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understanding the seas

Seasonal Anoxia over the Western Indian Continental Shelf

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- Biological impact
- Summary/Conclusions

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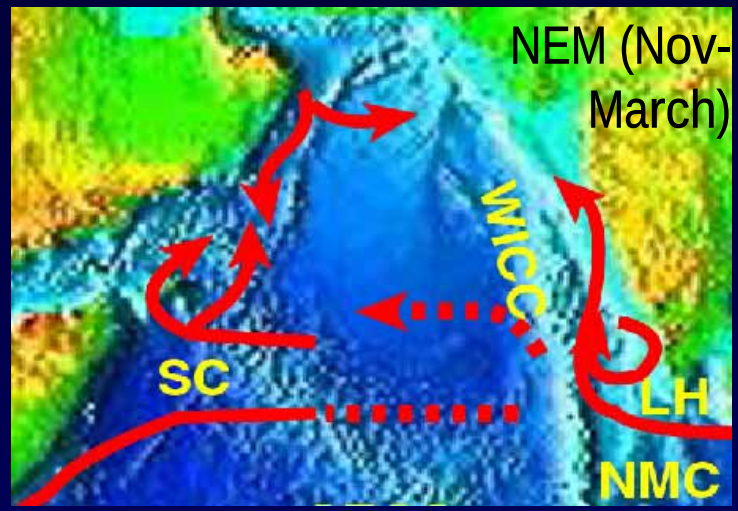
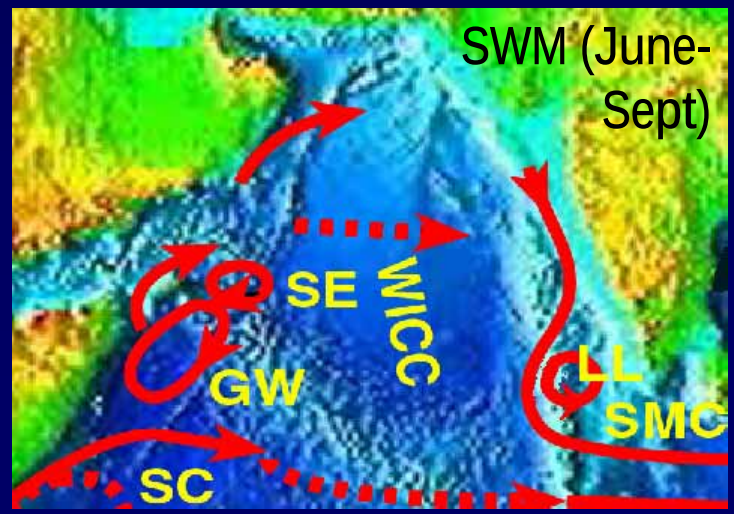
Coastal suboxic zone in the eastern Arabian Sea

- 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



Surface currents in Arabian Sea



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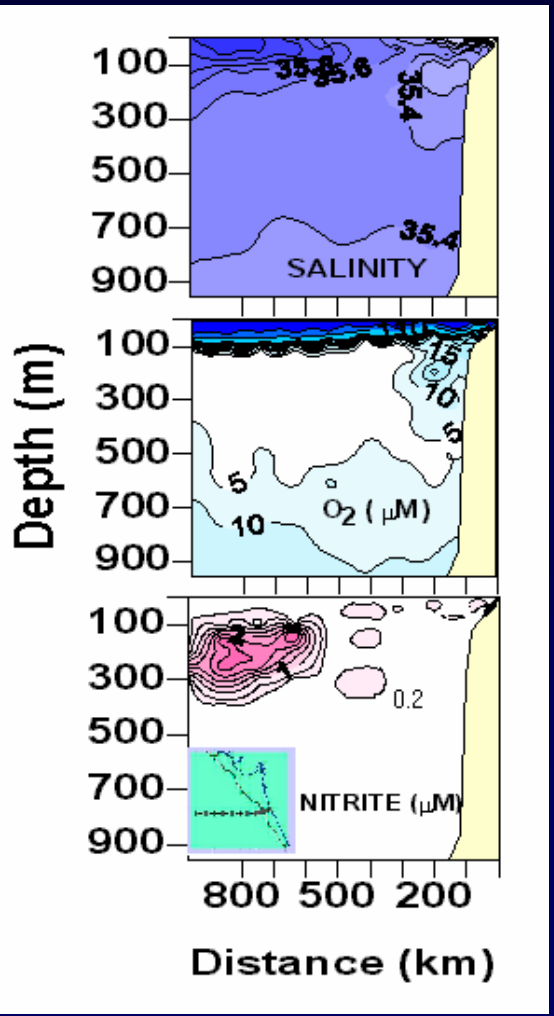
West India Undercurrent

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



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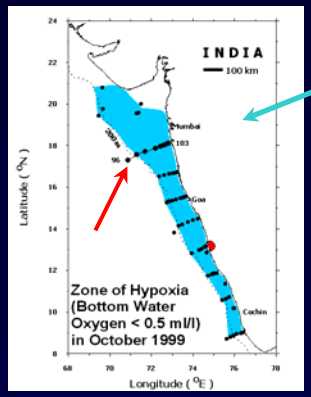
Seasonal anoxia over Indian shelf



Upwelling brings cold, saline, O_2-depleted (<0.5 ml/L, ~22 μM water over the shelf)

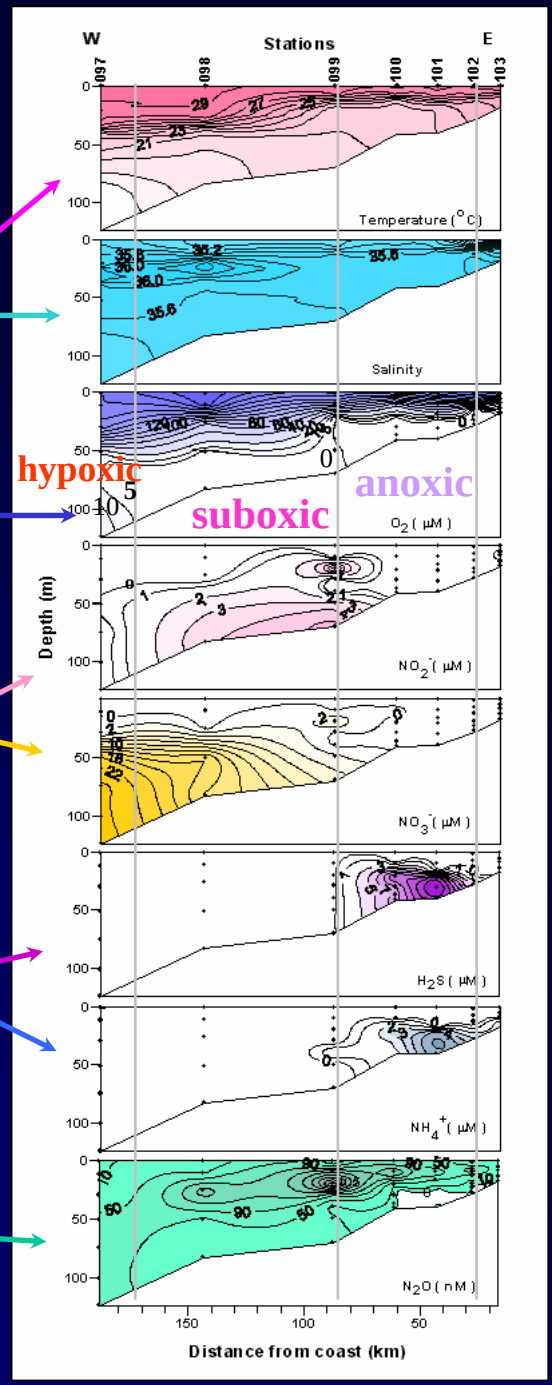
Upwelled water capped by a warm, low-salinity lens – strong stratification

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



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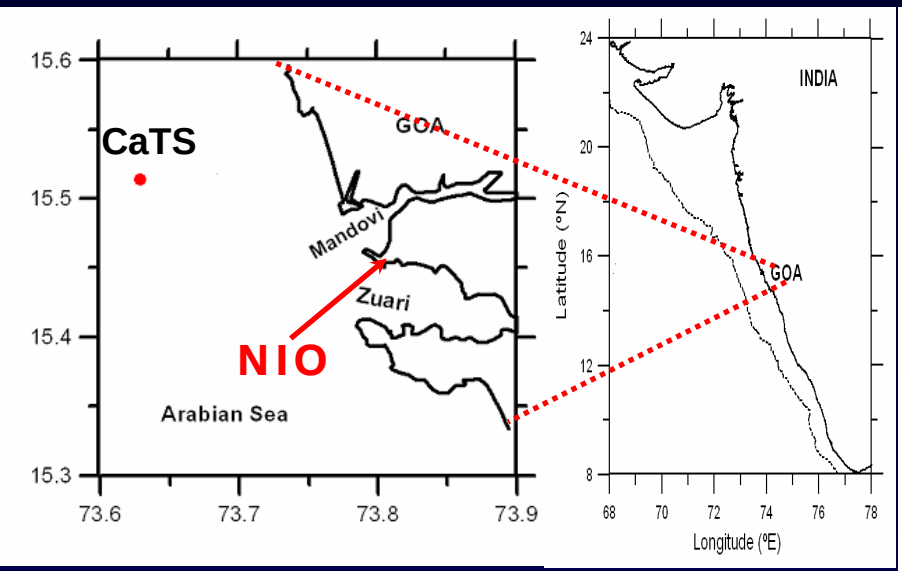
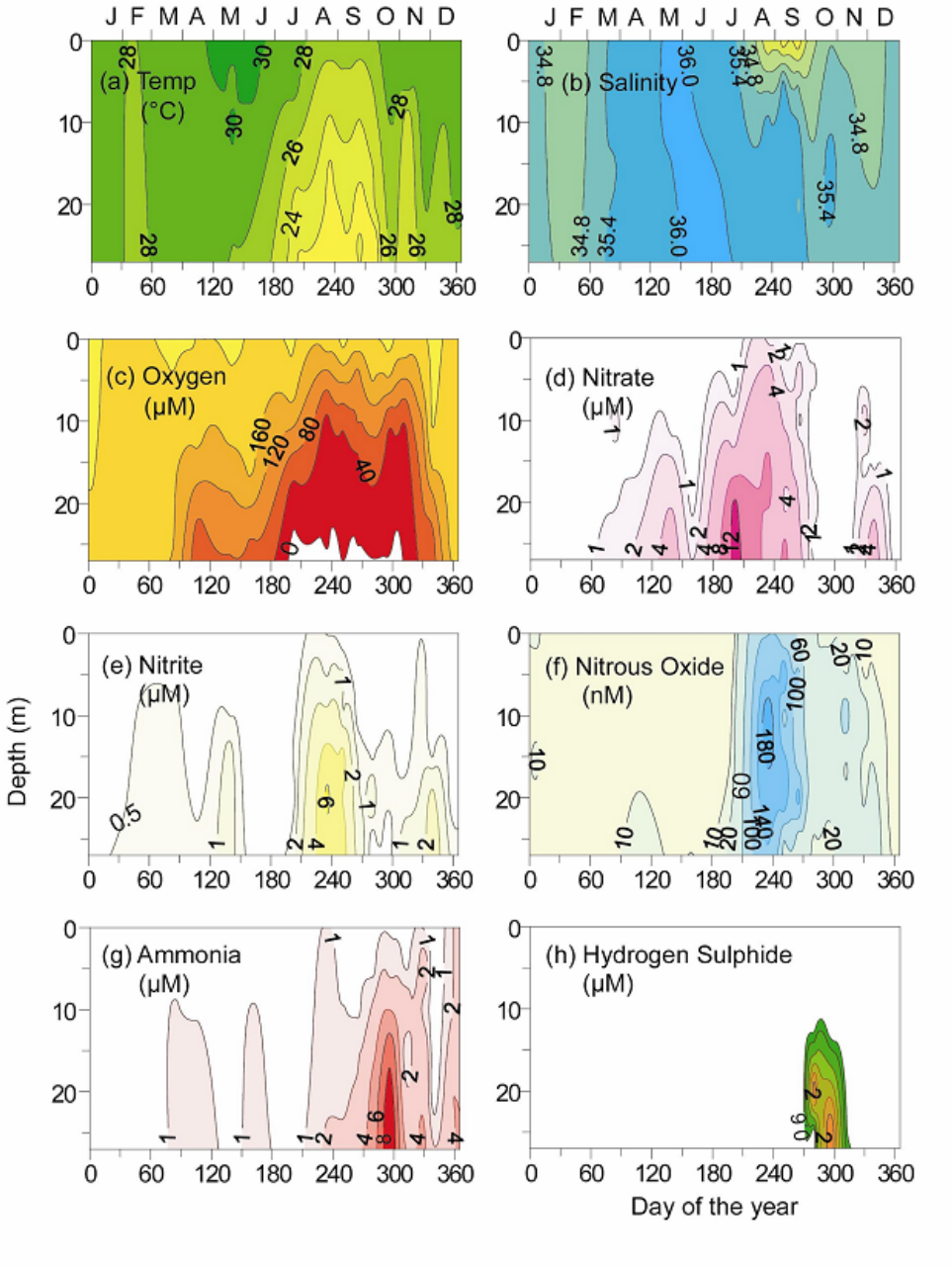


Mean hydrographic and chemical changes over the annual cycle at the Candolim Time Series (CaTS) location (depth 28 m) based on observations during 1997-2004



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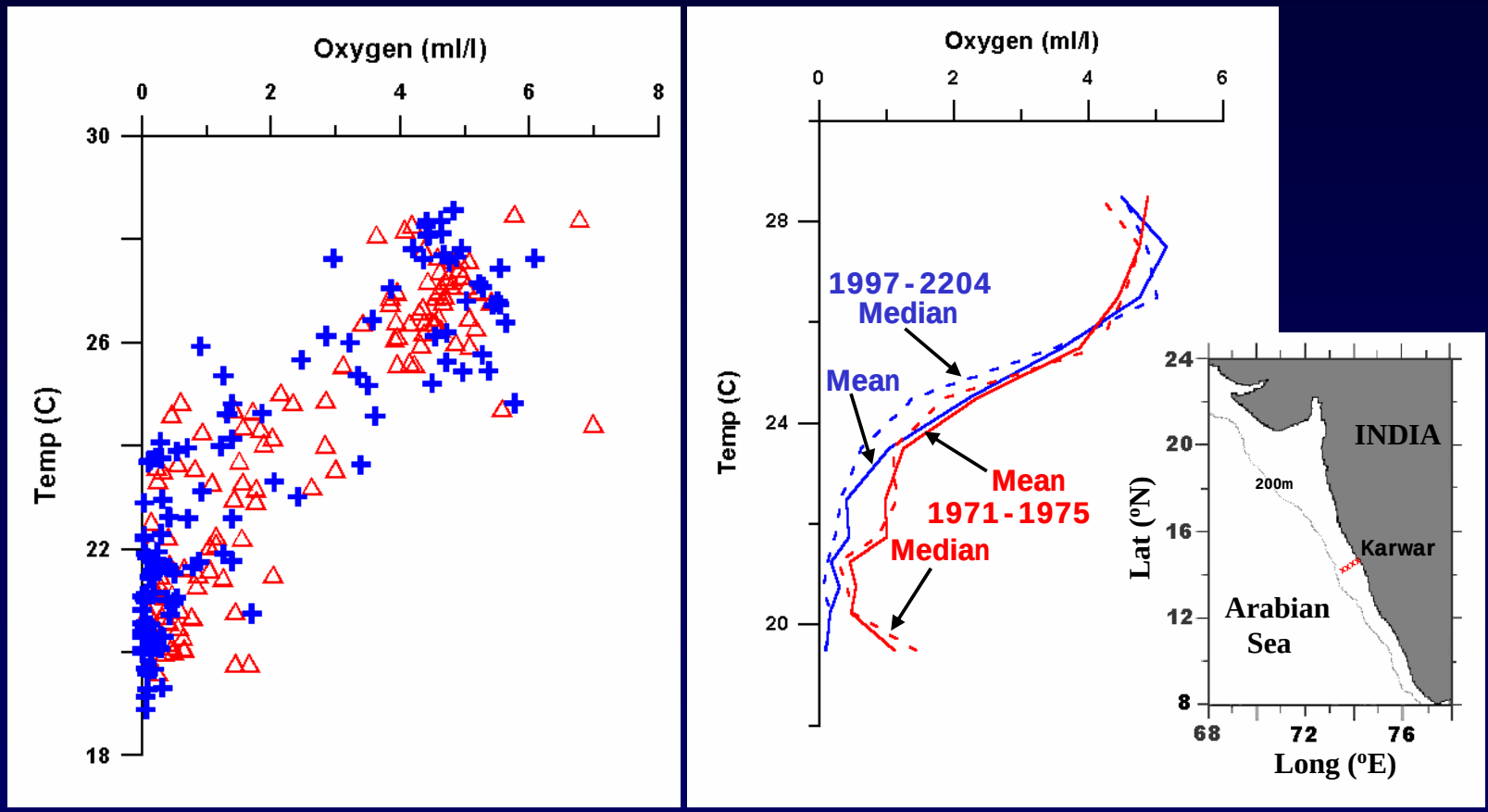
Evidence for intensification of oxygen deficiency



Temperature vs O_2 plots for data sets collected during UNDP/FAO-sponsored Integrated Fisheries Project (1971-1975) and NIO's cruises (1997-2004)

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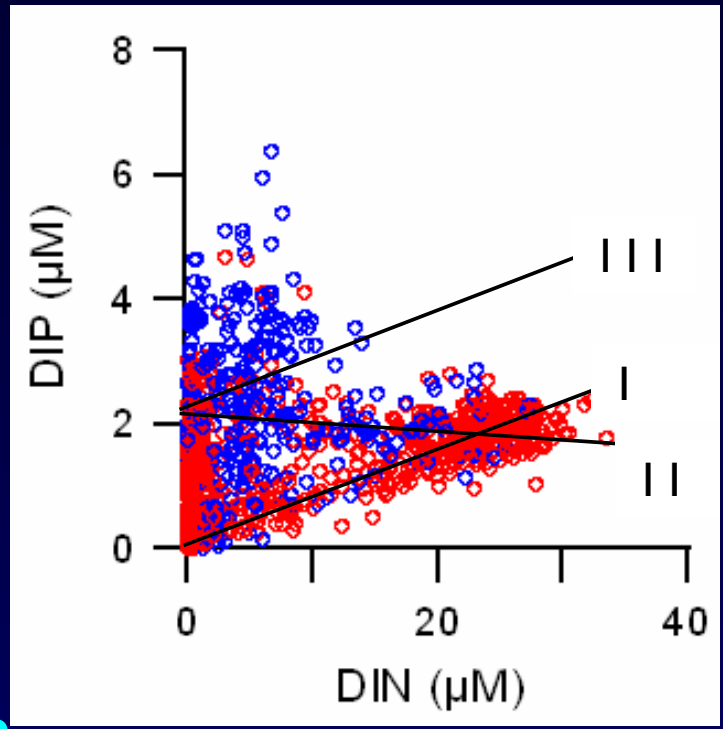
N-P relationships

- 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

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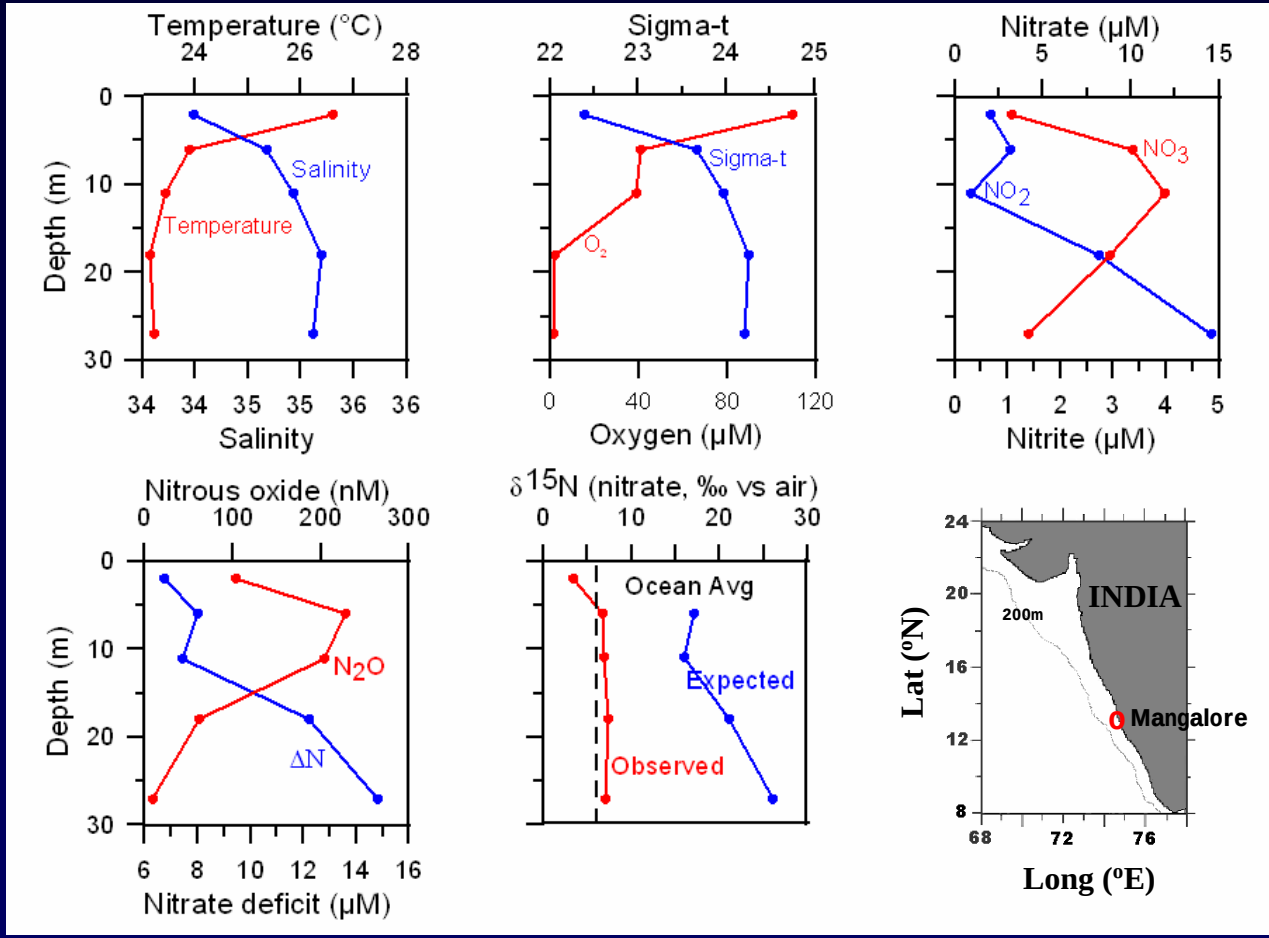
Nitrogen isotope abundance



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

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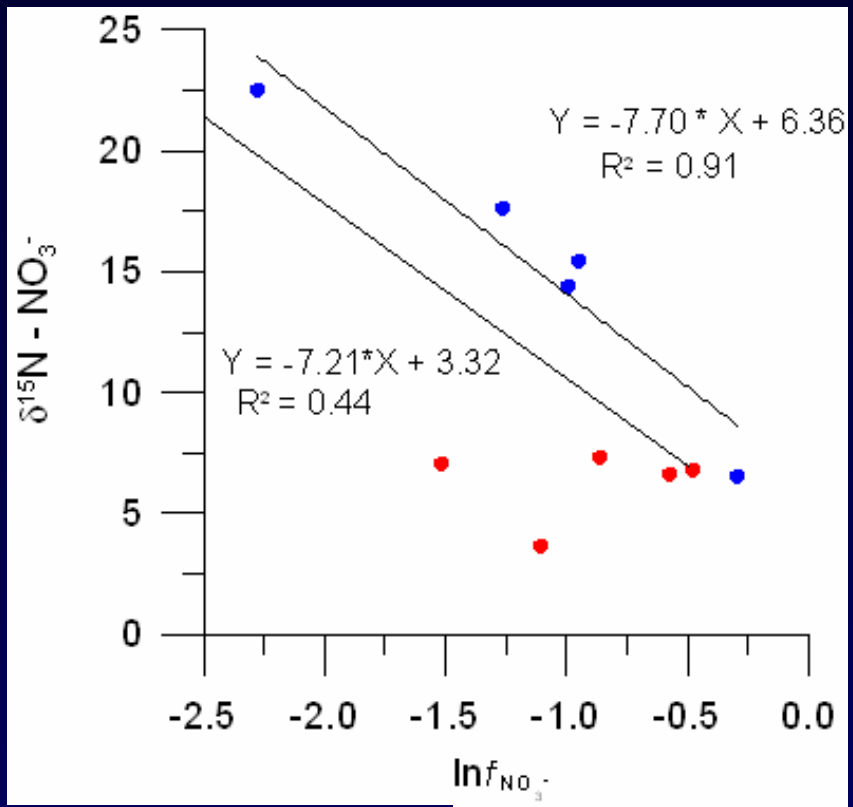
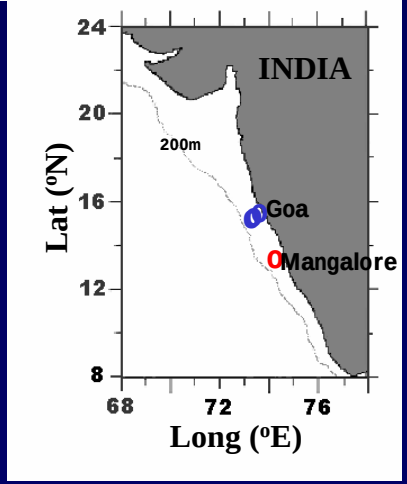
Possible causes of lower than expected $\delta^{15}N$ of NO_3^- + NO_2^-

- 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



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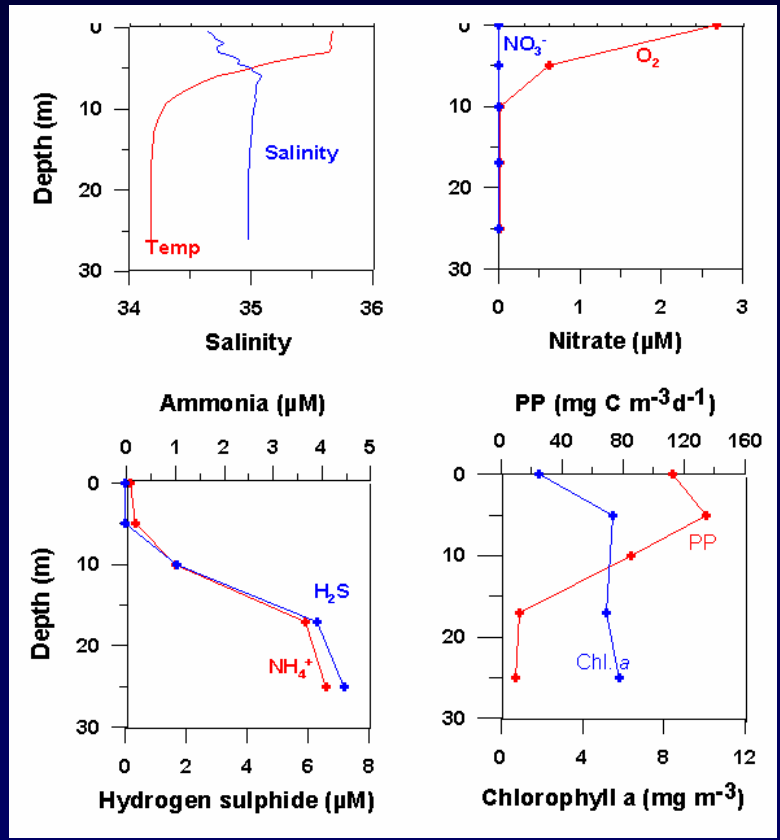
Biological Impact

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.



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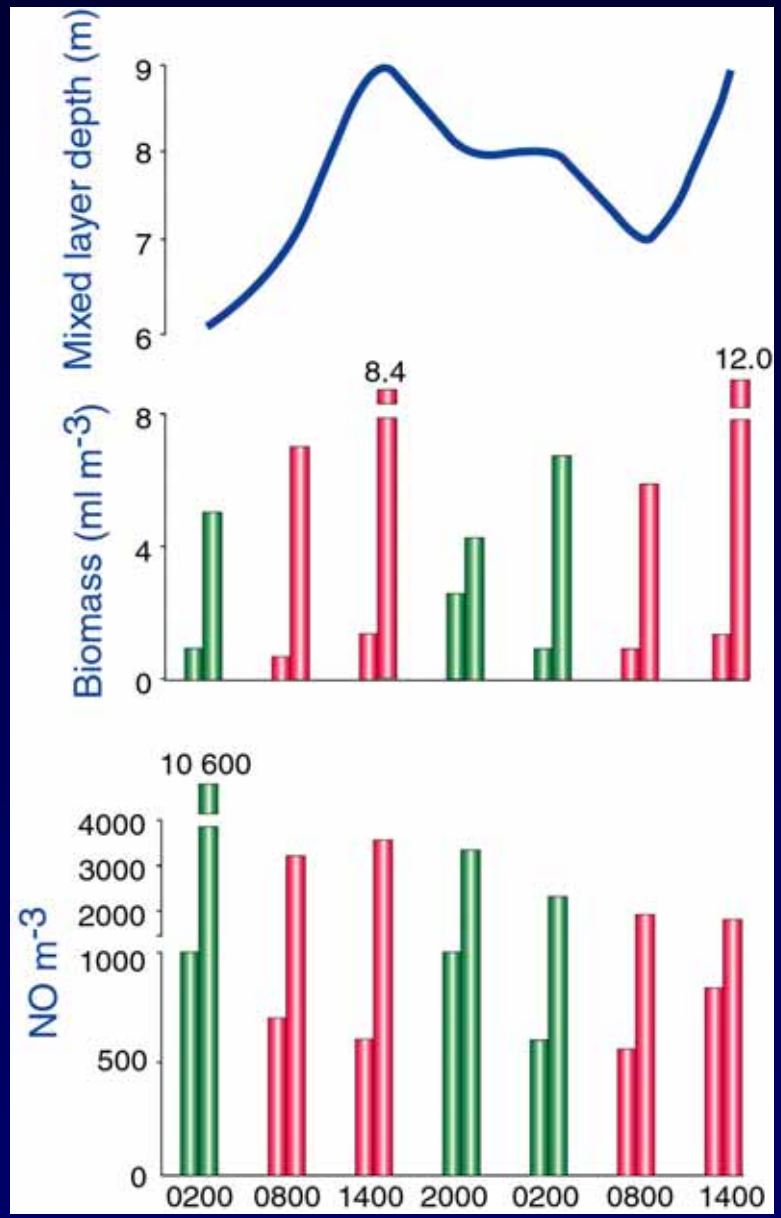
Effect on Zooplankton

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



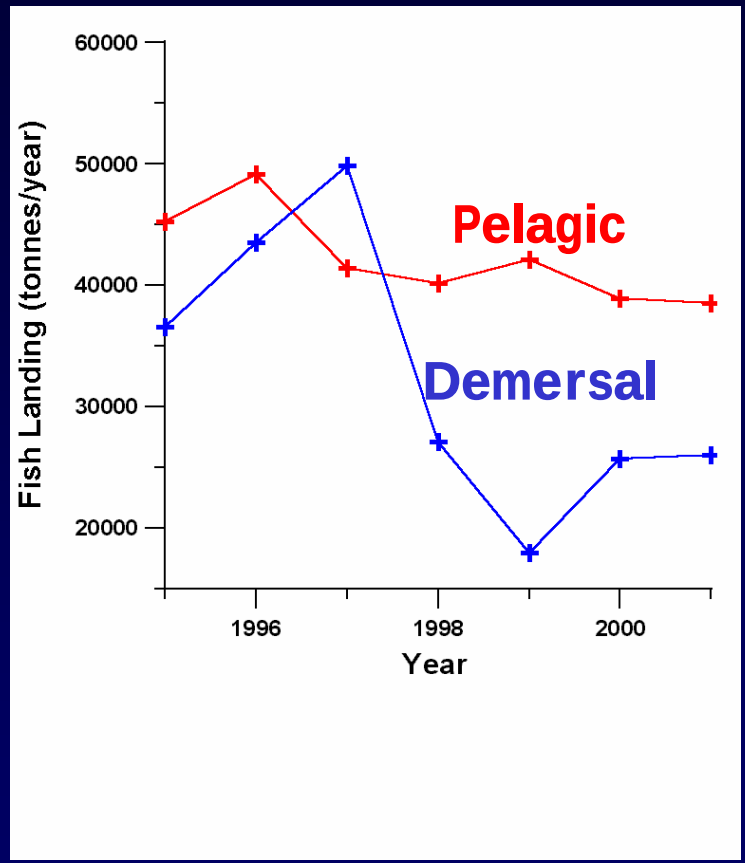
(Madhupratap *et al.*, *JPR*, 6(1990), 413-426)

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

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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_2O, often through denitrification – eutrophication may enhance N_2O 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

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Conclusions (contd)

- Large impact of O_2 deficiency on biology and living resources

Thank you