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Fate of organic matter in Arctic intertidal sediments: Is utilisation by meiofauna important?

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Abstract

This paper presents (1) a study of the fate of high-quality detritus in Arctic sandy beaches, in particular its use by the sandy beach meiobenthos, and (2) a comparison of organic matter mineralisation rates with those in other climatic regions. We performed a tracer experiment in which lyophilised ^{13}C-labelled cyanobacteria were added to sediments of two intertidal beaches (Tyskehytte and Breoyane) at Kongsfjorden (Spitsbergen) with contrasting sediment properties, benthic metabolic rates and meiobenthic communities. Tyskehytte was characterised by coarse sands on an exposed beach and Breoyane by medium sands on a relatively sheltered beach. Organic matter addition stimulated benthic metabolism in the coarser sediment but not in the finer one. Correspondingly, the added carbon was metabolised faster in the coarser sediment, respiration being its major short-term fate. Faster mineralisation of organic matter in coarser sediments was probably linked to a better availability to microbes and fauna in deeper sediment strata, resulting from a higher sediment porosity and a faster penetration of (labelled) organic matter to deeper sediment layers. Overall, organic matter mineralisation rates at both beaches compared favourably with those in temperate sediments. All major meiofauna taxa incorporated the added carbon source on both beaches, but specific uptake was substantially higher in the coarser sediment than in the finer one. Oligochaetes accounted for the largest share of meiobenthic carbon uptake. Despite a very high specific uptake, meiofaunal consumption accounted for but a small portion (<5% at both beaches) of the total ^{13}C-mineralisation. Thus our results do not support the hypothesis that meiofauna have a comparatively larger role in Arctic sandy beaches impoverished in macrofauna. However, more research including analyses on different spatial and temporal scales is needed before generalisations can be made.

Keywords: Arctic zone; Beaches; Organic matter processing; Meiobenthos; Stable carbon isotopes; Sediment respiration

1. Introduction

Sandy and gravel intertidal beaches are permeable sediments, i.e. their texture and structure allow measurable porewater flows under natural pressure gradients. One major feature of such sediments is effective transport (Huettel et al., 1996; Huettel and Rusch, 2000). Despite generally low organic matter concentrations and low standing stocks of reactants, these sediments are biogeochemically active and may play an important role in marine carbon cycles (Shum and Sundby, 1996).

Gravel and sandy beaches are common along the Arctic coasts of Spitsbergen (Węsławski et al., 1993),

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but little is known on their biotic communities and functioning. Macrofauna appear to be scant in comparison with beaches from other climatic regions (Węsławski et al., 1993, 1997). As a consequence, it has been suggested that meiofauna may have a comparatively larger role in benthic intertidal carbon fluxes in the Arctic (Szymelfenig et al., 1995). Meiofauna can affect the breakdown of organic matter in sediments both directly, through grazing on bacteria, and indirectly, through bioturbation, mucus production and perhaps other mechanisms that can affect the activity and/or species composition of microbial communities (Tietjen, 1980; Findlay and Tenore, 1982; Alkemade et al., 1992; De Mesel et al., 2004; Moens et al., 2005). Meiofauna thus can potentially contribute significantly to organic matter turnover in sediments (Kuipers et al., 1981; Coull, 1999). Their densities and biomass in Arctic intertidal sediments, while both being highly variable, are generally similar to those in non-Arctic beaches (Radziejewska and Stańkowska-Radziun, 1979; Mokievsky, 1992; Szymelfenig et al., 1995); however, studies on their activity and functioning are lacking.

A principal source of organic matter in glacial fjords is detritus derived from degraded macrophytes as well as from phyto- and zooplankton. Steep environmental gradients in sedimentation and salinity in glacial fjords result in high phytoplankton and zooplankton mortality (Węsławski and Legeżyńska, 1998; Zajączkowski and Legeżynska, 2001). Organic matter produced in fjord waters partly settles through the water column and partly swashes out into the intertidal (Hop et al., 2002). Studies on organic matter mineralisation in Arctic marine sediments suggest that rates are similar to those in temperate and tropical environments because they are governed primarily by organic matter quality and availability rather than by temperature (Arnosti et al., 1998; Glud et al., 1998; Rysgaard et al., 1998, 2000; Kostka et al., 1999). Again, however, studies on Arctic intertidal habitats are lacking.

A major question, therefore, pertains to the fate of organic matter in Arctic intertidal sediments and to the importance of meiofauna in organic matter processing. In this study, we report on a tracer experiment in which ^{13}C-labelled detritus was added to sediments of two intertidal beaches with contrasting sediment properties in Kongsfjorden (Spitsbergen). Our aims were two-fold: (1) to study the fate of freshly deposited phytodetritus in Arctic sandy beaches and compare mineralisation rates with those in other climatic areas, and (2) to assess the contribution, if any, of meiofauna to organic carbon mineralisation in these beach sediments. In addition, we measured rates of benthic oxygen consumption on both beaches and compared our results with published rates for non-Arctic beaches.

2. Materials and methods

2.1. Study site

This study was carried out in Kongsfjorden — a glacial, open Arctic fjord located on the west coast of Spitsbergen at 79°N, 12°E (Fig. 1). Kongsfjorden is 20 km long and its width varies from 4 to 10 km. The hydrology of this fjord is strongly influenced by freshwater inputs as meltwater from large tidal glaciers (Kronebreen and Kongsvegen at the head of the fjord, Conwaybreen and Blomstrandbreen on its northern coast) (Svendsen et al., 2002). Kongsfjorden is frozen during winter but open and influenced by the ocean during summer.

Phytoplankton in fjord waters is dominated by diatoms and daily primary production during summer ranges between 0.024 and 0.80 g C m^{-2} (Hop et al., 2002). The most abundant zooplankton are copepods (*Oithona similis, Calanus* spp., *Pseudocalanus* spp.), euphausiids (*Thysanoessa* spp.), amphipods (*Themisto* spp.), pteropods and ctenophores. Concentrations of particulate organic carbon (POC) in suspended matter in the fjord waters range between 0.70 and 1.46 g C m^{-3} in spring and summer, respectively (Hop et al., 2002).

Two intertidal sites differing substantially in sediment texture (Table 1) were selected for the experiment: (1) a beach in Tyskehytte dominated by coarse sand and gravels, and (2) a more sheltered beach characterised by finer sand, located on Breoyane Island, opposite the glacier Blomstrandbreen (Fig. 1). Water depth at high tide averaged 55 and 71 cm at the Breoyane and Tyskehytte sites, respectively. Details on the meiobenthos of both beaches have been reported elsewhere (Urban-Malinga et al., 2005); samples for the present experiment were taken in between the low- and mid-water levels reported in that study.

Sediment granulometry at both sites was determined in each of six samples taken to a depth of 10 cm. Analysis was done by standard sieving. The sediment fractions were defined according to the Wentworth scale as recommended by Buchanan (1984). Sediment organic carbon and nitrogen content were determined in each of six sediment samples taken to a depth of 10 cm by thermal combustion using a CHN-analyzer (Perkin Elmer 2400). Samples for C_{org} were pre-treated with dilute HCl to remove carbonates. Concentrations of suspended organic/inorganic matter in the water were