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Density of *Monoporeia affinis* and biogeochemistry in Baltic Sea sediments

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Abstract

This study focused on effects from *Monoporeia affinis* reworking and ventilation activities on benthic fluxes and mineralization processes during a simulated bloom event. The importance of *M. affinis* density for benthic solute (O_2, $\Sigma NO_2^- + NO_3^-$, NH_4^+ and HPO_4^{2-}) fluxes and sediment reactivity (mobilization of NH_4^+ and HPO_4^{2-}) following additions of organic material to the sediment surface was experimentally investigated using sediment–water and closed sediment (jar) incubations. Three different densities of *M. affinis* were used to resemble a low, medium and high density situation (1300, 2500 and 6400 ind. m^{-2}, respectively) of a natural amphipod community. The degradation of phytodetritus (*Tetraselmis* sp., 5 g C m^{-2}) added to the sediment surface was followed over a period of 20 days. Benthic solute fluxes of O_2, $\Sigma NO_2^- + NO_3^-$ and NH_4^+ were generally progressively stimulated with increasing number of *M. affinis*, while no such correlation was found for HPO_4^{2-}. Solute fluxes were initially enhanced 1 to 2 days after the addition of phytodetritius, caused by mineralization of the most labile organic material and a food-stimulated irrigation by the amphipods. There was no effect from the activity of *M. affinis* on total denitrification (Dtot = Dn + Dw) or denitrification utilizing nitrate from coupled nitrification/denitrification (Dn) for any of the densities examined. Denitrification utilizing overlying water nitrate (Dw) was only about 10% of Dtot. Dw was significantly enhanced for the highest *M. affinis* density investigated. The reactivity of the sediment decreased progressively with increasing density of *M. affinis* and with time of the experiment. However, enhanced ammonium production at least 6 days after the organic addition indicated excretion of N-containing organic compounds by *M. affinis*. In conclusion, large spatial and temporal variations in density of *M. affinis* may be of significant importance for benthic solute fluxes and overall mineralization of organic material in Baltic Sea sediments.

Keywords: Benthic mineralization; Bioturbation; Denitrification; Macrofauna density; *Monoporeia affinis*; Nutrient fluxes; The Baltic Sea

1. Introduction

Macrofauna may have a major impact on biogeochemical processes during organic matter mineralization in surface sediments of bioturbated deposits e.g. (Aller and Aller, 1998; Kristensen, 2000; Gilbert et al., 2003; Mermillod-Blondin et al., 2004; Karlson et al., 2005). Rates and pathways during mineralization and transport of organic and inorganic solutes across the sediment–water interface largely depend on the redox conditions of the bottom water and the surface sediment. Through particle reworking and pore water irrigation activities, a three dimensional structure of the sediment is created with

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effects on overall mineralization also in the anoxic layer deeper down in the sediment e.g. (Aller, 1982; Kristensen, 2000). Bioturbation increases the surface area of the sediment–water interface, and with that the total area available for solute and particle exchange. Through irrigation, fauna enhances the overall transport of dissolved components (e.g. oxygen and nutrients) (Aller and Yingst, 1985; Aller, 2001). Experimental studies have demonstrated that an increased transport efficiency of solutes and a decreased metabolite build-up in the pore water stimulate net mineralization rates in the sediment (Aller and Aller, 1998). In addition, environmental conditions for micro-organisms are directly affected by the redistribution and reconfiguration of organic material through macrofaunal feeding and excretion activities (Aller, 2001). Activities of benthic fauna in surface sediments may thus have significant effects on the form and amount of nutrients that is mobilized to the pore water and subsequently released to the overlying water.

Bioturbation and tube construction activities by macrofauna typically generate sharp gradients between oxic and anoxic environments, particularly pronounced close to biogenic structures (Brune et al., 2000; Hulth et al., 2002). A close spatial coupling between oxic and anoxic conditions stimulates nitrification and coupled nitrification/denitrification in the sediment (Mayer et al., 1995; Brune et al., 2000; Hulth et al., 2002; Gilbert et al., 2003). Experimental and model observations have also demonstrated that denitrification rates may vary inversely with bioirrigation intensity and spatial geometric configuration at high macrofauna densities due to more or less complete oxygenation of surface sediments (Berelson et al., 1998; Gilbert et al., 2003). According to Gilbert et al. (2003), rates of N remineralization and the balance between stimulation and inhibition of denitrification are highly dependent on sedimentary biogenic structures, particularly the geometry and spatial coupling of irrigated burrows. Animal density may, accordingly, have a significant effect on mineralization rates and reaction feedbacks between oxic and anoxic conditions. However, each sedimentary environment is unique and studies are normally required on species specific levels as each species makes particular traits in the ecosystem.

The effects of bioturbating macrofauna on rates and pathways of organic matter degradation during early diagenesis in surface sediments of the Baltic Sea are not well investigated and generally poorly understood. The overall aim of this study was to examine the effects of *Monoporeia affinis* reworking and ventilation activities on benthic mineralization processes during a simulated bloom event. We focused on the importance of *M. affinis* density for benthic solute fluxes and sediment reactivity following additions of organic material to the sediment surface. Three different macrofaunal densities were used to resemble a low, medium and high density situation of a natural amphipod community.

2. Materials and methods

2.1. Benthic macrofauna — *Monoporeia affinis*

The amphipod *M. affinis* is one of the most dominant and widespread macrofaunal species in the species-poor Baltic Sea e.g. (Elmgren, 1978; Andersin et al., 1984; Laine et al., 1997). Although large temporal and spatial variations in the reported numbers, *M. affinis* may occur in abundances of up to 10 000 ind. m^{-2} (Andersin et al., 1978; Elmgren, 1978; Laine et al., 1997; Lehtonen and Andersin, 1998). *M. affinis* is a deposit feeder that ingests particles mainly on the sediment surface (Lopez and Elmgren, 1989; Byrén et al., 2002). Although most individuals are found in the upper 5 cm of the sediment, they can burrow at least to about 10 cm (Hill and Elmgren, 1987).

In the Baltic Sea, *M. affinis* has an important role as a bioturbator and bioirrigator. For example, activities of *M. affinis* have been shown to improve oxygen conditions of the sediment, enhance overall mineralization rates, stimulate denitrification and effect nutrient fluxes across the sediment–water interface (Gran and Pitkänen, 1999; Tuominen et al., 1999; Bianchi et al., 2000; Modig and Ólafsson, 2001; Van der Bund et al., 2001; Karlson et al., 2005). Growth of individuals and population biomass of the amphipod seem to be tightly coupled to the spring bloom sedimentation and input of fresh organic material to the benthic community. In a study by Lehtonen and Andersin (1998) it was estimated that 5000–7000 ind. m^{-2} of *M. affinis* assimilated about 50% of the organic carbon supplied to the sediment during the period mid March to mid July. In addition to enhanced carbon mineralization, elevated oxygen consumption and ammonium excretion were observed in connection to an increased availability of high-quality food during a spring bloom sedimentation event (Lehtonen and Andersin, 1998). For example, ammonium excretion by *M. affinis* was found ca. 6 times higher during early summer compared to winter/spring conditions (Lehtonen, 1996).

2.2. Field sampling

Surface (0–5 cm) sediment was collected in May 2004 by an epibenthic sled from a depth of 25 m near the Askö field station, in the north–western Baltic Proper