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Responses of infaunal composition, biomass and production to discharges from a marine outfall over the past decade

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ABSTRACT

The largest municipal outfall on the west coast of Canada discharges into the southeastern Strait of Georgia, where high sedimentation from the Fraser River has maintained stable sediment geochemical and contaminant conditions from 2001 to 2011. Outfall exposure has not affected trophic structure or diversity (H′), but has significantly affected faunal composition and species richness, resulting in loss of crustaceans and echinoderms near-field. Organic biomass and production have mostly remained within expected background ranges for the Strait, due to recent increases in a low oxygen tolerant polychaete in the high deposition zone.

A significant regional shift in faunal composition occurred after 2003, followed by gradual declines in richness, abundance, calcareous organisms and production. This cannot be attributed to changes in outfall exposure, but is exaggerated by it. We hypothesize that changing river flow, extreme events and shifts in offshore upwelling water temperature, oxygen and pH may be increasing geochemical stress in benthos.

1. Introduction

Organic enrichment effects on macrobenthos of coastal marine sediments, related to discharges such as sewage, has been extensively studied (Pearson, 1975; Pearson and Rosenberg, 1978; Cromey et al., 1998; Gray et al., 2002; Conlan et al., 2004; Rees et al., 2006). In recent years, accumulated monitoring data has allowed researchers to examine temporal changes in such enriched sediments related to changes in sewage discharges (Arvai et al., 2002; Savage et al., 2002; Conlan et al., 2004; Smith and Shackley, 2006), as well as climatic shifts (Rees et al., 2006; Nixon et al., 2009).

It has become increasingly important to understand how changing conditions globally can influence the resilience of coastal marine sediments to extraordinary organic inputs (Harley et al., 2006; Rees et al., 2006; Johannessen and Macdonald, 2009). However, it will be difficult to understand how background environmental shifts possibly related to climate change are affecting existing coastlines with organic enrichment, unless long-term studies of stable organic input conditions can be examined in the context of dynamic changes in background conditions. In addition, it is necessary to have knowledge of the functioning of the background or ambient habitat (Nixon et al., 2009; Stein and Cadien, 2009), as it is not always obvious if changing background conditions will result in increased eutrophication, or reductions in natural organic input and productivity, and when and where abrupt changes to ecosystem functioning may occur. Such ecological thresholds are defined in Allen et al. (2009) as "*the point at which there is an abrupt change in an ecosystem quality, property, or phenomenon, or where small changes in one or more external conditions produce large and persistent responses in an ecosystem*".

In collaboration with the Canadian Department of Fisheries and Oceans, Metro Vancouver (responsible for liquid waste management in the greater Vancouver region, BC, Canada) has participated in a 10-year research program designed to understand the input, cycling and fate of organic material, particulates and contaminants in the Strait of Georgia on the west coast of Canada, which constitutes the northern portion of the Salish Sea (see Marine Environmental Research special issue S66, 2008). The purpose of the research program has been to inform regional management of outfalls and other marine discharges, and to help understand future changes in ecosystem responses to marine discharges.

In the present study, we examine benthic community changes from 2001 to 2011 in a coastal environment experiencing relatively stable organic loading, but which has also shown signs of regional trends likely related to shifting climatic conditions (Masson and Cummins, 2007; Johannessen and Macdonald, 2009). Specifically, we examine sediment infaunal responses over the past decade to the largest municipal outfall on the west coast of Canada, in the context of regional conditions. For this purpose, we draw upon data from two sources. A high quality and consistent annual

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sediment monitoring program has been in place for the Iona receiving environment from 2001 to 2011. In addition, an extensive background database for the Strait of Georgia has been compiled, which includes benthic invertebrate faunal samples and related sediment characteristics collected over a broad geographic and habitat range distant from anthropogenic discharges (described in Burd et al., 2008a, 2009). Along with sediment and organic flux data from extensive Pb_{210} dated cores collected throughout the Strait, the background biological database provides context for understanding the regional relevance of the Iona outfall discharge to benthic biomass and production. Specifically, we address the following questions;

(1) Have community composition, trophic structure, organic biomass and production of macrobenthic communities changed relative to outfall exposure since 2001?
(2) How do macrobenthic organic biomass and production relative to organic flux in the Iona receiving environment compare with the background Strait of Georgia?
(3) Is there evidence that larger scale environmental drivers (i.e.: Fraser River, climate change) have affected benthic macrofaunal responses to outfall deposition in the Iona receiving environment over the past decade?

1.1. Iona outfall receiving environment

The Iona Island Wastewater Treatment Plant has discharged primary treated wastewater from Vancouver since 1988 at water depths ranging from 72 to 106 m through a deep-sea outfall, into the south-eastern coastal margin of the Strait of Georgia. The outfall discharges to the delta shelf/slope straddling the three discharges of the Fraser River, the largest freshwater source on the coast (Fig. 1). Sediment deposition from the main (south) arm of the Fraser River contributes between $1–3 \times 10^{10}$ kg of particulates (∼60–95% of total river sediment discharge) each year to the delta (Hill et al., 2008), of which the heavier material settles quickly and is thereafter transported to the north and eventually down-slope with the prevailing bottom currents. The outfall monitoring stations (Fig. 1) experience this sedimentation in a declining gradient from the southern end of the sampling gradient (station 16) to the northern end (station 1).

Hodgins and Hodgins (2000) compared modeled outfall particulate deposition patterns with sediment silver concentrations (Gordon, 1997) in the region. They concluded that outfall deposition would peak between 60 and 90 m water depth, and ultimately end up near the 100-m water depth contour at 1.5 km and 4–5 km north of the diffusers, with reduced deposition immediately south of the outfall. For these reasons, detailed sediment effects surveys conducted by Metro Vancouver (formerly Greater Vancouver Regional District) annually since 2001 have focused on 16 stations along the 80-m water depth contour between 7 km N and 9 km S of the outfall (Fig. 1), with occasional samples at 60–120 m water depth orthogonal to some of the regular 80-m water depth stations (Monitoring reports available from the Metro Vancouver Library (email: Thora.Gislason@metrovancouver.org (McPherson et al., 2001, 2003, 2004, 2005, 2006, 2008, 2009; 2011a,b; Bailey et al., 2003; Lynch et al., 2011).

Along with the results of the outfall deposition modeling (Hodgins and Hodgins, 2000), a preliminary analysis of benthic faunal patterns (Burd et al., 2000; Burd, 2003), sediment geochemistry and contaminants associated with outfall particulates (Paine and Chapman, 2000; Yunker, 2000) resulted in identification of statistically significant outfall exposure zones (and see GVRD, 2004) from the beginning of the study period. Biotic responses indicate that organic enrichment of sediments is the primary driver of benthos patterns (Burd, 2003), since most sediment contaminants have remained below provincial sediment quality guidelines for protection of aquatic life (Lynch et al., 2011).

The outfall exposure zones are classified as near-field (maximum deposition; stations 5–8) within 2 km N of the outfall, mid-field (low deposition; stations 3,4,10,11) surrounding the near-field zone to the N and S, and far-field (no measurable deposition; stations 2, 12, 15 and 16) surrounding both the near-, and mid-field zones (Fig. 1). Within the near-field, outfall-specific indicators such as coprostanol, nonylphenols, sediment AVS and some metals have been consistently elevated (Lynch et al., 2011). These factors are much reduced, but still above background concentrations in the mid-field zone, and at background concentrations or undetectable in the far-field. Four of the 16 monitoring stations (1, 9, 13, 14) were identified in 2000 and later years as having intermittent confounding influences on biota unrelated to outfall particulate deposition and outside expected background conditions (Bailey et al., 2003; Burd, 2003; Lynch et al., 2011; McPherson et al., 2011b). These stations were excluded from the temporal comparisons in this paper. In addition, cross transect samples taken from 60 to 120 m water depth at some locations in 2003 and 2007 are not considered in this paper as they are depth confounded for purposes of temporal comparisons. However, these cross-transect samples have served to confirm that the maximum outfall particulate exposure zone is along the 80 m water depth contour N and S of the outfall.

2. Methods

2.1. Sediment and organic flux patterns

Sediment and organic carbon flux estimates were available from 51 Pb_{210} dated box cores collected throughout the Strait of Georgia. Locations and data for cores are collectively described in Wright et al. (2008), (Johannessen et al., 2005a,b, 2008), and Burd et al. (2008a), with basin-wide distribution patterns of organic flux described in Burd et al. (2008a, in press). Six of the cores were located in the region of the Iona outfall monitoring stations, and can therefore be used to estimate sediment and organic flux patterns in the outfall receiving environment.

Analytical calculations for estimating sediment and organic carbon flux (sum of buried and oxidized organic material) from $_{210}Pb$ dated cores for the Strait of Georgia and surrounding fjords are described in Macdonald et al. (2008), Johannessen et al. (2005a, 2008), with a justification and comparison of methods for core dating in Johannessen and Macdonald (2012). The cores were all approximately 50 cm long. Immediately on recovery, the cores were sectioned for analysis into 1 cm intervals for the top 10 cm, 2 cm intervals for the next 10 cm and 5 cm intervals for the remainder of the core. A sub-sample from each depth interval was analyzed by Flett Research Ltd., Winnipeg, Canada, for $_{210}Pb$ and $_{226}Ra$ to be used for radio-dating. The activity of supported $_{210}Pb$ was determined as the average of the $_{226}Ra$ activity measured at three depths (top, middle, bottom) in each core, from the ingrowths of $_{226}Rn$ over at least 4 days. Based on the assumption that bottom waters are always supplied with some oxygen (>2.5 mL L^{-1}; Masson, 2002), there will be an active benthic community which mixes the surface sediments. Sedimentation and mixing rates in the sediment cores were determined using excess ^{210}Pb profiles in sediments together with advective–diffusive models (see Johannessen et al., 2005a), assuming a constant supply of $_{210}Pb$ and constant sedimentation rate. The depth of the surface mixed layer in each core was determined by visual measurement from the ^{210}Pb profile. The incident flux of organic carbon (OC), the percent OC buried, and the percent OC oxidized, were estimated from the ^{210}Pb profiles of percent OC measured in the