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Response of phytoplankton and bacterial biomass during a wastewater effluent diversion into nearshore coastal waters

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A B S T R A C T

A 3-week diversion of the Orange County Sanitation District effluent discharge into nearshore waters off Newport Beach, CA constituted a considerable injection of secondarily-treated effluent into the coastal ecosystem. The location $\approx$1.6 km from shore, shallow water depth ($\approx$16 m), volume and nutrient content of the discharge ($\approx 5.3 \times 10^8$ L day^{-1} of effluent with inorganic nitrogen concentration >2 mM) during the diversion raised concerns regarding the potential for stimulating phytoplankton blooms and, in particular, blooms of toxic species. Remarkably, phytoplankton standing stocks during the event and shortly thereafter did not reach values associated even with minor blooms historically observed in the region (generally <5 μg l^{-1}), although shifts in community composition were observed. Diatom abundances increased early during the diversion, dinoflagellates, phototrophic picoplanktonic eukaryotes and other algae increased mid-diversion, and cyanobacteria (*Synechococcus*, *Prochlorococcus*) increased near the end of the diversion. Concentrations of domoic acid (a phycotoxin commonly present in the area) remained near or below detection throughout the diversion, and abundances of potentially-harmful algal species were unresponsive. Bacterial biomass increased during the diversion, and equaled or exceeded total phytoplankton biomass in most samples. Abundances of microbial grazers were also elevated during the diversion. We speculate that nutrient uptake by the bacterial biomass, acting in concert with or a response to a negative effect of disinfection byproducts associated with chlorination on phytoplankton physiology, played a significant role in muting the response of the phytoplankton to nutrients released in the effluent.

1. Introduction

Coastal ecosystems along the eastern boundaries of oceanic gyres are highly dynamic environments that support robust biological communities and important fisheries. The hydrography that drives the major biological processes of these regions has been well-characterized on a global scale (Carr, 2001; Chavez and Messié, 2009), and many regional studies have provided details pertinent to the coastlines of specific geographical areas. The Southern California Bight (SCB) extends for approximately 700 km along a portion of the west coast of North America from Point Conception, California, USA to Cabo Colnett, Mexico. Numerous studies spanning several decades have investigated the oceanographic features controlling

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primary production and food web structure of this coastal ecosystem (Cullen and Eppley, 1981; Hickey, 1992; Jones et al., 2002; Checkley and Barth, 2009; Kim et al., 2009; Nezlin et al., 2012). These studies have affirmed that upwelling events are important regional, seasonal events resulting in the injection of major nutrients (nitrogen, phosphorus) into surface waters that in turn support predominantly spring blooms of phytoplankton.

Studies in recent years, however, have also begun to demonstrate the increasing importance of other processes as important contributors of nutrients and promoters of algal blooms in nearshore waters of the SCB. Specifically, Howard et al. (2014) presented evidence that surface coastal waters bordering highly urbanized regions of the SCB, such as the greater Los Angeles area, receive inputs of anthropogenic nutrients, in particular nutrients discharged from Publicly Owned Treatment Works (POTWs), that are roughly equivalent to the load of nutrients injected by upwelling events annually. This assessment is supported by the study of Nezlin et al. (2012) who noted increasing numbers of phytoplankton blooms in the region during the period 1997–2007, and a spatial correlation between the location of phytoplankton 'hot spots' in the SCB and POTW discharge points. In highly urbanized subregions of the SCB, it has been estimated that more than 90% of terrestrial nutrient flux is wastewater effluent from local POTWs, most of which is discharged directly into coastal waters via a relatively small number of outfall pipes (Lyon et al., 2006; Sengupta et al., 2013).

The relative magnitude and nature of the effect of nutrients discharged by POTWs on nearshore plankton communities is largely uncharacterized but could be expected to affect phytoplankton production, standing stock, community composition and related parameters (e.g. water turbidity, sedimentation, nutrient cycling, food web dynamics and dissolved oxygen) if the effluent were introduced into lighted waters where phytoplankton could utilize them for growth. The designs of the discharge systems of these facilities have therefore attempted to minimize these effects through improved wastewater treatment (Stein and Cadien, 2009), and by locating effluent discharge points offshore, and at depths that might lessen the input of growth-stimulating nutrients to phytoplankton in the overlying waters. This has proven to be an effective strategy for routine operations of POTWs in the SCB, but the interruption of normal operating procedures for these facilities leaves them with little alternative other than discharging effluent close to shore in shallow water (Howard et al., Submitted).

The preferential stimulation of harmful algal blooms (HABs) presents a particular concern for the discharge of large volumes of nutrient-rich effluent into shallow coastal ecosystems, as anthropogenic nutrients have been shown to be a factor in the increased frequency of these events (Anderson et al., 2002; Heisler et al., 2008). Shifts in the concentrations and forms of growth-limiting nutrients could affect the standing stock of phytoplankton, as well as the species composition of the phytoplankton community due to nutrient preferences among algal taxa (Litchman et al., 2006). Nitrogen is generally considered the element limiting phytoplankton growth in many coastal waters dominated by upwelling (Capone and Hutchins, 2013), and while nitrate is the dominant form of nitrogen made available via upwelling, ammonium is overwhelmingly the dominant form of nitrogen in secondarily-treated effluent typical of POTWs in the SCB. Differences among algae in their preferences for these nitrogen forms could dramatically alter competition between algal taxa in the receiving waters, particularly with respect to harmful bloom-forming species (Dortch and Conway, 1984; Dortch, 1990; Kudela and Cochlan, 2000a; Dugdale et al., 2007; Kudela et al., 2008; Collos and Harrison, 2014).

The SCB has experienced an increase in the number, frequency and severity of toxic algal blooms in recent years. Massive discolorations of coastal water resulting from blooms of the relatively innocuous dinoflagellate, *Lingulodinium polyedrum*, have been reported along the coastline for many years (Holmes et al., 1967; Gregorio and Pieper, 2000; Kudela and Cochlan, 2000b), but toxic blooms of diatom species within the genus *Pseudo-nitzschia* have been documented throughout the last decade (Schnetzer et al., 2007, 2013). Recent field studies have implicated a relationship between blooms of *Pseudo-nitzschia* and upwelling events along the continental shelf bordering the cities of San Pedro and Long Beach (Schnetzer et al., 2013; Seubert et al., 2013), but it has become clear that anthropogenic sources of nutrients may also play a role in the frequency and/or severity of these events (Howard et al., 2014). The San Pedro shelf is now recognized as a "hot spot" for outbreaks of domoic acid, resulting in marine animal mortality events attributed to that neurotoxin (Schnetzer et al., 2007, 2013; Seubert et al., 2014). Other toxin-producing or noxious phytoplankton genera also occur along the coast of the SCB, and include raphidophyte and dinoflagellate species (Jessup et al., 2009; Caron et al., 2010; Garneau et al., 2011; Howard et al., 2012; Lewitus et al., 2012).

The Orange County Sanitation District (OCSD) conducted a planned diversion (September 11 to October 3, 2012) of its effluent discharge from its 8 km outfall pipe to a nearshore (1.6 km), shallower discharge pipe in order to make necessary repairs to the longer pipe (Howard et al., Submitted). This event provided a unique opportunity to investigate the response of a nearshore coastal ecosystem in the SCB to a significant release of anthropogenic nutrients. An array of instrumentation-based measurements provided contextual information while shipboard water sampling was conducted prior to, during, and following the diversion to evaluate the effect. The diversion resulted in the discharge of effluent containing dissolved inorganic nitrogen and other constituents at approximately 1000-fold higher concentration (>2 mM) than typical ambient concentrations in shallow water (<15 m water depth) in the region (Howard et al., Submitted). This effluent was also highly disinfected with sodium hypochlorite (higher than normal dosage) due to the close proximity of release to the shoreline. The goal of this study was to document the response of the phytoplankton to nutrient loading on the San Pedro shelf in the vicinity of the cities of Newport Beach and Huntington Beach. Surprisingly, the overall increase in phytoplankton biomass during the 3-week diversion was minor, although shifts in taxonomic composition did occur. We speculate that the muted response of the phytoplankton may have been a combined effect of short-term deleterious effects of disinfection byproducts in the effluent on phytoplankton growth and physiology, combined with rapid uptake of nutrients by the bacterial assemblage.

2. Methods and materials

2.1. Study site and discharge pipe location

The study was conducted in waters along the San Pedro continental shelf primarily near the border between the cities of Newport Beach and Huntington Beach (Fig. 1). An overview of the location of the nearshore discharge pipe of the OCSD, as well as the timing and magnitude of the diversion of effluent to that pipe within the study site has been provided by Howard et al. (Submitted). Instrumentation as described below was positioned near the discharge site and provided measurements of physical, chemical and biological parameters prior to, during and following the diversion of effluent. These instruments included two ocean moorings and an Environmental Sample Processor equipped with multiple sensors and sample processing capabilities.

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