BRIEF COMMUNICATIONS

Nitrogen balance and Arctic throughflow

Waters moving east through the Arctic Ocean significantly contribute to nitrogen fixation in the Atlantic.

The Atlantic Ocean contains organisms that fix nitrogen, using up phosphate in the process and causing the waters to be enriched in nitrate relative to phosphate. The balance is redressed by the relatively phosphate-rich waters that flow into the Atlantic from the Arctic Ocean, through Fram Strait and the Canadian Archipelago. Here we show that the phosphate in this throughflow accounts for 16% or more of the nitrogen fixation in the North Atlantic. This unexpectedly high contribution highlights the importance of the Arctic throughflow in preventing large swings in nutrient budget and productivity in the ocean.

Nitrogen and phosphorus compounds regulate the productivity of the ocean[1] and therefore have an impact on the global carbon cycle. Both nutrients are supplied to the ocean by river run-off and by airborne dust, and are removed by sedimentation. Nitrogen can also be made biologically available by nitrogen-fixing marine organisms, or released back into the atmosphere as a result of denitrification, a process in which bacteria use nitrate to oxidize organic matter. Both processes take place in the Pacific and Atlantic oceans, with the Pacific providing a net sink of nitrogen and the Atlantic a net source[2], but how these are balanced is not well understood.

The Arctic Ocean receives water from the Pacific Ocean, which is already depleted in nitrate with respect to phosphate, through the Bering Strait (Fig. 1a, b). The broad shelves of the Bering and Chukchi seas are also denitrification sites[3,4], so water of Pacific origin is further reduced in nitrate relative to phosphate during its journey: we calculate that about 0.8 μmol kg^{-1} of phosphate remains after all the nitrate has been removed (Fig. 1a). This excess phosphate is transported into and through the Arctic Ocean, as shown by a shift in the nitrogen:phosphate ratio in water that is leaving through the Fram Strait and the Canadian Archipelago[5,6].

Using a Pacific inflow[7] of 0.8 Sverdrup circulation units (10^6 m^3 s^{-1}), we estimate that 2×10^{10} mol excess phosphate is transported each year into the North Atlantic. Here, nitrogen-fixers use this excess phosphate and release nitrogen upon decomposition — initially in the form of ammonium — at a nitrogen:phosphorus ratio of about 45:1 (ref. 8). This enables organisms that are not nitrogen fixers to use phosphate with the newly fixed nitrogen at a ratio of 16:1. Under steady-state conditions, we estimate that nitrogen-fixers would consume about 16/45 of the excess phosphate from the Arctic throughflow to fix 4.5×10^{12} g N yr^{-1}: this represents 16% of the total nitrogen fixation in the North Atlantic[2].

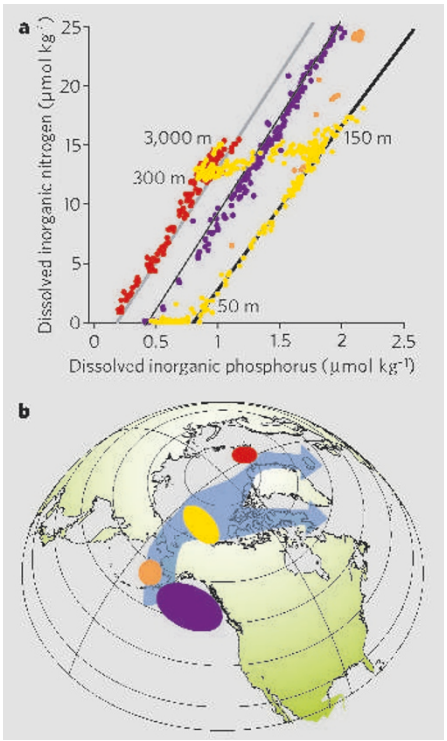

Figure 1 | Nitrogen balance between the Pacific and North Atlantic oceans. a, Relationship between dissolved inorganic nitrogen and dissolved inorganic phosphorus in waters in regions identified by colour on the map in **b**. Data are from the World Ocean Database 01 (red and purple), and from JAMSTEC (*RV Mirai* expeditions in 2000 and 2002; orange and yellow, respectively). The grey, thin black and thick black lines are regression lines for the uppermost 150 metres of the global ocean[2], northeastern Pacific waters and Canada Basin, respectively. Dissolved inorganic nitrogen comprises nitrates, nitrites and ammonium for the *Mirai* data set, and nitrates for the other data sets. Numbers indicate approximate depths in the Canada Basin. *Mirai* data were provided by T. Takizawa, K. Shimada, A. Murata and S. Nishino. **b**, Map showing the pathway followed by waters of Pacific origin into the North Atlantic[5,6] (blue arrows). Colours show areas from which data plotted in **a** originate.

If nitrogen-fixers are transported to depth before decomposition, however, uptake of excess phosphate by other organisms will be depressed and will allow more nitrogen-fixers to use the excess phosphate. Indeed, a higher nitrogen:phosphorus ratio is observed in sinking particles, including nitrogen-fixers, in the western subtropical Pacific[8], and we calculate (by using 23.3 as the mean nitrogen:phosphorus ratio) that an excess of 2×10^{10} mol phosphorus could account for 23% of the total nitrogen fixation in the North Atlantic.

This perspective suggests that in glacial times, when the Bering Strait was closed, excess phosphate (which was less then than it is now owing to lower denitrification[9]) remained in the Pacific. The strait is now open and, with climate warming, the productivity of the Bering and Chukchi seas may rise[10], thereby increasing denitrification[11] and the transport of excess phosphate. Rapid transport of this excess phosphate to the North Atlantic would enable a compensating increase in nitrogen-fixation to make a larger contribution to balancing the global ocean nitrogen cycle.

The role of the Arctic throughflow as a mediator between regions of denitrification and of nitrogen-fixation has until now not been specifically acknowledged in the calculation of nutrient budgets or in models of the global ocean[2,12].

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