Iron biogeochemistry in Fram Strait and on the Northeast Greenland Shelf

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Abstract

Fram Strait is the major gateway for Arctic Ocean sea-ice export, and the only deep-water connection between the Arctic Ocean and high latitude North Atlantic. The region is confined by the NE Greenland Shelf to the west and Svalbard to the east; approximately half is covered by summer sea-ice. Glacial and sea-ice lead to strong year-round light limitation of phytoplankton growth across the region. Yet, rapid declines in the extent of summer sea-ice (~40%) and ice shelf coverage (~95% for the Zachariæ Isstrøm ice tongue) have been documented since the 2000s which may have increased marine primary production in Fram Strait. The bioessential micronutrient iron (Fe) limits primary production across much of the high latitude ocean, including parts of the sub-polar North Atlantic south of Fram Strait. Whilst primary production in the Arctic Ocean is generally thought to be controlled by a combination of light and fixed nitrogen availability, the potential role of trace elements as co-limiting factors for phytoplankton growth and their role in ecosystem dynamics has scarcely been investigated. What factors control the supply of Fe to the dynamic Fram Strait region and how does this affect marine primary production? To answer these questions, in late summer 2016, we performed a detailed investigation into the macronutrient and trace element micronutrient distribution across Fram Strait as part of the GEOTRACES GN05 cruise, including full Fe speciation analysis, and conducted nutrient addition bioassay experiments to assess spatial patterns in limiting nutrients.

Surface dissolved Fe (dFe), the biologically most accessible form of Fe, showed an east-to-west gradient across Fram Strait. Concentrations were elevated near the Greenlandic coast in proximity to the marine-terminating glaciers Nioghalvfjerdsbrae and Zachariæ Isstrøm, and depleted in the West Spitsbergen Current near Svalbard. Fixed nitrogen (N), the sum of nitrate, nitrite and ammonium, and dFe were deficient in seawater relative to typical phytoplankton requirements. An east-to-west trend in the relative deficiency of N and Fe was apparent, with N becoming more deficient towards Greenland and Fe more deficient towards Svalbard. This aligned with phytoplankton responses in bioassay experiments, which showed greatest chlorophyll-a increases in +N treatments near the Greenland continental margin, and +N+Fe near Svalbard. Collectively, our results suggest primary N limitation of phytoplankton growth throughout the study region, with conditions

potentially approaching secondary Fe limitation in the eastern Fram Strait. The supply of Atlantic-derived subsurface N and Arctic-derived Fe therefore exerts a strong control on summertime primary production in the Fram Strait region. Future primary production in Fram Strait region will experience relief from light limitation yet would require additional supply of N during the post-bloom season to raise levels of phytoplankton growth. Conversely, changes in the southward flow of Arctic-derived Fe may have implications for Fe-limited productivity further south.

On the NE Greenland Shelf, surface dFe concentrations near Nioghalvfjerdsbrae and Zachariæ Isstrøm showed no connection to observed maxima in the East Greenland Current further offshore which instead appear to have arisen from Arctic sources further north. Analyses of Fe species immediately adjacent to the Nioghalvfjerdsbrae glacier terminus revealed a decoupling of dFe from labile particulate Fe inputs likely due to a prolonged residence time of meltwater beneath Greenland's largest floating ice-tongue. Subglacial removal in combination with limited stabilization from organic material (i.e. Fe-binding ligands) leads to restricted supply of 'new' Fe from meltwater. Water exchange between the subglacial cavity, formed by the 80 km long floating ice tongue, and the shelf, is driven by the cavity overturning circulation, and exerts a strong control on subglacial dFe discharge to the NE Greenland Shelf. Comparison of findings at Nioghalvfjerdsbrae to observations in Antarctica suggests a more universal role for cavity overturning circulation in determining the extent of lateral dFe fluxes to broad glaciated shelf regions. Future retreat of deep-grounded marine termini, as projected for Nioghalvfjerdsbrae, may result in increased export of glacial dFe to shelf environments and more direct connectivity between meltwater discharge and marine primary production.

Fluxes of dissolved trace elements across Fram Strait were calculated with the most recent year-round synopsis of volume transport rates available. Transport was dominated by the southward-directed East Greenland Current and the northward-directed West Spitsbergen Current, and comprised ~80% of gross dFe, dMn, dCo and dZn transport across Fram Strait. Dissolved Fe, Mn, Co and Zn fluxes on the NE Greenland Shelf were of only local importance and contributed ~10% to gross northbound and southbound transport. Greenland Ice Sheet discharge and associated near-shore sedimentary enrichment from Nioghalvfjerdsbrae were much smaller than dFe, dMn and dCo fluxes in the EGC and WSC and comprised <1% of southbound export across Fram Strait. The advection of Central

Arctic Ocean waters including the trace element-rich Transpolar Drift, feeding into the East Greenland Current, plays a fundamental role in dFe, dMn and dCo supply to surface Fram Strait. Comparison of fluxes to estimates from the Barents Sea Opening and Davis Strait stresses the importance of Fram Strait as the main gateway for Arctic-Atlantic dFe, dMn, dCo and dZn exchange, a consequence of intermediate and deep water transport between Svalbard and Greenland. Fluxes of all three gateways combined suggests the Arctic is exporting $2.7 \pm 2.4\ \mathrm{Gg \cdot a^{-1}}$ dFe to the North Atlantic Ocean. Arctic export of dMn ($2.8 \pm 4.7\ \mathrm{Gg \cdot a^{-1}}$) and dCo ($0.3 \pm 0.3\ \mathrm{Gg \cdot a^{-1}}$) appears more balanced and within uncertainty. For dZn, Arctic-Atlantic exchange was balanced with an insignificant net northbound flux of $3.0 \pm 7.3\ \mathrm{Gg \cdot a^{-1}}$. More observational data, particularly from non-summer months, is needed to project changes in seasonal and interannual Arctic-Atlantic micronutrient exchange and potential effects on ecosystem services sensitive to (micro)nutrient stoichiometry.