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Benthic foraminifera as bio-indicators of chemical and physical stressors in Hammerfest harbor (Northern Norway)

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ABSTRACT

We investigated benthic foraminiferal assemblages in contaminated sediments in a subarctic harbor of Northern Norway to assess their utility as indicators of anthropogenic impacts. Sediments in the harbor are repositories for POPs and heavy metals supplied through discharges from industry and shipping activities. Sediment contaminant concentrations are at moderate to poor ecological quality status (EcoQS) levels. The EcoQS based on benthic foraminiferal diversity reflects a similar trend to the EcoQS based on contaminant concentrations. Foraminiferal density and diversity is low throughout the harbor with distinct assemblages reflecting influence of physical disturbances or chemical stressors. Assemblages impacted by physical disturbance are dominated by *L. lobatula* and *E. excavatum*, while assemblages impacted by chemical stressors are dominated by opportunistic species *S. fusiformis*, *S. biformis*, *B. spathulata* and *E. excavatum*. The foraminiferal assemblage from an un-impacted nearby fjord consists mainly of agglutinated taxa. These assemblages provides a valuable baseline of the ecological impacts of industrialization in northern coastal communities.

1. Introduction

Urbanization and industrialization lead to the contamination of coastal marine waters, altering the ecological quality of the environment. As a result, faunal assemblages in these water bodies often deviate from those present under natural, undisturbed conditions. With increasing environmental pressure on the marine Arctic, there is a need for accurate, quick and cost effective tools to monitor and assess their ecological quality status (EcoQS). Assessment of EcoQS is based on the extent of deviation of the macro-benthic community to reference conditions, following the EU legislation of the Water Framework Directive (WFD, 2000). Reference conditions, or environmental baselines, are site-specific due to the broad diversity range of ecological regions within Europe. As macro-benthic fauna leaves an incomplete fossil record, reconstruction of in-situ reference conditions at already impacted sites is often not possible. In recent years, progress has been made to test the use of other biological groups, which better fossilize in the sedimentary record (e.g. Alve, 1991b; Andersen et al., 2004; Borja et al., 2008). Among those groups, benthic foraminifera have proved as effective indicators of environmental impact (Alve et al., 2009; Dolven et al., 2013).

Benthic foraminifera are considered as meiofauna and live in the upper layers of the seafloor. They are one of the most diverse and widely distributed groups of unicellular organisms in the oceans (Murray, 2006; Sen Gupta, 1999). They play a key role in the functioning of the benthic environment, actively contributing to bioturbation, ventilation of the sea floor and fate of organic matter (Gross, 2002). Foraminifera are sensitive indicators of environmental conditions, including both natural and anthropogenic alterations (Murray, 2006). In pristine environments, foraminifera are affected by parameters including temperature, salinity, nutrient availability, bottom substrate and dissolved oxygen (Murray, 2006). Anthropogenic stressors include among others heavy metals and polycyclic aromatic hydrocarbons (PAH) and organic matter enrichment. Foraminiferal reproductive cycles are short, and therefore their response to environmental change is fast (Kramer and Botterweg, 1991).

As benthic foraminiferal assemblages respond to geographical location and characteristics of the physical environment, site specific impact studies are a critical precursor to the use of foraminifera as a bio-monitoring tool. Benthic foraminifera have proven to accurately reflect the impact of pollution in several harbors located in the Mediterranean region (e.g. Armynot du Châtelet et al., 2004; Coccioni et al., 2009; Frontalini and Coccioni, 2011). However, the impact of anthropogenic activities in harbors in the sub-arctic regions has not been extensively studied (Dabbous and Scott, 2012). The main objective of this paper is

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to examine the suitability of benthic foraminiferal assemblages as indicators of different environmental stressors active in a subarctic harbor. Additionally, we test the applicability of foraminiferal diversity as measure of EcoQS (Bouchet et al., 2012) in this high latitude environment.

The harbor of the town of Hammerfest, Northern Norway (Fig. 1a) is an example of a harbor were various local pollution sources have resulted in pollution levels requiring immediate action (Pedersen et al., 2015). By studying living and fossilized foraminiferal assemblages from this harbor, the foraminiferal method enables both quantification of present and past impact of environmental stressors active in the harbor. At the same sites, the physical environment was mapped by means of grain size, total organic carbon and measurement of a range of heavy metals and POPs. We additionally quantified the natural baseline in a nearby un-impacted fjord. This dataset provides a useful baseline for future investigations of the ecological impacts of industrialization in northern coastal communities.

2. Study area

We focus on the inner harbor of Hammerfest which includes the city center (east side) and the industrial area of Fugleneset (west side) (Fig. 1b). The inner harbor is a 600 m wide embayment with water depths ranging from 2 to 40 m. A CTD profile of the water column was measured during core collection in June 2015. The average salinity and temperature was 33.7 psu and 6.3 °C respectively (Suppl. Fig. 1). Bottom current speeds in the inner part of the harbor are <5 cm/s, occasionally exceeding 10 cm/s (Akvaplan-niva, 2013). The harbor receives freshwater from lake Storvatn via the river Storelva which enters the harbor from the east.

Urban activities connected to Hammerfest harbor include ship traffic associated with the petroleum industry and service-related industries. These activities include various contaminant sources (Pedersen et al., 2015) the main ones being: petrol stations located at the harbor; (former) shipyards; discharges of untreated wastewater and sewage; and inflow of freshwater from the POPs polluted lake Storvatn. Additionally pollution from land based sources enter the harbor basin by, for example, subsurface water, rainwater, and snow melt. Polluted harbor sediments may be redistributed through resuspension by ships and marine organisms.

These pollution sources have resulted in elevated levels of heavy metals and POPs in harbor sediments as illustrated by several environmental studies carried out since 1985 (e.g. Dahl-Hansen, 2005; Evenset et al., 2006; Jahren and Helland, 2009; Johnsen and Jørgesen, 2006; Pedersen et al., 2015; Skjegstad et al., 2003). Previous investigations revealed a complex mixture of sediment pollutants such as heavy metals, PAH, PCB and TBT at levels of risk for the harbor environment and human health (Norwegian Environment Agency, 2014).

We used the nearby Revsbotn fjord (Fig. 1c) as a reference site for this study. The inner part of Revsbotn has water depths ranging between 0 and 50 m. A CTD profile of the water column taken at the time of collection showed bottom water temperatures of 5.8 °C, and bottom water salinity of 33.6 psu (Suppl. Fig. 1). A layer of fresh water transported from the river Russelva occurs at the harbor surface. No industrial or harbor activities occur at proximity to this site.

3. Material and methods

3.1. Sample processing

In this study, we perform a multi-proxy study on a sediment core (core 6; Fig. 1) from Hammerfest harbor to reconstruct the pollution history of the area. In addition, the same parameters are investigated on a reference core from the nearby Revsbotn fjord (core 7; Fig. 1) to reconstruct reference conditions. The present day conditions in both the harbor and at the reference site were assessed by a set of surface

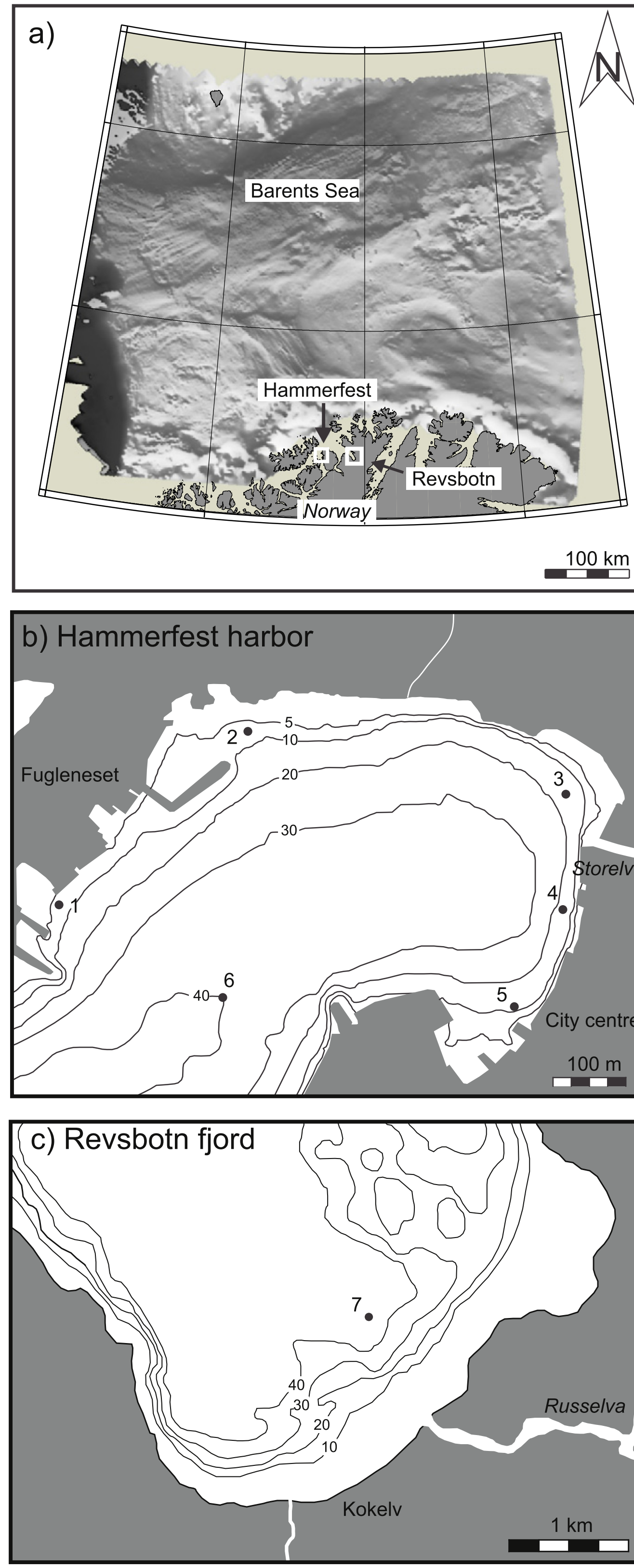

Fig. 1. Location maps. Maps showing: Northern Norway and SW Barents Sea region (Andreassen et al., 2008). (a) The location of the town of Hammerfest and Revsbotn is indicated (top panel); (b) The inner harbor of the town of Hammerfest with the locations of sites 1–6; (c) location of site 7 in Revsbotn (bottom panel). Bathymetric contours are in meters (m).