Seasonal Anoxia over the Western Indian Continental Shelf

S.W.A. Naqvi, Hema Naik, A.K. Pratihary, M. Gauns, Witty D’Souza, Gayatree Narvenkar, D.A. Jayakumar, M.S. Shailaja & P.V. Narvekar

National Institute of Oceanography
Dona Paula, Goa
Contents

- Introduction - differences with the open-ocean suboxic zone
- Spatial and temporal variability
- Evidence for recent intensification of $O_2$ deficiency
- Some aspects of N cycling ($N_2O$, denitrification, N:P relationships, Natural abundance of $^{15}N$ in $NO_3^-$)
- Biological impact
- Summary/Conclusions
Coastal suboxic zone in the eastern Arabian Sea

- Seasonal – associated with the summer (SW) monsoon circulation
- Smaller volume (~4 x 10^{12} m^3), but more extreme conditions
- Has undergone intensification due to human activities
- Not contiguous with the open ocean suboxic zone
West India Undercurrent

Flows along the margin (~100-400 m) during the period of upwelling (May-November)

- Core of undercurrent fresher (by > 0.3) and more oxygenated (>10 μM) than waters at same depth offshore
- Maintains O$_2$ concentrations marginally above the threshold (~1 μM) for denitrification off Indian margin
- Large impact on biogeochemistry

Offshore intensification of denitrification unique to Arabian Sea
Seasonal anoxia over Indian shelf

Upwelling brings cold, saline, $O_2$-depleted ($<0.5$ ml/L, $\sim 22 \mu$M water over the shelf)

Upwelled water capped by a warm, low-salinity lens - strong stratification

Further $O_2$ depletion shoreward (hypoxia at shelf break; suboxia over mid-shelf; anoxia over inner shelf)

Vigorous denitrification in suboxic waters evident from large $NO_2^-$ accumulation and $NO_3^-$ loss

Sulphate reduction over inner-shelf - accumulation of $H_2S$ and $NH_4^+$

Unprecedented buildup of $N_2O$ in subsurface waters
Mean hydrographic and chemical changes over the annual cycle at the Candolim Time Series (CaTS) location (depth 28 m) based on observations during 1997-2004.
Evidence for intensification of oxygen deficiency

N-P relationships

- Relationship in oxic waters consistent with Redfield model (uptake/regeneration ratio ~14) – Line I
- Ratio in denitrifying water (-79) also comparable with Redfield value (-94) – Line II
- Relationship in anoxic waters exhibits large deviation from expected trend (Line III) due to dissolution of iron oxy hydroxophosphate complex

Excess phosphate released should prime the system for N-fixation
Profiles of temperature, salinity, density, inorganic N species and $\delta^{15}$N of NO$_3^-$ at Sta SS3939 (13.126°N; 74.631°E) sampled on 30/8/1997
Possible causes of lower than expected $\delta^{15}N$ of NO$_3^-$ + NO$_2^-$

- Lower fractionation factor
- Sedimentary denitrification
- Mixing between anoxic and oxic waters
- Presence of isotopically light NO$_2^-$ in high concentrations

$\delta^{15}N$ of NO$_3^-$ vs natural log of fraction of the original NO$_3^-$ remaining
Biological Impact
Effect on Phytoplankton

- Low PP in anoxic waters that extend to euphotic zone (High chlorophyll but low PP in sub-pycnocline waters at this station, located off Mangalore, suggest inhibition of both photosynthesis and chlorophyll degradation). Anoxygenic photosynthesis?

- Nitrate replaced by ammonia as the nitrogen species that supports new production

- Diatoms still the dominant micro-plankton group.
Effect on Zooplankton

Zooplankton biomass and numbers much higher above pycnocline (right bars) than below it (left bars); increase with MLD.

Distributions off Goa – Sept. 84

(Madhupratap et al., JPR, 6(1990), 413-426)
Effect on Benthos

Abundant bivalve shells in surface sediments but no live animals over the inner shelf indicating recent intensification of anoxic conditions
Effect on Fisheries

- Demersal fish driven out of the oxygen-depleted waters
- Sharp decline in demersal fish catch - shrimp landing in Goa down by 2/3 since 1995
Effect on Fisheries (contd)

Shorter fishing season

Frequent episodes of fish mortality
Summary/Conclusions

- Widespread O$_2$ deficiency over Indian shelf makes the region highly vulnerable to human induced changes - sufficient evidence for recent intensification of O$_2$ deficiency

- Intense production of N$_2$O, often through denitrification - eutrophication may enhance N$_2$O emissions from the oceans

- Indication of different isotopic fractionation factors (rate dependency or sedimentary/mixing effects?)

- Net loss of combined nitrogen: 1-4.5 Tg N y$^{-1}$ - to be made up by supply from deep waters through upwelling
Conclusions (contd)

- Large impact of $O_2$ deficiency on biology and living resources
Thank you