Enhanced recycling of bioavailable nitrogen in sediments underlying the Peruvian oxygen minimum zone

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Oxygen minimum zones (OMZ) are key regions for pelagic and benthic nitrogen turnover. During Meteor cruise M77-1/2, conducted within the SFB 754, the shelf and upper slope sediments off Peru were identified as major recycling sites for bioavailable nitrogen. This is in strong contrast to the common perception that continental margin sediments in upwelling regions generally represent a major sink for bioavailable nitrogen releasing dinitrogen gas, N_2, into the environment.

As part of the SFB 754 "Climate - Biogeochemistry Interactions in the Tropical Ocean", redox-sensitive sedimentary nitrogen (N) cycling was extensively studied along a transect traversing the Peruvian oxygen minimum zone (OMZ) at 11° S. This transect covered the transition from anoxic bottom water conditions to low oxygen concentration of around 40 µM (Fig. 1). As a limiting element for biological productivity, the availability of dissolved inorganic nitrogen, DIN, (nitrate, NO_3^-; nitrite, NO_2^- and ammonium, NH_4^+) occupies a central role in ocean biogeochemistry, exerting a significant influence on cycles of many other elements, in particular carbon. While DIN, also known as fixed nitrogen, can generally be taken up by phytoplankton, dinitrogen gas (N_2) is only accessible for a small group of nitrogen fixing organisms called diazotrophs. Hence, the balance of DIN removal and production is linked to primary production and carbon cycling with its availability controlling not only the productivity of the oceans but also the sequestration of carbon dioxide from the atmosphere. Due to the redox–sensitivity of many processes involved in the marine N cycle a globally significant proportion of N turnover proceeds in the relatively restricted areas of the world ocean OMZs.

Marine sediments have been perceived to represent a main sink for DIN (e.g. Gruber, 2004) with denitrification and anammox representing the main processes. During denitrification organic matter is decomposed using nitrate as electron acceptor instead of oxygen (O_2), during the recently discovered anammox pathway NH_4^+ is oxidized using NO_2^-. Both processes convert DIN into N_2 and thus lead to a loss of bioavailable N. Denitrification and anammox are generally inhibited by O_2. Hence, these processes are restricted to areas where O_2 concentrations are very low such as in OMZs or reactive sediments where O_2 only penetrates a few millimeters deep into the sediment.

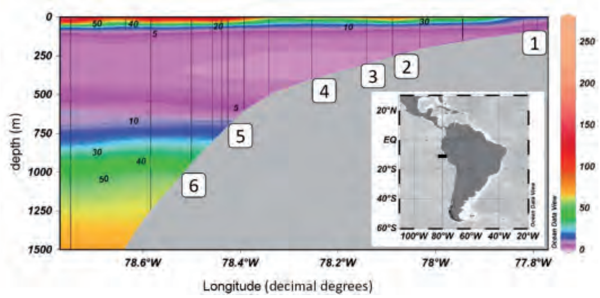

Fig. 1: Cross–section of oxygen concentrations (µM) on the shelf and slope of the Peruvian OMZ at 11 °S. The vertical lines denote the CTD casts where O_2 measurements were made during cruise M77 leg 1. Station locations 1 to 6 for benthic studies are indicated.

In order to determine to what extent the sediments underlying the Peruvian OMZ serve as a sink for bioavailable N, DIN fluxes across the sediment water interface were measured *in situ* at six stations along the transect using benthic landers (Fig. 1). With regards to the net flux of DIN the transect can be separated into two sections. At the slope stations 3 to 6 the uptake of NO_3^- + NO_2^- was higher than the release of NH_4^+ and the sediments represented a net sink for DIN. However, at the shelf and the upper slope (station 1 and 2) uptake of NO_3^- + NO_2^- almost balanced release of NH_4^+ indicating strong recycling of bioavailable N. This finding is in great contrast to the common belief that OMZ sediments represent major sinks (e.g. Middelburg et al., 1996; Devol and Christensen, 1993). At the shelf

Fig. 2: Bacterial mats (white) on the sediment surface at the Peruvian shelf. The length of the ground-weight is 20 cm.

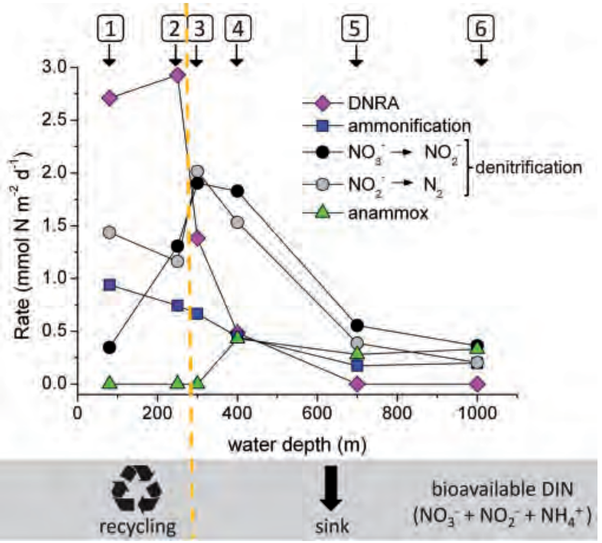

Fig. 3: Model-predicted depth-integrated rates of nitrogen turnover along the 11°S transect. Station numbers are indicated by the arrows at the top. The dashed line denotes the shift from DNRA to denitrification as the major N-turnover process.

and upper slope extended mats of giant sulfur bacteria such as *Beggiatoa* and *Thioploca* were observed (Fig. 2). These organisms can store high amounts of NO_3^- in their cells to oxidize sulfide and thereby release NH_4^+. This process is termed dissimilatory nitrate reduction to ammonium (DNRA). In contrast to denitrification and anammox, DNRA retains bioavailable N in the ecosystem and opposes the "self-cleaning" effect of denitrification and anammox.

To resolve the different N turnover processes the *in situ* DIN fluxes as well as measured porewater concentration profiles were used to constrain a 1-D reaction-transport model (Bohlen et al., 2011). The model allows a detailed simulation of the N cycle including simultaneous two-step denitrification and nitrification, DNRA, and anammox. Results show that the relative importance of the different N turnover processes distinctively changes along the transect (Fig. 3). At stations 1 and 2, DNRA indeed governed N turnover and accounted for more than half of the benthic NO_3^- + NO_2^- uptake. At greater water depth, denitrification became dominant and the sediments turn into a sink for DIN. Anammox was of minor importance on the shelf and upper slope yet contributed up to 62% to total N_2 production at the deepest station.

These new findings illustrate that OMZ sediments do probably not remove as much bioavailable N as previously thought. High rates of DIN recycling by DNRA counteract the overall loss of bioavailable N from the system. Consequently, the role of OMZ sediments as strong sinks for DIN need to be revised. Moreover, strong NH_4^+ release potentially stimulates primary production and O_2 consumption in the water column. Such a positive feedback mechanism maintains or even promotes further expansion of OMZs (Stramma et al., 2008).

References

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Scientific Highlights