



Research paper

Do foraminifera mirror diversity and distribution patterns of macrobenthic fauna in an Arctic glacial fjord?



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ABSTRACT

This paper compares the distribution and diversity patterns of benthic foraminifera (all taxa and only calcareous forms) and macrozoobenthos in an Arctic glacial fjord. The samples were collected at 22 stations located in Hornsund (west Spitsbergen). The activity of tidal glaciers located in the inner basins causes steep environmental gradients of turbidity, organic matter supply, and sediment stability. Clear differences in density, diversity and species composition were documented for both foraminifera and macrofauna between the groups of stations located in three zones along a gradient of increasing tidal glacier impact. The assemblages of both benthic compartments in the glacial bay were dominated by small, opportunistic, infaunal species (i.e., *Cassidulina reinforme* for foraminifera and cirratulid polychaetes for macrofauna) which occurred throughout the fjord, but showed an increase in density and/or dominance when approaching the glaciers. A parallel decreasing pattern from the central basin to the inner glacial bay was noted with regard to species richness and faunal density of both groups. Macrofaunal evenness decreased close to glaciers, but this was not observed in the foraminiferal assemblages. The distribution patterns of calcareous foraminifera were correlated ($p = 0.001$) both with those of all foraminifera (agglutinated and calcareous taxa) and with macrofauna, with the Spearman's rank correlation between the respective Bray Curtis similarity matrices ranging from 0.94 to 0.99 (total foraminifera), and from 0.37 to 0.67 (macrofauna), respectively. Species richness, expressed as the number of species per sample, and diversity, expressed by the Shannon–Wiener index, of foraminifera and macrofauna were also significantly correlated (Pearson correlation $r = 0.79$, $r^2 = 0.62$, $p < 0.0001$ for species richness, Spearman correlation $\rho = 0.96$, $p < 0.05$ for diversity). Our study provides evidence that the patterns of calcareous foraminifera density, diversity and species composition in a glacial fjord can be effective, reliable indicators of variability of these characteristics in other benthic compartments.

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1. Introduction

Tidal glaciers are conspicuous elements of Arctic landscapes. Glacial activity, especially meltwater outflows, is an important environmental driver of fjordic and coastal marine ecosystem functioning (Syvitski et al., 1987). The inflow of fresh water loaded with mineral material into the marine environment changes the distribution of water masses and produces steep gradients of salinity, suspended matter concentration, and water turbidity (Syvitski et al., 1987). Increased turbidity in glacier proximal regions decreases the depth of the euphotic zone, and, thus, influences standing stocks and the composition of phytoplankton (Keck et al., 1999; Piwosz et al., 2009). Mass zooplankton mortality in glacial bays is a direct effect of dramatic decreases in surface water salinity (Zajączkowski and Legeżyńska, 2001). Benthic biota dwelling close to glacial or glaciofluvial outflows are exposed to chronic physical disturbances including high sedimentation rates of mineral

material, unstable sediments, frequent iceberg scouring, and sediment gravity flows, and shortage of organic matter (Syvitski et al., 1987; Włodarska-Kowalczyk et al., 2005). The extent and activity of glaciers in the European Arctic have varied tremendously throughout the past 13 kA. The fjords of west Spitsbergen were filled with glaciers during the Late Weichselian glaciation, while glacier fronts retreated beyond the sea shore, and the glacial influence on fjord ecosystems was limited during the Holocene Thermal Optimum (Forwick and Vorren, 2009). Following the expansion of tidal glacier fronts after the Holocene Thermal Maximum, their retreat in west Spitsbergen fjords recently accelerated significantly (Ziaja, 2001; Palli et al., 2003). As current climate warming progresses, increased Arctic tidal glacier activity is predicted, which means the supply of terrigenous material to coastal waters will also increase (Syvitsky and Andrews, 1994; Zajączkowski et al., 2004). This will, in turn, impact the diversity and functioning of coastal and fjordic benthic systems (Włodarska-Kowalczyk and Węśławski, 2001; Węśławski et al., 2011).

Benthic community species composition and diversity are used widely as indicators of both natural and anthropogenic environmental changes (Warwick, 1993). Monitoring the species composition of all

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benthic biocenosis components would be very expensive, time consuming, and would require considerable levels of taxonomic expertise. The efficiency and accuracy of indicators (i.e., quantities that reflect species-level patterns in distribution or diversity, but which can be determined more easily) have been explored in a number of case studies of the macrobenthic response to environmental impacts (e.g. [Olsgard et al., 2003](#); [Włodarska-Kowalczyk and Kędra, 2007](#)). These studies tested whether lowering the taxonomic resolution of macrofaunal organism identifications or selecting and analyzing indicator groups among macrobenthic taxa would yield patterns that are correlated with overall macrofaunal community variability. The performance of selected groups in macrobenthic communities was variable and dependent on the nature of environmental stressors. For example, excellent indicator performance was reported for both polychaetes ([Olsgard et al., 2003](#); [Włodarska-Kowalczyk and Kędra, 2007](#)) and molluscs ([Anderson et al., 2005](#); [Smith, 2005](#)). The predictive potential of a given group can also be largely dependent on local habitats, as was documented with regard to polychaetes in benthic communities sampled in muddy or sandy substrates ([Quijon and Snelgrove, 2005](#)). However, these studies were limited to benthic macrofauna. Correlations between patterns expressed by different compartments of the benthic biocenosis, such as megafauna, macrofauna, meiofaunal invertebrates, or foraminiferal microfauna, have been studied rarely. Foraminifera are used widely as bio-indicators of environmental variability both in ecological and paleontological surveys. Several features make this group a model candidate for bioindication: common occurrence and high densities, high species richness, and highly diversified ecological strategies and environmental requirements ([Mojtahid et al., 2008](#); [Jorissen et al., 2009](#); [Denoyelle et al., 2010](#)). Signs of change in macrofaunal and foraminiferal communities have been compared in studies of oil spill impacts ([Jorissen et al., 2009](#)), organic pollution ([Mojtahid et al., 2008](#)), and oil drilling mud disposal ([Denoyelle et al., 2010](#)), and in a study of natural diversity patterns in a temperate Norwegian fjord ([Klitgaard-Kristensen and Buhl-Mortnesen, 1999](#)). The patterns of response to environmental disturbances expressed by the two groups were inconsistent in some cases, and the discrepancies observed were linked to differences in dispersal modes and the dependency of recolonization processes on bottom currents ([Alve, 1999](#)).

Both modern and fossil foraminifera assemblages have been identified as good indicators of spatial and temporal variability in environmental settings in Arctic sediments (e.g., [Hald and Korsun, 1997](#); [Ślubowska-Woldengen et al., 2008](#); [Majewski et al., 2009](#); [Knudsen et al., 2012](#)). Most components of recent macrofaunal communities in Arctic fjord and shelf sediments have little fossilization potential since up to 86% of the genera are not likely to be preserved. Molluscs are one exception contributing more than 50% of the macroscopic hard parts in Quaternary fossil records ([Aitken, 1990](#)). However, patterns of modern mollusc diversity and distribution in glacial fjords differ substantially from those described for whole macrobenthic communities, which means that its potential use as an indicator group is low ([Włodarska-Kowalczyk, 2007](#); [Włodarska-Kowalczyk and Kędra, 2007](#)). The present study explores the possibility of using calcareous foraminifera as indicators of change in other compartments of ecosystems, more specifically in the macrozoobenthos of polar soft bottom sub-tidal habitats subjected to the impact of glacial activity. The aim of the present study was 1) to describe the patterns of distribution, density, and diversity of foraminifera (for both the entire faunas and only calcareous taxa) and macrozoobenthos in an Arctic glacial fjord; and 2) to assess the level of correlation between the patterns described for the two ecological groups. This study is the first attempt to assess the efficacy of using foraminifera as indicator taxa of benthic biodiversity variability.

2. Study area

Hornsund is the southernmost fjord off west Spitsbergen, located at 76 to 77° N. It is 24 km long and 11 km wide at its mouth. A shallow sill

separates the outer and central parts of Hornsund from its inner basin. In the central basin depths exceed 250 m, while the inner basins are shallower at maximum depths of 150 m in Brepollen and 180 m in Burgerbugkta and Samarinvågen. Seventy percent of the fjord's catchment area is covered by glaciers, and 13 glaciers directly enter the fjord. The Brepollen inner glacial bay coasts are almost entirely formed by the cliffs of five tidal glaciers (Storbreen, Hornbreen, Svalisbreen, Mendelejevreen, Chomjakovbreen). Most Hornsund glaciers are currently retreating at rates of approximately 100 m per year ([Palli et al., 2003](#)).

The area is directly influenced by Transformed Atlantic Water (TAW) that is formed by the mixing of warm, saline Atlantic Water (AW) transported by the West Spitsbergen Current and colder, fresher Arctic Water (ArW) transported by the East Spitsbergen Current. TAW occupies the lower part of the water column in the outer and central parts of the fjord, while the water in the inner basin in its deepest part is cold, saline Winter Water produced by salt rejection during sea-ice formation in the fall–winter period. The salinity of the bottom water is stable and does not fall below 33 PSU. The surface water layer is less saline, rarely exceeds 30 PSU, and seasonal horizontal gradients occur from mixing with glacial meltwater ([Węśławski et al., 1991](#)). The depth of the euphotic zone decreases, so phytoplankton biomass and primary production declines moving from the outer fjord towards the glaciers from 2100 to 608 mg C m⁻² and from 87 to 14 mg C m⁻² h⁻¹, respectively, as was recorded in summer 2002 by [Piwosz et al. \(2009\)](#).

The seabed is covered mostly by glaciomarine mud ([Grzelak and Kotwicki, 2012](#)). Sediment input flows with meltwater discharges from eight major tidewater glaciers. The concentrations of mineral particles in surface waters vary from 35 mg dm⁻³ in Brepollen to 1.5 mg dm⁻³ in the central and outer basins ([Zajączkowski, unpublished data](#)). Sediment accumulation rates were estimated with ²¹⁰Pb profiles, and they ranged from 0.25 to 0.59 cm y⁻¹ in the outer and central basins ([Glud et al., 1998](#)) to 0.7 cm y⁻¹ in the central part of Brepollen ([Szczuciński et al., 2006](#)). Based on the distribution of light and dark laminae in a core, [Gorlich et al. \(1987\)](#) estimated that sediments could accumulate at rates of up to 35 cm y⁻¹ in a glacial frontal zone. The longer persistence of fast ice (i.e. sea ice that remains attached to the coast) cover and high water turbidity in the inner basins of the west Spitsbergen fjords reduces primary production in the water column, and, consequently, the organic matter content in sediments is lower in the inner basin than in the central and outer basins ([Włodarska-Kowalczyk and Pearson, 2004](#); [Winkelmann and Knies, 2005](#)). Additionally the organic matter is diluted in a large mass of sedimenting mineral material ([Gorlich et al., 1987](#)).

3. Material and methods

3.1. Sampling and laboratory analysis

Samples were collected with the R/V *Oceania* in July 2007 ([Fig. 1](#)). Macrofauna and foraminifera were collected at 22 stations distributed on the sub-tidal soft bottom in several basins in Hornsund. Macrofauna was collected using a van Veen grab (0.1 m² sampling area). These samples were sieved on 0.5 mm mesh size sieves and fixed with 4% formaldehyde. All macrofaunal individuals were identified to the species or the lowest possible taxonomic level and counted in the laboratory. Foraminiferal samples were collected with a 6 cm diameter core inserted into undisturbed sediment samples that had been collected with a box-corer to a depth of 10 cm. The samples were frozen at -20 °C. The samples were not stained, and living and dead specimens were not separated. The sediment cores were not cut into finer slices, and the foraminifera were counted in bulk 0–10 cm sediment samples. The samples were thawed at 4 °C, and then weighed and wet sieved through 500 µm and 100 µm sieves. Both fractions were dried and weighed. The 100 µm fraction was analyzed under a

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