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A springtime source of toxic *Pseudo-nitzschia* cells on razor clam beaches in the Pacific Northwest

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ABSTRACT

Concentrations of domoic acid (DA) above the regulatory limit in Washington coast razor clams are usually higher on northern beaches from summer to fall. Recent field studies have confirmed that the primary source of toxic *Pseudo-nitzschia* (*PN*) cells in those seasons is a semi-retentive topographically trapped seasonal eddy located offshore and north of the clamming beaches. Another semi-retentive coastal feature, Heceta Bank, that has been shown to support toxic *PN* cells in summer, is located south of Washington's clamming beaches. In this paper we present evidence to demonstrate that Heceta Bank, although not a likely source of toxic cells to Washington in summer due to the prevailing southward seasonal currents, may be a source of cells in springtime before the southward currents develop. In contrast to summer and fall seasons, concentrations of DA in razor clams are typically higher at southern beaches in spring. The likelihood of a southern source is explored using biological and transport data surrounding a period of toxic razor clams in April 2005. In particular, satellite-derived chlorophyll data confirm that a bloom occurred over Heceta Bank in March of that year, just prior to a period of strong storm-driven northward transport. *PN* cells of the same species observed in the April bloom on Washington beaches and in offshore waters were documented in Oregon offshore waters on the northern edge of Heceta Bank. That species, *P. australis*, has been shown to be highly toxic in this region; shore-based data show that razor clams on Oregon beaches were also toxic at the time when *P. australis* was observed offshore. Both measured and modeled currents show that transport was more than sufficient to move cells from the vicinity of Heceta Bank, Oregon to southern Washington beaches by the time the toxic cells were observed on those beaches. The rapid transport was due in part to the presence of the buoyant plume from the Columbia River, a common feature in winter and spring in nearshore waters of the U.S. Pacific Northwest.

1. Introduction

Accurate risk assessment for the arrival of a harmful algal bloom (HAB) at a coastal beach depends on a detailed understanding of the ecology of the toxigenic organism producing a toxin, the triggers for toxin production, and transport from the toxic bloom development site to the beach. The ecology of organisms responsible for toxic blooms, including several species of *Pseudo-nitzschia* (*PN*) that can produce the neurotoxin, domoic acid (DA), as well as triggers for cellular toxicity in situ are still poorly understood. A complement to detailed information about species ecology and toxin triggers is knowledge of bloom development sites ("hotspots") in combination with robust transport and biological models that incorporate the variable conditions occurring along *PN* transport pathways.

The Pacific Northwest shelf and slope are set within an eastern boundary upwelling system, the California Current System (CCS) (Hickey, 1979, 1998). Isopycnals begin to tilt upward toward the coast following the transition from winter wind conditions to spring/summer wind conditions (Huyer et al., 1979; Huyer, 1983; Strub and James, 1988) resulting in the upward movement of deeper, nutrient-rich water. Although seasonal oceanographic properties in this region generally have large alongshore scales

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(>500 km) (Hickey, 1989; Hickey and Banas, 2003), smaller scale (∼10–50 km) features such as capes and banks may have a controlling influence on regions of HAB initiation. A whole-coast map of particulate domoic acid (pDA) concentrations collected during summer 1998 shows high concentrations of toxin *only* near the several mesoscale features where the typical upwelling circulation patterns are known to be interrupted (Fig. 1) (Hickey and Banas, 2003; Trainer et al., 2001). Recirculating current patterns form over banks such as offshore of the entrance to Juan de Fuca Strait in the feature known as the Juan de Fuca eddy (Freeland and Denman, 1982; Foreman et al., 2008), and, to a lesser extent, on Heceta Bank, off central Oregon (Kosro, 2005; Barth et al., 2005; Gan and Allen, 2005). These features tend to be retentive; i.e., they retain phytoplankton and other particles for longer time periods than an open, straight coastline (e.g., MacFadyen and Hickey, 2010 for the Juan de Fuca eddy; Venegas et al., 2008 for Heceta Bank). Due to the greater retention of phytoplankton in these regions, and low grazing rates relative to growth rates (Olson et al., 2006, 2008, for the Juan de Fuca eddy), phytoplankton can accumulate to high densities (Spitz et al., 2005 for Heceta Bank; MacFadyen et al., 2008 for the Juan de Fuca eddy region). They may also be subjected to both macro- and micro-nutrient stress in these regions (Trainer et al., 2009a,b), potential contributors to toxin production by *PN* (e.g., Bates et al., 1991; Pan et al., 1996; Maldonado et al., 2002; Wells et al., 2005; Schnetzer et al., 2007).

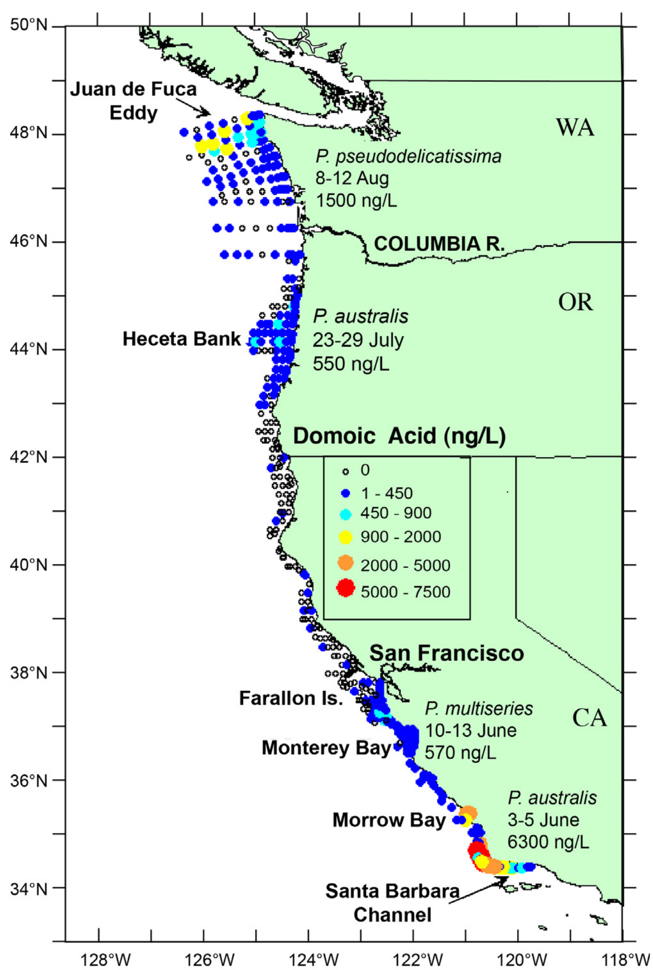

Fig. 1. Particulate DA along the whole U.S. west coast in summer 1998. Note regions of high pDA near recirculating topographic features.
Adapted from Springer Fig. 7, p. 1016, Hickey and Banas, 2003, original copyright; with kind permission from Springer Science and Business Media. Original data and maps in Trainer et al. (2000, 2001).

On six 3-week summer/fall interdisciplinary surveys of the Juan de Fuca eddy and coast region over a 4-year period, pDA was found in and downstream of the eddy in every case, but was rarely measured near the coast (Trainer et al., 2002, 2009a). Seasonal currents over the mid shelf to the upper slope are southward during the summer–fall season in the northern CCS and continuous over distances of a few hundred kilometers (MacFadyen et al., 2005, 2008), suggesting that the eddy is the likely source of toxic cells for Washington razor clam beaches, all of which are located south of the eddy. Recent research shows that the eddy is more retentive during and just following periods of downwelling-favorable (northward) winds; whereas escape from the eddy and travel downcoast occurs following periods of upwelling-favorable (southward) winds (MacFadyen et al., 2005; MacFadyen and Hickey, 2010). If a transition to downwelling-favorable winds (a summer storm) occurs during the period that the toxic cells are transiting down the coast, frictional surface currents move algae shoreward and onto coastal beaches, where razor clams and other crustaceans are impacted (Trainer et al., 2002; MacFadyen et al., 2005; MacFadyen and Hickey, 2010).

Like the Juan de Fuca eddy, Heceta Bank can readily be identified as a local maximum in chlorophyll concentration (e.g., Fig. 2) (also see Landry et al., 1989; Venegas et al., 2008 for the seasonal mean). Its circulation is retentive (Kosro, 2005; Barth et al., 2005), although not as retentive as the Juan de Fuca eddy. During summer, modification of the southward coastal jet by the bank introduces an alongshore pressure gradient that enhances northward velocity over the inner shelf onshore of the bank during downwelling-favorable winds, thus making the region more

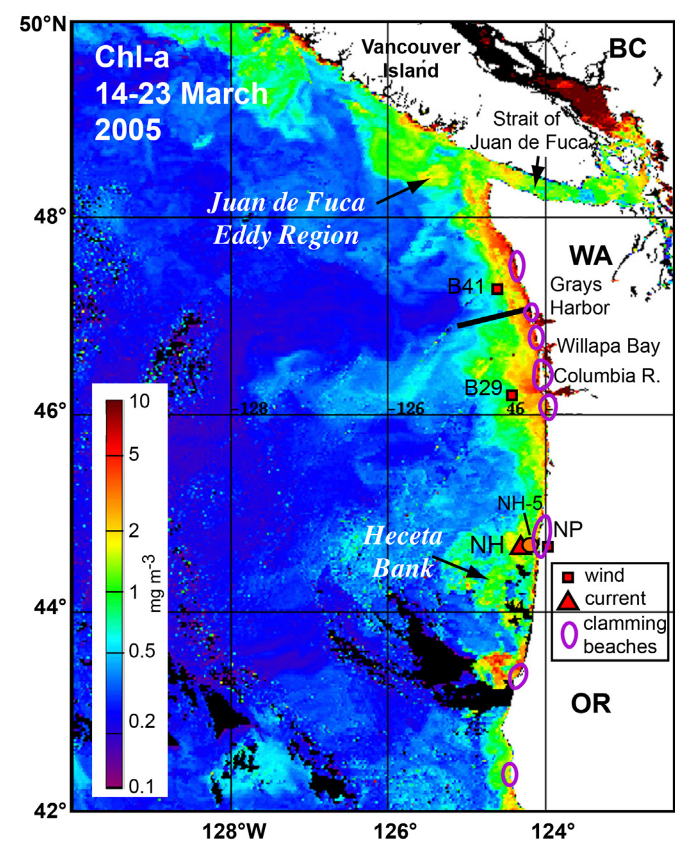

Fig. 2. MODIS satellite-derived chlorophyll image, averaged over 14–23 March 2005 (Kudela, Pers. Comm.). Physical features of interest are labeled and razor clam beaches are identified. The offshore sampling transect is denoted by a black line. Locations of wind buoys (B41, B29, and NP), a moored current profiler (NH) and a *PN* sampling station (NH-5) are also shown. Note higher chlorophyll concentrations near Heceta Bank, Oregon and along the Washington coast/British Columbia.