Nutrient and CO$_2$ dynamics in the northern Benguela

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Changes in the biogeochemical regime (oxic-suboxic-anoxic) are direct consequences of climatic forcing via changes in water mass origin and properties.

Changes in the nutrient mass and ratios (qualitative and quantitative) cause changes at the base of the food chain, in the CO$_2$ balance, and in the composition of higher trophic levels.

Such changes are communicated to the adjacent epipelagic or mesopelagic ocean.

_Nutrient sources, turnover, and sinks in the upwelling system CO$_2$ sources and sinks, and relation to water masses_
The role of intermediate (=source) water masses

Upwelling feed waters derive from the Subantarctic and lose $O_2$/gain $CO_2$ and nutrients on the way. They are $O_2$ to start with (light limitation in the Subantarctic) and have an excess of phosphate. SACW has taken a longer route, has more nutrients and $CO_2$, and less oxygen.

In the northern BUS, oxygen is lost through oxidation of organic matter produced in the surface layer, advected organic matter, oxidation of gases/reduced components, and of organic matter in sediments.
Online measurements (FerryBox)

RV Meteor: Cruise M 76-2
May 2008 (moderate upwelling)

RRS Discovery: Cruise D-356
September 2010 (strong upwelling)

RV Maria S. Merian: Cruise MSM 17-3
February 2011 (weak upwelling)

Data acquisition: every 30 seconds, >90,000 measurements
Ferrybox results - nitrate:phosphate ratios surface waters

High temporal and spatial variability locked to oxygenation status in deep water
Low oxygen effects

- incoming Redfield-Ratio: N/P~16
- phosphate release from sediments and denitrification in OMZ reduce the ratio in upwelling to <10, CO$_2$ degassing
- compensated by N$_2$ fixation and CO$_2$ uptake offshore?
N loss due to denitrification estimated to 0.38 to 0.54 Tg (10^{12} g) N per year at a water residence time on the shelf of 80 days and suboxic conditions for 9 months per year.
Sediments on the shelf: diatomaceous muds

Up to 14 m thick, anoxic, filled with gas, settled by bacteria

water content > 90%, ~10% organic carbon!
34 stations from 17°S to 27°S

phosphate flux from
+3.3 μM m^-2d^-1 (in, n=6)
-1,350 μM m^-2d^-1 (out, n=28)

ammonium flux from
+171 μM m^-2d^-1 (in)
-2,640 μM m^-2d^-1 (out)

average N:P ratio outflux ~5

*Neumann et al., in prep.*
Fluxes across sediment water interface

%TOC @ Depth [m]=first

Oxygen [ml/l] @ Depth [m]=last
Controls on fluxes across sediment water interface

Very rough flux estimate @ 9 months/year suboxic area of mud belt ~ 15,000 km²:

- reflux ammonia: ~0.04 Tg N
- reflux phosphate: ~0.02 Tg P

Phosphate reflux contributes <1/3 to N-deficit

Oxygen <70 μM, <400 m water depth:
- median ammonium: -660 ± 800 μM m⁻² d⁻¹
- median phosphate: -140 ± 350 μM m⁻² d⁻¹, median N:median P: 4.8 (M/M)
Possible developments

O$_2$ concentration in feed waters set remotely by processes in the Antarctic Confluence and Angola Dome.

Shoaling thermocline above OMZ (related to regional long-term wind patterns) increases nutrient pool for assimilation, more OM production, O$_2$ in feed waters sinks, N:P ratio of MUW sinks.

But: tendency for thickening mixed layer (warming) in subtropical ocean tends to deplete nutrient availability there. Will increased upwelling offset this loss of nutrients?
$pCO_2$ underway observations by FerryBox

M-76/2 May 2008

AF-258 Dec 2009

atmosphere
CO$_2$-balance of the Benguela upwelling system

moderate CO$_2$ uptake in S-BUS
strong CO$_2$ release in N-BUS

Rixen et al., in prep.
Why this variability?

**Southern sector:** Significant assimilation of pre-formed phosphate that is not associated with $\text{CO}_2 \rightarrow \text{CO}_2$ is taken up from the atmosphere.

**Northern sector:** Upwelling of phosphate mainly from organic matter recycling $\rightarrow$ outgassing of $\text{CO}_2$ liberated from organic matter during recycling.
Research need: Clarify the trend of oxygenation in the BUS by observation and modeling, geological archives, search for/recognise remote forcing

Research need: Expand the view beyond the immediate BUS and look for changes in the adjacent hemipelagic ocean to test if upwelling fertilisation occurs; further clarify the role of material exchange at the sediment-water interface; quantify N$_2$ fixation (why is it not ubiquitous?)

Research need: Investigate the short-term and small-scale dynamics in the coupled CO$_2$, N, P, Si and O$_2$ system of matter fluxes, explore the links to biological productivity and foodwebs patterns (r/v Meteor expedition 100)