THE SPATIO-TEMPORAL DYNAMICS OF THE NITROGEN FLUX IN THE NORTHERN BENGUELA UPWELLING SYSTEM: A MODEL VIEW

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Introduction

The Northern Benguela ecosystem is characterised by a strong, but variable coastal upwelling of cold, nutrient-rich water (Fig. 1). The modeled vertical nitrate flux into the euphotic zone on the shelf off Namibia ranges between 5 and 20 mmol m^{-2} d^{-1} (Fig. 2A). The flux is much higher in the upwelling cells (Cunene cell: 20-60 mmol m^{-2} d^{-1}). Additionally, the polward transport of nitrate onto the shelf with the Angola undercurrent is substantial (400-1600 10^9 mol d^{-1} at 20° S, Fig. 2B).

A high spatio-temporal variability in the hydrographic and nutrient characteristics of an ecosystem causes a respective variability of primary production and associated trophic dynamics. We adopted a regional 3D ecosystem model coupled to a hydrodynamic model. A close interdisciplinary cooperation within the GENUS project is necessary to both set-up the ecosystem model (e.g. to define physiological characteristics of the organisms or kinetics of metabolic processes), and to verify and calibrate the model. The model is the appropriate tool to identify the major processes underlying the variability of the Northern Benguela upwelling ecosystem and to quantify regional (nutrient) fluxes and budgets.

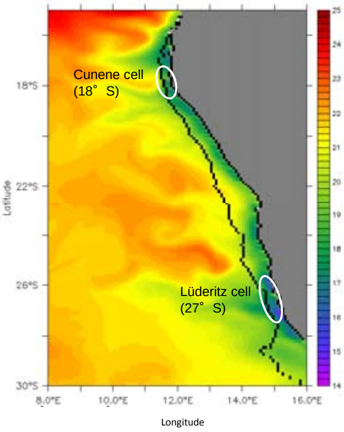

Fig. 1. Sea surface temperatures on 1-Feb-2002. The black line depicts the 200 m depth contours of the shelf.

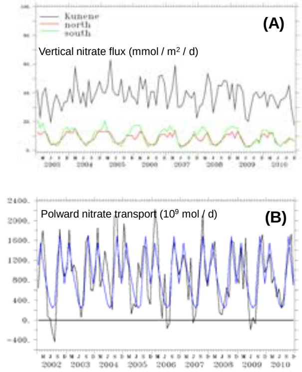

Fig. 2. (A) Time series of the mean vertical nitrate flux, averaged for the Cunene cell and the shelf area north and south of Walvis Bay. (B) Time series of the polward nitrate transport at 20° S with the Angola undercurrent (black line) and the climatology (blue line).

Primary production and spatial phytoplankton succession

The cold, nutrient-rich upwelled water sustains a high primary productivity on the shelf and filaments with high chlorophyll concentrations of 1500-2500 mg m^{-2} moving offshore are observed (Fig. 3A). The mean chlorophyll concentration on the shelf shows a high temporal variability (500-2400 mg m^{-2}), however the pattern is more complex compared to the seasonal cycle of sea surface temperatures (Fig. 3B).

The large, fast growing phytoplankton type dominates the phytoplankton community at high nutrient concentrations, i.e. on the shelf (Fig. 4A). The small, slow growing phytoplankton type reaches high biomass on the shelf only during the warm season and grows otherwise further offshore (Fig. 4B). The diazotrophic phytoplankton type benefits from nitrate-depleted nutrient conditions (Fig. 4C). The phytoplankton supports a high biomass of grazing zooplankton. Its spatial distribution is additionally limited by low oxygen concentrations on the shelf (Fig. 4D).

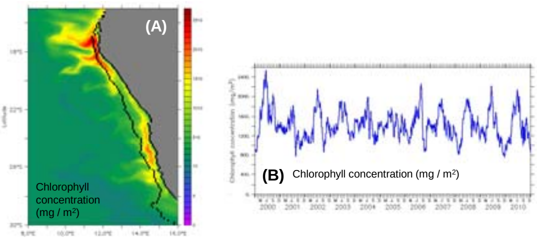

Fig. 3. (A) Integrated chlorophyll concentration over the upper 100 m on 1-Feb-2002. The black line depicts the 200 m depth contours of the shelf. (B) Time series of the 0-100 m integrated, mean chlorophyll concentration above the shelf area.

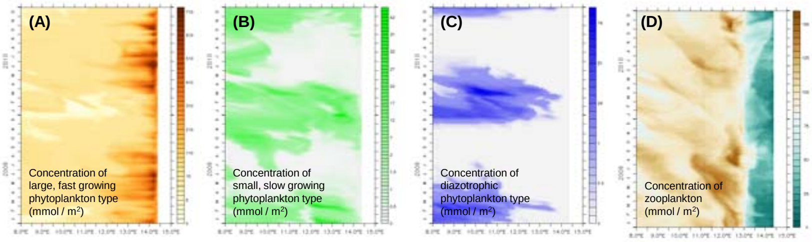

Fig. 4. Concentration of the three phytoplankton types (A-C) and zooplankton (D) for the complete years 2009 and 2010 at the 23° S transect and integrated over the water column.

Mineralisation of detritus

Both dead zooplankton and phytoplankton turn into detritus. Even though it is mineralised in the water column, a substantial part reaches the sea floor (Fig. 5A). Over the year 2010, 1-2 $\cdot 10^9$ mol m^{-2} nitrogen are accumulated on the shelf. In comparison, the detritus concentration in the water column is lower with typically $20 \cdot 10^6$ mol m^{-2} and higher concentrations north of the Walvis Ridge (Fig. 5B).

Depending on the redox conditions and the availability of terminal electron acceptors (i.e. oxygen, nitrate, sulfate), different mineralisation processes dominate. Oxygen concentrations are very low on the shelf (<5 mmol m^{-3}), but nitrate is upwelled (>30 mmol m^{-3}, Fig. 6). In 2010 and independent of water depth, much more detritus is mineralised via oxygen respiration (0-100 m: 277 µmol m^{-2} d^{-1}) than via denitrification (0-100 m: 33 µmol m^{-2} d^{-1}, Tab. 1). Additionally, high mineralisation rates of 324 µmol m^{-2} d^{-1} take place in the sediment.

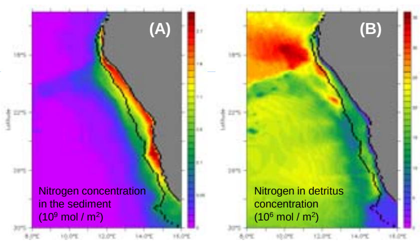

Fig. 5. (A) Annual accumulation of nitrogen in the sediment over the year 2010. (B) Concentration of nitrogen in sinking detritus, integrated over the entire water column and the year 2010.

Tab. 1. Mean rates of aerobic and anaerobic mineralisation of detritus (i.e. oxygen respiration and heterotrophic denitrification) in the water column and mineralisation in the sediment in the region 10-15° E and 18-24° S of the year 2010.

Depth interval	Oxygen respiration	Nitrate respiration (heterotrophic denitrification)	Mineralisation in the sediment
	(µmol / m² / d)	(µmol / m² / d)	(µmol / m² / d)
0-100 m	277	33	
100-600 m	194	36	
600-5000 m	201	0	
Sediment			324

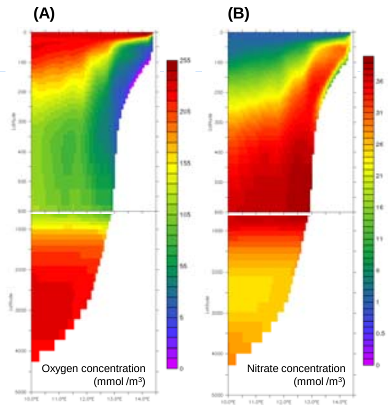

Fig. 6. Mean annual concentration of (A) oxygen and (B) nitrate in the water column along the 23° S transect in 2010.

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