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Using species traits to assess human impacts on near shore benthic ecosystems in the Canadian Arctic

K. Krumhansl*, R. Jamieson, W. Krkosek

Centre for Water Resources Studies, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada

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ABSTRACT

Human activities have the potential to alter the diversity and composition of biological communities in natural environments, which can cause changes in ecosystem functioning. This has led to the development of environmental assessment techniques that take into account species identity, as species can contribute differently to various ecosystem processes. Biological Traits Analysis (BTA) is used to compare the abundances of specific biological traits in samples to produce information about how ecosystem functioning may change across a specific terrestrial or aquatic system. In the present study, BTA was used to assess the influence of municipal wastewater effluent on benthic marine communities in near shore soft sediments in four locations across the Canadian Arctic Territory of Nunavut, Canada. Shifts in trait composition were assessed relative to indicators of sediment enrichment (sediment chlorophyll, organic content, degree of anoxia), and natural variation in habitat characteristics (water depth, porosity, average grain size) at a site receiving wastewater and a reference site in each sampling location. The results indicated a mild enrichment effect of wastewater, as evidenced by changes in trait composition at three of the four sites that received wastewater inputs. However, the amount of variance in trait composition explained by metrics of wastewater enrichment in these locations were generally equal to or lower than the amount of variance explained by sediment characteristics related to natural processes. These results provide greater insight into the underlying causes and consequences of human activities than more traditional methods for environmental impact assessment, and can be directly applied in a management context.

1. Introduction

A growing body of literature suggests that assessing the ecological impacts of human activities requires explicit consideration of how species traits may change in a potentially impacted ecosystem, which can influence how that ecosystem functions (Bremner, 2008; Peru and Doledec, 2010). Benthic invertebrates in marine and freshwater systems play important roles in nutrient cycling, sediment oxygenation, and organic matter decomposition (Rhoads, 1974; Snelgrove, 1998; Constable, 1999; de Wilde, 1991; Bremner et al., 2006a). Individual species can contribute to different ecosystem functions, and therefore shifts in species composition due to natural and human-mediated changes may have important implications for ecosystem functioning. There may however be functional redundancies in macrofaunal communities that buffer the effects of changes in species composition (Walker, 1992; Snelgrove, 1998). Given these facts, it is recognized that considering both species identity and species trait composition can provide important insights into the implications of ecosystem change.

Biological Traits Analysis (BTA) is a technique that can be used to compare the abundances of various biological traits of interest in sampled communities (Bremner et al., 2003, 2006a, b). This technique was first developed for terrestrial ecosystems (Olff et al., 1994; Townsend and Hildrew, 1994), and has been applied in the marine environment to assess natural variation in species traits across different geographies in relation to factors such as water depth and degree of riverine input (Pacheco et al., 2011; Bolam and Eggleson, 2014). More recently, this technique has been used to detect potential shifts in ecosystem function associated with human activities such as the development of coastal defense structures (Munari, 2013) and coastal discharges of municipal and industrial wastewater effluents (Oug et al., 2012), but it's utility for this purpose is not well known.

Although it is recognized in the scientific literature that species identity and functional traits are important to consider when assessing human impacts, risk assessment frameworks for the

* Corresponding author. Present address: Department of Resource and Environmental Management, Hakai Institute, Simon Fraser University, Burnaby, British Columbia V5A 1S6, Canada. Tel.: +1 902 802 9498.
E-mail address: kkrumhan@sfu.ca (K. Krumhansl).

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purpose of management generally still rely on comparisons of univariate community measures such as diversity, richness, abundance, or species presence (Kilgour et al., 2005; CCME, 2009; Peru and Doledec, 2010; Trefry et al., 2013). This approach may be too simplistic given our current understanding of the complexity of natural systems and how they respond to environmental change (e.g. Peru and Doledec, 2010). Detecting human impacts is further complicated by the inherent variability of the underlying environment. Traditional approaches to risk assessment often involve comparisons between impacted and control locations (Underwood, 1997; Kilgour et al., 2005). However, ensuring that the only variable that differs between impacted and reference sites is the presence or absence of a certain human impact is difficult and often impossible (Borja et al., 2012). Natural variation in sediment or other environmental characteristics can mask or obscure patterns driven by anthropogenic stress, or lead to a misinterpretation of the cause of differences between sites if not properly considered in an analysis.

Municipal wastewater effluent is a common source of pollution in coastal systems, and its impact on natural communities has been studied extensively (Pearson and Rosenberg, 1978; Reish, 1986; Cromey et al., 1998). Very few of these studies have been conducted in polar habitats (Samuelson, 2001; Conlan et al., 2004), reflecting a general gap in our knowledge of near shore benthic community dynamics and their response to wastewater effluent in these regions. This is concerning given that resource development and human activities are increasing in the Arctic and Antarctic. In most communities in the Canadian Arctic Territory of Nunavut, wastewater is collected and trucked to Wastewater Stabilization Ponds (WSPs), where it is stored through the winter months and eventually decanted during the summer months into a marine or freshwater environment. Mechanical wastewater treatment plants have been built in only two communities in Nunavut (Iqaluit and Pangnirtung), and in both of these locations effluent is discharged continuously into the ocean.

In this paper, we examine shifts in benthic invertebrate species traits in relation to the discharge of municipal wastewater effluent from four communities in Nunavut. We predict that shifts in species trait compositions towards those indicating reduced ecological functioning will occur at sites receiving wastewater input, and that these patterns will be driven by elevated levels of sediment chlorophyll, organic content, and anoxia over what is observed at reference sites. We predict that the influence of these factors will be high relative to factors reflecting variation in sediment properties due to natural processes. We compare the results of our analysis to a more traditional approach to analyzing the same species data (Krumhansl et al., 2015) to assess the degree to which our results can be directly applied to developing management practices for these wastewater treatment systems. This comparison will also illustrate the potential for using Biological Traits Analysis for assessing human impacts on benthic macrofaunal communities.

2. Methods

2.1. Study sites

Variation in benthic community composition and biological traits were assessed in four locations across Nunavut: Grise Fiord (76°25′3.01″N, 82°53′38.00″W), Pangnirtung (66°08′47.61″N, 65°42′04.38″W), Pond Inlet (72°42′00.42″N, 77°57′30.72″W), and Kugaaruk (68°20′29.04″N, 90°14′25.80″W) (Fig. 1). In all locations, samples were taken within 225 m from shore in an area that receives wastewater effluent from a nearby WSP (Grise Fiord, Pond Inlet, and Kugaaruk) or treatment plant (Pangnirtung), termed the "receiving site", and a reference site located >2 km away from the discharge location that was assumed to be unaffected by wastewater. Throughout the manuscript, "location" will refer to the geographic location (e.g. Grise Fiord), while "site" is used to refer to the receiving water and reference sites in each location. Details on these treatment systems and the quality of wastewater effluent are given in Krumhansl et al. (2015). Briefly, the WSPs in Grise Fiord and Pond Inlet discharge 4270 L year^{-1} and 80,880 L year^{-1} of advanced primary treated wastewater (50–90% removal of Total Suspended Solids [TSS] and Carbonaceous Biochemical Oxygen Demand [$CBOD_5$]), respectively. The WSP in Kugaaruk discharges 25,330 L year^{-1} of secondary treated wastewater (>97% removal of TSS and $CBOD_5$), and Pangnirtung discharges 46,810 L year^{-1} of primary treated wastewater (<50% removal of TSS and $CBOD_5$). Discharge is intermittent in Grise Fiord, Kugaaruk, and Pond Inlet, occurring for a period of several weeks during the treatment season (June–September), and continuous in Pangnirtung. Benthic invertebrate sampling campaigns were conducted while systems were discharging wastewater into the marine environments.

In Grise Fiord and Pangnirtung, wastewater discharges over gently sloping tidal flats that are exposed during the lowest tides. These tidal flats are mainly composed of sand interspersed with gravel and boulders. In Kugaaruk, wastewater discharges through a moderately sloping boulder field that transitions to soft sediments ~50 m from shore. Only a small rocky area is exposed at the lowest tides. In Pond Inlet, effluent discharges over a shallow shelf (1–8 m depth) composed mainly of rocks and gravel interspersed with patches of sand. This shelf extends ~200 m from shore before dropping off to deeper depths, with very little of the shelf exposed at the lowest tides. Detailed site descriptions are given in Krumhansl et al. (2015).

2.2. Benthic invertebrate sampling

The tidal range and bathymetry in Grise Fiord and Pangnirtung are such that tidal flats can be sampled at low tide within a distance range of ~250 m from shore. At these sites, duplicate benthic samples were taken at five locations along four sampling transects running parallel to shore that were positioned at increasing distances from the effluent source. Only three sampling transects were sampled at the reference site in Grise Fiord because the extent of the tidal flat exposed at low tide was smaller than in the receiving water at the effluent discharge site. Benthic sediments were sampled at low tide at these sites using hand cores (12 cm diameter) inserted to a sediment depth of 6–10 cm. In Pond Inlet and Kugaaruk, tides do not expose benthic sediments within the range of ~250 m from shore, so these communities were sampled subtidally using a Petite Ponar benthic grab (2.4 L capacity, 300–500 cm^3 subsampled from each grab). In Kugaaruk, samples were taken at three locations along four sampling transects that were positioned at increasing distances away from shore at the receiving and reference sites. In Pond Inlet, benthic sediments do not extend >50 m from shore, so duplicate grab samples were taken at various positions along a single transect running parallel to shore at both the receiving water and reference sites. Samples from all sites were sieved with a 0.5 mm sieve, and preserved with 5% buffered formalin. Samples were later transferred to 70% ethanol. In the laboratory, benthic invertebrates were sorted from sediments, identified to the lowest taxonomic level possible, and enumerated.

2.3. Sediment metrics

Sediment grain size distribution, chlorophyll, and organic content were assessed in all samples. We note that these metrics are not explicit measures of effluent characteristics, but rather indicate relevant impacts to benthic communities caused by wastewater. Porosity was also assessed in samples collected at intertidal sampling locations only (Grise Fiord and Pangnirtung). For sediment