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Risks of hypoxia and acidification in the high energy coastal environment near Victoria, Canada's untreated municipal sewage outfalls

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ABSTRACT

Wastewater disposal often has deleterious impacts on the receiving environment. Low dissolved oxygen levels are particularly concerning. Here, we investigate the impacts on dissolved oxygen and carbon chemistry of screened municipal wastewater in the marine waters off Victoria, Canada. We analyzed data from undersea moorings, ship-based monitoring, and remotely-operated vehicle video. We used these observations to construct a two-layer model of the nearfield receiving environment. Despite the lack of advanced treatment, dissolved oxygen levels near the outfalls were well above a 62 μmol kg^{-1} hypoxic threshold. Furthermore, the impact on water column oxygen at the outfall is likely < 2 μmol kg^{-1}. Dissolved inorganic carbon is not elevated and pH not depressed compared to the surrounding region. Strong tidal currents and cold, well-ventilated waters give Victoria's marine environment a high assimilative capacity for organic waste. However, declining oxygen levels offshore put water near the outfall at risk of future hypoxia.

1. Introduction

The occurrence of hypoxia in coastal zones and its accompanying negative impacts on marine ecosystems has increased in recent decades (Gilbert et al., 2010; Diaz and Rosenberg, 2008; Diaz and Rosenburg, 1995). In many cases, anthropogenic inputs of nutrients from farm-runoff, wastewater, and atmospheric deposition are responsible (Rabalais et al., 2010). In attempts to mitigate the impacts from wastewater, environmental managers in many developed countries have implemented minimum treatment standards to reduce organic enrichment (Law and Tang, 2016; Canadian Fisheries Act; Igbinosa and Okoh, 2009).

In addition to treatment, the properties of the receiving environment are critical in determining the ultimate impacts of the waste (Puente and Diaz, 2015; Gómez et al., 2014; Dinn et al., 2012a; Li and Hodgins, 2010; Chapman et al., 1996). For example, if waste is discharged close to bathing waters or in a constrained environment, the public health risks are considerable. Or, if discharged into a nutrient-limited environment, as is often the case for freshwater (e.g. Lake Winnipeg, Schindler et al., 2012) or sheltered marine ecosystems (e.g. the Baltic Sea, Ronnberg and Bonsdorff, 2004), eutrophication can result. The frequency of harmful or otherwise undesirable algal blooms can increase and the rapid growth of aquatic plants can poison wildlife, contaminate drinking water, and deplete oxygen to hypoxic levels (Smith and Schindler, 2009; Tchobanoglous and Burton, 1991). However, if discharges enter non-nutrient-limited or high turnover environments, impacts on oxygen are generally smaller. However, the organic load within the sewage itself can be considerable, and, if the respiration of sewage organic material occurs in a small area, significant oxygen depletion and hypoxia can occur. As with all respiration, inorganic carbon is released, lowering the pH of water and increasing ocean acidification in the local marine environment (Cai et al., 2011). Low oxygen combined with lower pH and warmer water temperatures have the potential to act synergistically to the detriment of many marine organisms (Haigh et al., 2015). Chemical contamination of the receiving environment with metals and persistent organic pollutants is of universal concern (Balasubramani et al., 2014; Chapman, 2007; Tchobanoglous and Burton, 1991). However, these contaminant concerns are often secondary to the eutrophic and oxygen-depleting impacts of domestic sewage (Tchobanoglous and Burton, 1991).

In this study, we investigate the impact of untreated sewage on a unique, highly energetic, well-ventilated, marine receiving environment. We use temporally resolved multi-year time series of near bottom O_2 and ship-based vertical profiles at the outfall to quantify the impact on water column oxygen by sewage. These results are supplemented by spectral analyses of ambient oxygen and sewage volume flow and

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qualitative analysis of benthic species composition. Discrete sampling of the carbonate system at the outfall is used to investigate potential acidification. Water masses are characterized and the tidal control of O_2 variability at the site is assessed, allowing risk assessment for future hypoxia. Finally, a simple two-box model is constructed to assess the sewage impact on the region at present-day and under future conditions of increased sewage volume and temperature.

2. Study site and regional oceanography

Greater Victoria, the capital city of British Columbia (BC), Canada, (Fig. 1a) is a lightly industrialized city home to nearly 350,000 inhabitants (Statistics Canada, 2012). The greater Victoria region has come under increasing public and international pressure to upgrade its sewage treatment system, which currently consists of only pre-treatment (6 mm screen) before discharge into the ocean in Juan de Fuca Strait, JdF (CRD, 2014).

This discharge is split between two major sewage outfalls located at Clover and Macaulay Points (Fig. 1b). The pipes extend 1.1 and 1.8 km offshore, respectively, to depths of 62 m and 67 m, making them relatively deep and far from shore (Philip and Pritchard, 1997). At the end of each outfall, wastewater is discharged through a series of small diffuser ports along the final 150 m of the outfall pipe (Fig. 1b inset) designed to maximize mixing and dilution. Both outfalls experience strong tidal currents (~1 m s^{-1}), with Clover experiencing slightly stronger currents (Chandler, 1997). The dominant bottom current direction, as determined by mooring studies, is to the southeast, matching a general pattern of seafloor sediment contamination (Krogh et al., 2017; Dinn et al., 2012b; Chandler, 1997; CRD, 2014; Chapman et al., 1996). Water temperatures are consistently cool, varying seasonally between 7 °C in the winter and 10 °C in the summer (Chandler, 1997). Thus, compared with many other coastal cities, Victoria is blessed with highly

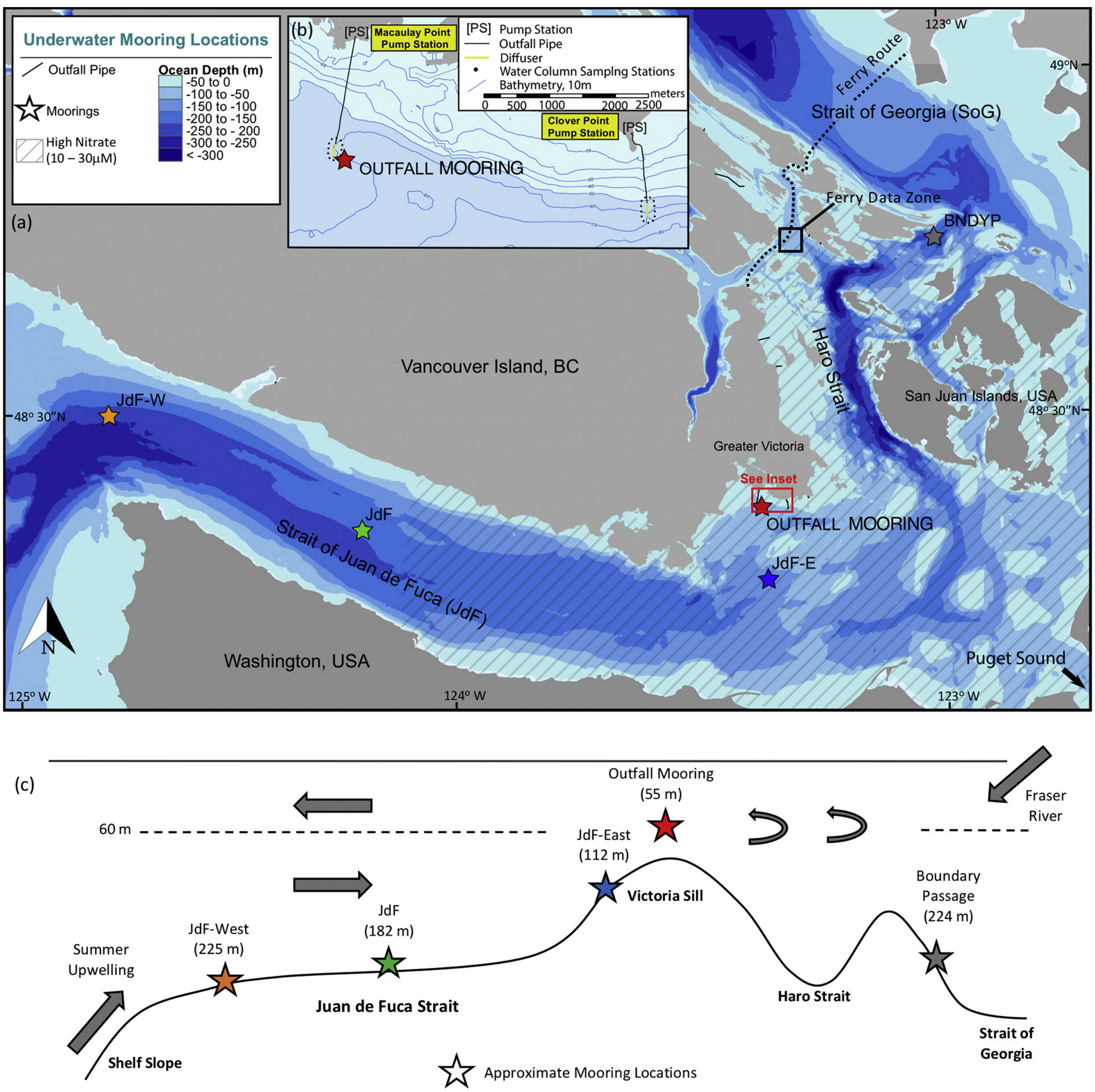

Fig. 1. (a) Map of the region, the colored stars show the locations of sea bottom moorings, the hashed area is a zone of high surface nutrients where primary production is light limited year-round (Mackas and Harrison, 1997). (b) Close-up map of the sewage outfalls with the black dots showing the location of monitoring stations where DIC/TA samples were collected and vertical profiles taken. (c) Schematic cross-section of the average flow and approximate depth along the thalweg. The outfall mooring is not located along the thalweg, but is still attached to the seabed, north of the thalweg nearer to shore. While there are two outfalls, Clover Point and Macaulay Point, only the less energetic Macaulay Point was monitored with a mooring.