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The effects of wastewater effluent and river discharge on benthic heterotrophic production, organic biomass and respiration in marine coastal sediments

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ABSTRACT

We examine effects of high river particulate flux and municipal wastewater effluent on heterotrophic organic carbon cycling in coastal subtidal sediments. Heterotrophic production was a predictable ($r^2 = 0.95$) proportion (56%) of oxidized OC flux and strongly correlated with organic/inorganic flux. Consistent growth efficiencies (36%) occurred at all stations. Organic biomass was correlated with total, OC and buried OC fluxes, but not oxidized OC flux. Near the river, production was modest and biomass high, resulting in low P/B. Outfall deposition resulted in depleted biomass and high bacterial production, resulting in the highest P/B. These patterns explain why this region is production "saturated". The $\delta^{15}N$ in outfall effluent, sediments and dominant taxa provided insight into where, and which types of organisms feed directly on fresh outfall particulates, on older, refractory material buried in sediments, or utilize chemosynthetic symbiotic bacteria. Results are discussed in the context of declining bottom oxygen conditions along the coast.

1. Introduction

Changing climate conditions are likely to influence the resilience of coastal marine sediments to extraordinary organic inputs (Harley et al., 2006; Rees et al., 2006; Johannessen and Macdonald, 2009). In order to predict or prepare for such changes, it is first necessary to understand how coastal ecosystems function under existing carbon cycling conditions (Nixon et al., 2009; Stein and Cadien, 2009), as it is not always intuitively obvious whether changing climate-related temperature, pH and oxygen conditions will result in increased eutrophication, reductions in organic input and productivity (Allen et al., 2009), or when and where abrupt changes to ecosystem functioning may occur. Relating sediment heterotrophic production, biomass inventory and turnover in coastal areas to total and organic input is critical for understanding carrying capacity for organic enrichment (Probert, 1986; Burdige et al., 1992; Manini et al., 2002; Dolbeth et al., 2003; Rowe et al., 2008). In recent years, a number of studies have focused on sediment carbon budgets and flow through benthic food webs (Accornero et al., 2003; van Oevelen et al., 2006), particularly in areas with organic enrichment gradients.

The current study focuses on heterotrophic organic carbon cycling in sediments along exposure gradients for marine sewage outfall discharges of wastewater effluent, as well as for unusually high natural sediment accumulation from a coastal river in the southern Strait of Georgia. This is the portion of the Salish Sea that spans the southern half of the Canadian west coast. This work was done as part of a collaborative research program between Fisheries and Oceans Canada and Metro Vancouver on organic carbon cycling in the Strait (see Marine Environmental Research special edition Volume 66, Supplement 2008).

Burd et al. (2012a) found that invertebrate (macrofaunal and meiofaunal) organic biomass (defined here as standing stock inventory) and production (defined as annual incorporation of organic matter into growth) throughout the Strait of Georgia away from areas of anthropogenic inputs (background), could be reasonably well predicted (69–74%) by depth, percent sand and organic flux/quality. It was found later that percent sand was misleading, particularly in areas with mixed gravel or rock, and that the ratio of organic/inorganic flux was a much better predictor, improving the published regression model fits to 81–85% (see posted discussions in Burd et al., 2012a). Depth was suggested to be a surrogate for other factors, such as poor quality and patchiness of organic deposition in deeper areas with primarily marine input. The unavoidable conclusion is that the dynamics of sediment flux conditions are the primary, overwhelming drivers of sediment

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organic cycling, and that other factors simply describe some aspect of sediment flux which is not directly measurable on a broad scale. However, there were two unusual situations in the Strait that did not fit the regression models based on habitat factors described above;

(1) Background sediment invertebrate organic biomass could mostly be explained by total organic flux and quality (Burd et al., 2012a). However production was much more dependent on organic/inorganic flux, and thus levelled off above a certain threshold of increasing natural sediment flux from the Fraser River discharge (Fig. 1). Because sediment invertebrate biomass and production were considerably higher near the river discharge than anywhere else in the Strait (Burd et al., 2012a), this area was of particular concern with respect to understanding carbon cycling. Several possible reasons for the production "saturation" near the river include rapid burial of smaller faunal forms and promotion of large, long-lived burrowers, as well as the unknown contribution to production from bacteria.
(2) The river margin also encompasses the receiving environment for the two marine primary-wastewater treatment plant outfalls which service the greater Vancouver region. Spatial and temporal patterns in invertebrate biomass, production and faunal composition related to the deposition from the largest of the two wastewater effluent discharges (Iona) were described in Burd et al. (2012b), and unpublished data are available from the receiving environment of the other marine wastewater effluent discharge (Lions Gate; McPherson et al., 2012). Invertebrate production and biomass were both depressed near the Iona discharge, relative to other locations in the Strait with similar organic flux.

Therefore, although invertebrate organic biomass and production have been described previously in the region, deviations from the expected patterns for the Strait under these unusual sedimentation conditions highlight the imperative to include microbial production. Although viable (producing) bacterial biomass is expected to be small in terms of total sediment biomass (see Luna et al., 2002), this assumption cannot be made for production, regardless of the method of estimation (Fallon et al., 1983; Luna et al., 2002). In addition, bacterial production is typically nutrient limited in marine sediments (Luna et al., 2002) and thus tends to be responsive to organic enrichment.

In this paper, we incorporate recent estimates of bacterial organic biomass and production with previously measured values for invertebrates, to obtain a more complete picture of how total sediment heterotrophic production, respiration and organic biomass relate to total sediment accumulation, oxidized and buried organic flux in a coastal region subject to high river-derived organic and inorganic fluxes, as well as organic loading from two marine municipal wastewater effluent discharges. Specifically, the purpose of this paper is threefold;

(1) To determine if production, respiration and biomass inventory estimates in these unusual sediment flux conditions can be predicted and understood from organic and inorganic particulate flux to sediments.

Fig. 1. Strait of Georgia, southwest coast of Canada with specific sample region in rectangle. Background shows an enlarged aerial photograph of the Iona outfall and Fraser River discharge plume during spring freshet.