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Glacial Influence on Micronutrient Cycling in Arctic Fjords: Seasonal and Spatial Variability in Svalbard

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1. INTRODUCTION

The Arctic coast undergoes rapid environmental changes due to glacier retreat and transition from marine-terminating to land-based (Kochtitzky et al. 2022). This transformation alters the pathways through which elements such as iron (Fe) and manganese (Mn) are transported from glaciers. These two key micronutrients, together with other trace elements like aluminum (Al), are delivered to fjords and coastal marine ecosystems from subglacial runoff and benthic processes (Herbert et al. 2020, 2021). These dramatic environmental changes can affect phytoplankton growth and marine biogeochemical processes (Wyatt et al. 2023). While previous research has emphasized the role of benthic recycling and riverine dissolved (<0.45 μm) elemental inputs, the seasonal and spatial variability of sediment-bound micronutrients, particularly in relation to glacier type and catchment geology, remains poorly understood. It is also unknown how a shift from tidewater to land-based glacier will affect micronutrient cycling and associated biogeochemical processes in the fjords (Meire et al. 2017).

With this study we aimed to determine the impact of local conditions (bedrock geology, glacier type and seasonality) on micronutrient cycling in three high Arctic fjord systems (Svalbard Archipelago).

2. METHODS

We investigated the influence of glacier type (tidewater vs. land-based), bedrock geology, and seasonal changes (spring vs. summer) on micronutrient cycling in ten fjords and associated riverine catchments in western and southern Svalbard. Sampling locations included fjords with both tidewater (TD) and land-based (LB) glaciers: 1) Trygghamna (LB) – Ymerbukta (TD), 2) Fridtjovhamna (TD) – Berzeliuselva (LB), 3) Recherchfjorden (TD) – Vestervågen (LB) – Josephbukta (LB), 4) Skoddebukta (TD) – Hansbukta (TD) – Gåshamna (LB).

Water samples were collected using Niskin bottles during summer 2022 and spring and summer 2023. For dissolved trace element concentrations, water samples were filtered (pore size 0.45 μm syringe filters) and acidified prior to analysis. Suspended particulate matter (SPM) for sequential extraction of iron species was collected on pre-weighed 0.45 μm PES (Polyethersulfone) membrane. These solids were also imaged and analyzed by scanning electron microscopy (FEI FEG Quanta 3D Dual Beam). Dissolved trace elements (Fe, Mn, Al) were quantified using high-resolution Inductively Coupled Plasma tandem Mass Spectrometry, (ICP-MS/MS, PerkinElmer NexION 5000), employing KED and DRC modes to reduce or remove interferences. Recovery of certified reference materials (NASS-5, CASS-6, and SLEW-4) was 80–120%. In all SPM samples, highly reactive iron and manganese (e.g., ferrihydrite, surface-bound Fe(II), poorly ordered Mn oxides) and more crystalline (oxy)hydroxides (e.g., aged ferrihydrite, lepidocrocite, and goethite) were extracted by ascorbic acid (FeA) and dithionite reagents (FeD), respectively (Raiswell et al. 2010; Lenstra et al. 2021).

3. RESULTS

Fjords influenced by tidewater glaciers generally exhibited higher concentrations of SPM and sediment-bound micronutrients compared to those fed by land-based glaciers. SPM levels were elevated in summer, especially in fjords with active tidewater glacier calving fronts such as Hansbukta, Ymerbukta, and Fridtjovhamna. In contrast, land-based glacier systems like Gåshamna, Josephbukta, and Berzeliuselva showed more stable and lower SPM concentrations across seasons. Intermediate values were observed in Vestervågen and Recherchfjorden, where glacial influence is present but less intense.

Sediment-bound Fe (FeD and FeA) was consistently (329 nM, 88 nM, respectively) higher than dissolved Fe (median 18 nM), with tidewater glacier systems showing significantly higher concentrations. Seasonal patterns were evident, with higher concentrations of both dissolved and particulate Fe observed in summer, likely due to increased meltwater input. Dissolved Fe showed less seasonal variation. SEM analysis showed iron oxyhydroxides on clay minerals in glacier SPM. In contrast to Fe, dissolved Mn (57 nM) was generally more abundant than sediment-bound Mn (20 nM and 6 nM for MnD and MnA, respectively) across all sites. Nevertheless, both forms of Mn showed higher concentrations in tidewater glacier fjords and during summer months, particularly in Fridtjovhamna and Recherchfjorden. Aluminum, although not a biologically essential micronutrient, was also measured due to its provenance from physical and chemical weathering on land (i.e. it is a potential geochemical tracer). Both dissolved and particulate Al were elevated in fjords influenced by tidewater glaciers and in riverine inputs such as Berzeliuselva.

4. CONCLUSIONS

Our results highlight the importance of glacier type and seasonal meltwater dynamics in controlling the availability and distribution of micronutrients in Arctic fjords (Svalbard Archipelago). Tidewater glaciers contribute more SPM and sediment-bound micronutrients than land-based glaciers, especially during summer. These findings suggest that continued glacial retreat and the transition to land-based systems may reduce the flux of bioavailable micronutrients to Arctic coastal waters as well as meltwater induced upwelling, potentially impacting marine productivity. Understanding these processes is crucial for predicting ecosystem responses to ongoing climate change in the Arctic.

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