in combined revenue to these states. Due to the popularity of these fisheries, the accumulation of phycotoxins in shellfish poses serious risks for both human health and local economies (Hoagland et al., 2002; Hoagland and Scatasta, 2006; Picot et al., 2011). As a result, the Oregon Department of Agriculture (ODA) has been routinely monitoring STX and DA concentrations in shellfish since 1979 and 1992, respectively. When thresholds of 80 μg 100 g^{-1} for STX or 20 ppm for DA are exceeded, shellfish harvesting is suspended. Until the MOCHA project (2007–2012), the ODA's shellfish toxin data (Lewitus et al., 2012) were the only time-series record of HAB events in Oregon, and few data regarding the spatial or temporal variability of HAB forming species were available.

High primary productivity along the Oregon coast occurs from late spring through early fall when net northerly wind stress brings nutrient-rich waters to the surface through Ekman transport. Variability in net northerly and southerly winds occurs on the order of 3–10 days (Hickey and Banas, 2003), driving fluctuations in surface currents and water properties. Phytoplankton blooms are initiated by upwelling-favorable (northerly) winds and, as measured by in situ chlorophyll-*a*, vary at similar scales (McKibben et al., 2012). Relaxation of these upwelling winds can transport blooms to the shore (Shanks et al., 2014). Du and Peterson (2014) have shown that the patterns of phytoplankton community structure during upwelling season in coastal Oregon follow the classic paradigm of diatom dominance in spring/summer during the early/mid upwelling season and dinoflagellate dominance in autumn/late upwelling season, as the water column warms and stratifies. The trends in species composition (e.g. which diatoms bloom in summer), however, are unpredictable. Given that diatoms and dinoflagellates are favored under different environmental conditions (Smayda and Trainer, 2010), STX- (dinoflagellate) and DA-related (diatom) HAB events do not regularly co-occur. Prediction of specific HAB events is a goal for coastal managers, but is not currently possible due to the high biophysical variability inherent in coastal upwelling regions (Shanks and McCulloch, 2003). Even so, long-term (years to decades) HAB datasets can be used to determine regions and seasons with the greatest probability of a HAB event; HAB-specific parameters associated with shellfish tissues should be useful as early warning proxies of future HAB events.

The 5-year MOCHA project collected the first extensive time series database of the Oregon coast's biological, chemical, and physical variables in both the surf zone and offshore habitat over a variety of sampling scales. "HAB events" are defined here as DA or STX levels in coastal shellfish tissue that exceed the threshold values that trigger a closure decision. In order to provide a comprehensive overview of HAB occurrence in Oregon and to inform future HAB monitoring efforts the following are presented: (1) a retrospective analysis of long-term (decades) historical shellfish toxin levels; (2) synoptic, coastwide analysis of HAB events and phytoplankton counts during the MOCHA project and (3) case studies of two major HAB events that occurred during the MOCHA project, including a combined view of shipboard, surf zone, and environmental data.

2. Data & methods

2.1. Surf zone monitoring

Coastal HAB monitoring was conducted via (1) monitoring of STX and DA levels (1979–present and 1992–present, respectively) in tissue samples from mussels and razor clams and (2) collection of surface water from the surf zone for phytoplankton cell counts (2007–2012). For the former, the ODA collects shellfish at intertidal sites along the Oregon coast (Fig. 1) every 2–4 weeks. Shellfish sampled include predominantly mussels (*Mytilus californianus*, *Mytilus edulis*) and razor clams (*Siliqua patula*). Concentration of STX is measured using the standard mouse bioassay method (AOAC, 1990) and DA concentrations are measured using high performance liquid chromatography (HPLC) methods recommended by the Canadian Food Inspection Agency's Shellfish Sanitation Program[1]. Detection limits for STX and DA are approximately 38 μg 100 g^{-1} and 1 part per million (ppm), respectively. Closure thresholds for STX and DA in shellfish tissue are 80 μg 100 g^{-1} and 20 ppm, respectively.

The second type of coastal HAB monitoring, phytoplankton counts in the surf zone, was conducted coastwide (Fig. 1) from 2007 to 2012. These samples were collected and analyzed by the Oregon Department of Fish and Wildlife (ODFW) every 2–4 weeks for the MOCHA project. Water was collected in the surf zone using a bucket and gently swirled to provide a well-mixed sample. The water was poured into a 125 mL glass jar and fixed with 5 mL of 37% formaldehyde solution buffered with sodium acetate for a final concentration of 1.5% formalin.

Surf zone data were separated into 3 latitudinal bins: north (45–46.5°N), central (43–45°N), and south (42–43°N) (Fig. 1). Bins partition the data according to distinct hydrographic features: the Columbia River Plume in the north, a retentive feature that is a source of freshwater (and buoyancy); Heceta Bank, a retentive central coast shelf feature (Fig. 1); and Cape Blanco, a region characterized by a strong coastal jet that both transports water offshore north of Cape Blanco (Fig. 1; ~43°N) but causes also retention to the south between ~42 and 43°N (Tweddle et al.,

[1] Method disseminated at the 1992 Washington Sea Grant Program, Workshop on Domoic Acid, Seattle, WA.