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ORIGINAL RESEARCH ARTICLE

Deposition, return flux, and burial rates of nitrogen and phosphorus in the sediments of two high-Arctic fjords

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Summary The aim of this study was to determine the burial rates of nitrogen (N) and phosphorus (P) in the sediments of two high-latitude fjords: Hornsund and Kongsfjorden (Spitsbergen). Both deposition to sediments and the return flux from sediments to the water column of the various forms of these elements were, therefore, quantified. The burial rates were then calculated as the difference between deposition and return flux. The required concentrations of N and P species were measured in surface sediments, in pore water extracted from the sediments, and in the above-bottom water at sampling stations situated along the axes of the fjords.

Annual deposition to sediments ranged between 2.3–8.3 g m^{-2} for N and 0.9–2.8 g m^{-2} for P. The nitrogen return fluxes ranged from 0.12 to 1.46 g m^{-2} y^{-1}. At most stations, the N flux was predominantly of dissolved organic (about 60–70%) rather than inorganic N. The P return flux varied between 0.01 and 0.11 g m^{-2} y^{-1}, with organic species constituting 60–97%. The N and P burial rates differed between fjords: 2.3–7.9 g N m^{-2} y^{-1} and 0.9–2.8 g P m^{-2} y^{-1} in Hornsund vs. 0.9–1.3 N g m^{-2} y^{-1} and 1.0–1.2 g P m^{-2} y^{-1} in Kongsfjorden. This was accompanied by a different efficiency of N and P burial – higher in Hornsund than in Kongsfjorden, in both cases. This suggests differences in the quality and quantity of N and P organic species deposited to

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sediments and therefore differences in the intensity of their mineralization and/or decomposition.

1. Introduction

Nitrogen (N) and phosphorus (P) limit or co-limit primary production in the global ocean (Moore et al., 2013; Tremblay et al., 2015). Some of the substances containing these elements are deposited to surface sediments, whether as organic or inorganic compounds. The differences in the chemical and physical forms (species) of these substances reflect their different sources. Inorganic species are mostly transported by river runoff, as a result of weathering and anthropogenic activity and/or from the exoskeletons or skeletons of dead marine organisms. In sediments, N is bound in organic substances or occurs as lattice-bound ammonium in clay minerals (Knies et al., 2007), while P is usually present as loosely sorbed phosphate (PO_4^{3-}), iron-bound PO_4^{3-}, authigenic fluorapatite, detrital P, and organic P (Ruttenberg and Goni, 1997). Organic matter (OM) formed during autochthonous production and/or supplied from land is important form of N and P in sediments. Terrestrial sources of OM may be fresh, produced recently on land, or ancient, mobilized by the melting and thawing of the permafrost. Hence, the processes related to OM production, mineralization, and transformation shape the pools of inorganic N and P species in the water column and thus primary production as well. The short loops between the organic and inorganic forms of N and P are strongly evidenced in productive coastal zones, where the inventories of both are supplemented by return fluxes from the sediments (Benitez-Nelson, 2000; Cloern, 2001; Nixon, 1995).

Global warming and its consequences are becoming increasingly evident, especially in the Arctic, where the respective changes have come early and are of particular intensity. Shifts such as a significant reduction in the amount of sea ice extent or, in some parts of the high Arctic, even the complete disappearance of sea ice, have increased the amount of irradiance reaching the water column and therefore the level of primary production (Fernandez-Mendez et al., 2015; Polyakov et al., 2017). Since it is known that, in the Arctic, N is the main element limiting production (Reigstad et al., 2002; Tremblay et al., 2015), studies on the cycling and origin of N have become particularly important.

Despite the many studies of OM cycling in the Arctic Ocean and especially in its fjords, very little is known about N and P deposition and burial in bottom sediments. Sedimentary N is usually analyzed as total nitrogen, without distinguishing between inorganic and organic forms, while phosphorus in sediments has been generally neglected (Carroll et al., 2008; Kim et al., 2011; Koziorowska et al., 2016; Kuliński et al., 2014; Zaborska et al., 2006, 2016). Moreover, investigations into N accumulation and burial rates in fjord sediments usually do not take into account the fraction of organic N that undergoes mineralization and/or hydrolysis in surface sediments and returns to the water column in the form of dissolved compounds. The only available results for the Svalbard region are those of Blackburn et al. (1996). According to that study, only ~23% of the organic N deposited in surface sediments remains there, which suggests that sediments are a significant source of N in the water column. However, there are no published data on the burial of P in the sediments of the Svalbard region, nor on the return fluxes of phosphates from bottom sediments to the water column. In other regions, sediments were shown to be an important sink for P (burial), although some fraction of sedimentary P diffuses back into the water column in the form of bioavailable PO_4^{3-} (Filippelli, 2001; Rydin et al., 2011; van der Zee et al., 2002).

The goal of this study was to quantify the burial rates of N and P in the surface sediments of two high-latitude fjords located on the west coast of Spitsbergen: Hornsund and Kongsfjorden. This was achieved by measuring the concentrations of total N and total P (TN, TP), organic N and P (ON, OP) and inorganic N and P (IN, IP) in the surface sediments, pore water, and in the seawater overlying the sediments in samples acquired at four sampling stations in Hornsund and three in Kongsfjorden. The stations were situated along the axes of the respective fjords. The return fluxes of both dissolved organic nitrogen (DON) and dissolved organic phosphorus (DOP) as well as inorganic forms of N and P, including nitrate (NO_3^-), nitrite (NO_2^-), and phosphate (PO_4^{3-}) were calculated based on diffusion from the pore water to the bottom water and using the Fick's first law of diffusion. N and P burial rates were calculated as the difference between the accumulation in the sediments and the return flux. The results presented in this report supplement those of studies on the deposition and burial of carbon in the same region (Koziorowska et al., 2018).

2. Study area

The study area was already described in sufficient detail by Koziorowska et al. (2018). The important features as regards the study subject are as follows. Both fjords are situated on the west coast of Spitsbergen. Hornsund is the southernmost, medium-size fjord with a complex coastline (Beszczyńska-Moller et al., 1997; Blaszczyk et al., 2013). The largest bay – Brepollen is situated in the innermost part of the fjord and isolated from the central basin by an underwater riffle and the Treskelen Peninsula. Hornsund is influenced by two main current systems: the coastal Sørkapp Current and the West Spitsbergen Current (WSC; Piechura et al., 2001; Promińska et al., 2017). The sediments are composed of sandy mud and mud (Drewnik et al., 2016), with a maximum OC concentration ~20 mg g^{-1} at the inner part of the fjord (Koziorowska et al., 2016; Zaborska et al., 2016). Primary production ranges from 120 to 220 g C m^{-2} y^{-1} (Piwosz et al., 2009; Smoła et al., 2017).

Kongsfjorden, located on the northwestern Spitsbergen coast, is a relatively small fjord, divided into two parts by a

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