

RELATIONSHIPS BETWEEN NUTRIENTS, DISSOLVED OXYGEN, AND NITRATE REDUCTION IN THE ARABIAN SEA

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This investigation deals with some consequences of oxygen-deficient conditions prevailing within a large body of intermediate waters in the northern Arabian Sea. Using recent data, some processes affecting oceanic nitrogen cycling were focussed upon.

The true levels of dissolved oxygen within the oxygen minimum zone, determined colorimetrically, were about an order of magnitude lower than those reported previously. Evidence for denitrification was provided from microbiological work, as well as from the distribution of inorganic combined nitrogen compounds. The secondary nitrite maximum occurred when O_2 was less than $3 \mu\text{mol dm}^{-3}$, in conjunction with a pronounced minimum in nitrate. Both features exhibited significant temporal changes and were not confined to a specific water mass. Occurrence of an additional minimum in nitrate and a corresponding maximum in nitrite within the depth range 700-1,200 m at several stations in the northeastern Arabian Sea suggests the occasional development of a deeper denitrifying layer. This appears to be related to an observed increase in POC at this level. Possible mechanisms of the occurrence of these features were examined.

Relationships between the apparent oxygen utilization and inorganic micronutrients were studied in the Arabian Sea and the Red Sea to determine the composition of organic matter. The results suggest that while the composition of organic matter oxidized within the thermocline of the Arabian Sea (C:N:P = 95:15:1, by atoms) is not very different from the Redfield ratios (106:16:1), the atomic ratios between carbon, nitrogen, and phosphorus in the biomass of the Red Sea (188:21:1) are vastly different. Re-evaluation of the nutrient budgets in the Red Sea indicates a net flux of inorganic combined nitrogen, estimated to be 0.74 Tg N/y, out of the Red Sea over the amount added from the Gulf of Aden. It is suggested that this anomaly represents the amount of nitrogen fixation, largely through *Trichodesmium* bloom, which may contribute up to 6% of the total primary production in the Red Sea.

The procedures followed for estimating expected nitrate in the Arabian Sea were evaluated. A modified method involving the stoichiometric model was used. Additionally, a novel procedure, which eliminates errors inherent in previous methods, was developed. This technique is based on the observed linear relationships between the property NO (defined as $O_2 + 8.65 NO_3$) and potential temperature outside the denitrification zone in the Arabian Sea, and their application to the estimation of expected nitrate within the denitrifying layer. Several vertical sections of nitrate deficits are

presented and discussed in my thesis. The distribution of nitrate deficits is characterized by large spatial and temporal variabilities. The southern boundary of denitrification appears to oscillate between 12° and 14°N. In the western Arabian Sea, where intense upwelling occurs during the southwest monsoon, the southern boundary could shift to 18°N, implying quick renewal of waters derived from outside the denitrification zone to compensate for the vertical advection. Nitrate deficits integrated over the entire water column exhibited a northward increase, consistent with increases in the thickness of the oxygen minimum layer. However, peak values of the deficits were not observed within or near zones of high biological productivity, i.e., off the Indian and Arabian coasts. This is attributed to increased renewal along the eastern and western boundaries. Evidence for large short-term variability in denitrification is provided from the distribution of integrated deficits.

The rate of denitrification in the Arabian Sea was computed from exports of nitrate deficits out of the denitrification zone. The horizontal advective losses were calculated by combining the nitrate deficits with dynamic calculations based on observations along 15°N. Advective transports through the upper boundary were estimated from the reported rate of upwelling off Arabia. Diffusive losses through the upper, lower, and southern boundaries were deduced from the average gradients of the deficits at these boundaries and published values of diffusion constants. The results indicate that the horizontal processes are responsible for removal of the bulk (> 85%) of the nitrate deficits from the denitrifying layer.

The rate of denitrification in the Arabian Sea was estimated to be 29.5 T gN/y. This is at least an order of magnitude higher than previous estimates. Combining this value with the estimated "standing crop" of denitrified nitrogen (115 Tg), the average renewal time of the intermediate layer is approximately 4y. This indicates that the old belief that waters within the main thermocline of the Arabian Sea were highly stagnated is not valid. The short renewal time is consistent with the observed short-term variability in denitrification. It also indicates that the oxygen-deficient reducing layer in the Arabian Sea is an unstable time variable feature, and that the acute deficiency in oxygen is primarily due to excessive consumption.

The high rate of denitrification deduced for the Arabian Sea would require scaling-up of global water-column denitrification estimates by about 50%. This will further increase the apparent anomaly in the marine combined nitrogen budget (excess of net losses over net inputs) close to 100 Tg N/y. It is suggested that the anomaly results largely from erroneous estimates of oceanic nitrogen fixation. This is supported by the high rate of nitrogen fixation deduced for the Red Sea.