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Biological effects of long term fine limestone tailings discharge in a fjord ecosystem

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ABSTRACT

Benthic infaunal data collected from 1993 to 2010 were analysed to examine the effect of long term discharge of fine limestone tailings on macrofaunal species assemblages in a fjord. Relative distance from the outfall and proportion of fine tailings in the sediment were correlated with benthic community structure. Diversity decreased with increasing proportion of fine tailings. Biological Traits Analysis (BTA) was used to explore the temporal and spatial effects of the tailings gradient on macrofaunal functional attributes. BTA revealed that all stations along a pressure gradient of fine limestone tailings were dominated by free-living species. As the proportion of fine tailings in the sediment increased, there was an increase in fauna that were smaller, highly mobile, living on or nearer the surface sediment, with shorter lifespans. There was a decrease in permanent tube dwellers, those fauna with low or no mobility, that live deeper in the sediment and have longer lifespans (>5 yrs).

1. Introduction

The majority of studies investigating the biological responses of benthic assemblages to pressure gradients, either natural and/or anthropogenic, have focused on changes in community structure and species sensitivity. In recent years however the application of Biological Traits Analysis (BTA) has proved useful in extending our understanding of why changes in species assemblages occur and what the ecological consequences may be, by linking the functional traits of the organisms with the ecosystem processes (Bremner et al., 2006; Cooper et al., 2008; Oug et al., 2012).

Biological Traits Analysis was used in this study to examine changes in functional attributes of macrofaunal species assemblages, focusing on the impact of long term discharge of fine particulates from a large limestone processing plant into the Frænfjord, Norway. The benthos in the fjord has been monitored since 1991 to determine the potential effects of the continuous discharge of limestone tailings. Over this time clear gradients (both temporal and spatial) in sediment content of fine particles (silt fraction) through the input of fine calcium carbonate ($CaCO_3$) tailings have been reported (DNV, 2013).

Tailings from limestone processing have been discharged into a designated impact area in the Frænfjord on the west coast of Norway since 1978. The solid phase of the discharge consists of inert milled natural minerals with traces of flocculation chemicals, which are strongly attached to the mineral surface. Approximately 50% of the discharge is limestone ($CaCO_3$), mainly as fine particles smaller than 20 μm in diameter. The remaining 50% is composed of particles, up to 400 μm in diameter, of quartz, feldspar, mica and iron sulphides, as well as traces of graphite. In total, 84% of the solid phase of the discharge consists of fine particles <63 μm (silt size class) (DNV, 2001a,b). The total quantity of tailings discharged as water-borne slurry increased from 3.5×10^5 to 5×10^5 tonnes (dry weight) per year between 1993 and 2011, and after process improvements reduced back to 3.5×10^5 tonnes in 2012 and 2013.

Results reported here are based on data collected as part of the long term monitoring programme including soft bottomed macrobenthic fauna, sediment size and content of fine $CaCO_3$ particles. The aim of this study was to examine the structure of the benthic communities with regard to temporal and spatial changes, and to highlight relationships of the functional features of the benthic species with the fine tailings (<63 μm) gradient.

2. Methods

2.1. Study area

The Frænfjord is a well flushed, long and narrow sill fjord with a maximum depth of around 70 m. The current is tidally governed (tidal range 2 m) and is influenced by the anticlockwise current movement typical to western Norwegian fjords. Water quality

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monitoring in 2012 indicated that the study area is not eutrophic and that pH falls within typical values for similar water bodies, and remains stable. Oxygen levels throughout the water column have been classified as good for all years from 1998 to 2012, while turbidity is low in the fjord, with higher levels generally only found closer to the discharge (DNV, 2012). Before the tailings are discharged to the fjord, freshwater used in the processing is removed and seawater is added, in order to reduce spreading of the particles and maximise transport downwards to the fjord bottom. In areas near the outfall more than 90% of the top few metres of sediment can be made up of fine (<63 μm) $CaCO_3$ particles. As a result of the discharge, the depth of the fjord in certain areas has gradually decreased by up to 25 m from that recorded in 1973. The discharge outlet is at a depth of around 20 m, and as sediment has accumulated around the outfall pipes they have been relocated and extended within the discharge area (DNV, 2013, 2012). Over the last 35 years the spatial extent of the fine tailings has increased, and by 2011 a thin layer of fine $CaCO_3$ could be found up to 2000 m west of the discharge point (DNV, 2012). No negative impact on the fauna has been observed outside the designated impact area (DNV, 2012). In this study measurements of fine $CaCO_3$ in the sediment were used as a 'tracer' of the limestone tailings and were able to map the spread of the discharge.

2.2. Species and environmental parameters

The sediment and benthic data presented here were collected every one to three years from 1993 to 2010. Data from six stations at increasing distance from the discharge were analysed in detail (Map Figs. 1 and 2).

These stations represent a gradient of influence by distance from the discharge. The stations were assigned 'zones' of proximity to the outfall, accounting for the change in location of the pipe: SB7, within 500 m of the outfall; SB11 and SB12, ~1 km; SB13, ~1.5 km; SB15 ~2 km; and SB17 ~3 km. Five stations are in the main channel while one (SB12) is set back from the main current

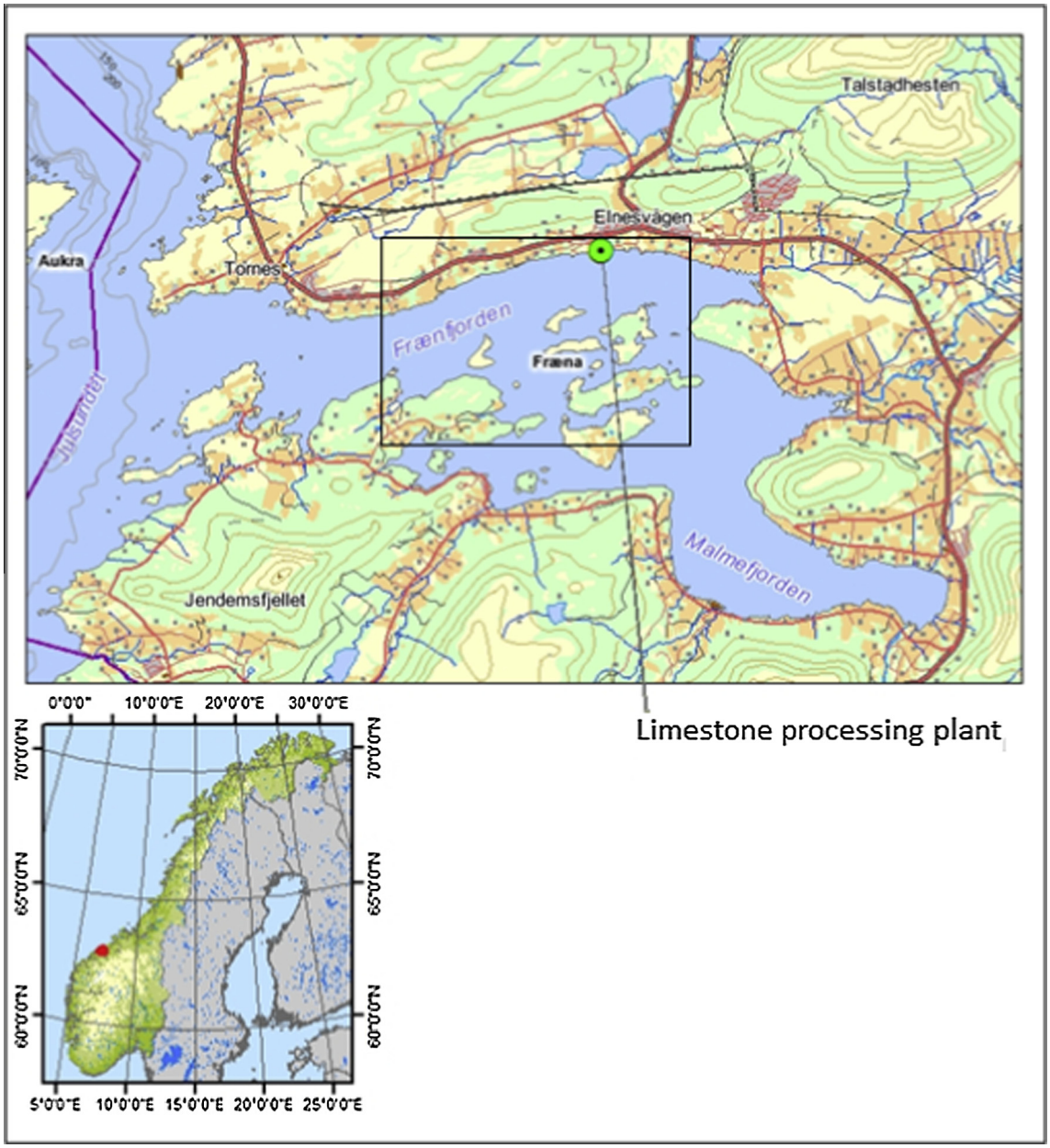

Fig. 1. Location of the Frænfjord on the west coast of Norway and the position of the limestone processing plant.