ABSTRACT

Nitrogen plays a key role in oceanic productivity and hence its unavailability can be a limiting factor. The present work uses nitrogen as a tool to estimate primary productivity of different parts of the Indian Ocean and thus assess its role in Global Carbon Cycle.

As the oceans play a major role in the global carbon cycle, it is required to quantify the amount of inorganic carbon taken up by the individual ocean basins. Also the assessment of different ocean basins as source/sink of carbon is important. The present study was carried out using the ^{15}N tracer technique which gives total production as a sum of new production (nitrate uptake) and regenerated production (ammonium and urea uptakes). The advantage of this technique lies in the quantification of new productivity which is a measure of carbon removed from the surface for significantly longer time periods (>1000 yrs). The present work is a comprehensive study of primary productivity in different regions of the Indian Ocean such as the Arabian Sea, equatorial Indian Ocean and Southern Indian Ocean. Though some study has been carried out previously in some selected parts of the Arabian Sea, most of them are concentrated on the north-western and central Arabian Sea. No study has been done in the equatorial Indian Ocean and Southern Indian Ocean. The present study concentrates on the north-eastern Arabian Sea and is the *first* to measure primary productivity in the *equatorial Indian* and *Southern Indian Oceans*.

The biogeochemistry of the Arabian Sea, one of the most biologically productive regions of the world ocean, is driven by seasonally reversing southwest and northeast monsoons; both the monsoons trigger high primary production but the underlying mechanisms are different. Results from the present study suggest that the Arabian Sea is characterized by the presence of two different biogeochemical provinces during the late winter monsoon: low productive southern province and highly productive northern province with an overall increasing trend from the south to the north. Total productivity in the southern region averaged around 5.5 $mmolNm^{-2}d^{-1}$ (440 $mgCm^{-2}d^{-1}$) whereas in the north it was 19 $mmolNm^{-2}d^{-1}$ (1520 $mgCm^{-2}d^{-1}$);

increase in productivity from the south to north was more than three fold. New productivity also increased on south-north transect, from 2.1 $mmolNm^{-2}d^{-1}$ (168 $mgCm^{-2}d^{-1}$) in the south to 15.7 $mmolNm^{-2}d^{-1}$ (1256 $mgCm^{-2}d^{-1}$) in the north. Increase in new productivity was more than 7-fold. The column integrated total production (x) and new production (y), show a significant correlation (Fig.2): for non-bloom stations: $y = (0.44 \pm 0.23)\,x - (0.30 \pm 1.38)$ (coefficient of determination, $r^2 = 0.43$); and for bloom stations, $y = (1.08 \pm 0.23)\,x - (4.68 \pm 4.46)$ ($r^2 = 0.91$). The slope of regression (i.e., 0.44 and 1.0 for non-bloom and bloom stations respectively) is the maximum possible value of the *f*-ratio.

During the early winter monsoon total productivity varied from 4.07 $mmolNm^{-2}d^{-1}$ (326 $mgCm^{-2}d^{-1}$) to 23.31 $mmolNm^{-2}d^{-1}$ (1865 $mgCm^{-2}d^{-1}$) with a mean of 8.65 $mmolNm^{-2}d^{-1}$ (692 $mgCm^{-2}d^{-1}$). Productivity during this season was almost half of that during the bloom but was more than the productivity in the south during the late winter monsoon. New productivity showed a large variation; it varied from a low of 1.95 $mmolNm^{-2}d^{-1}$ (156 $mgCm^{-2}d^{-1}$) to a high of 19.70 $mmolNm^{-2}d^{-1}$ (1576 $mgCm^{-2}d^{-1}$). The *f*-ratio varied from 0.46 to 0.87. This suggests that 46-87% of the total productivity can be exported to the deep under a steady state condition. Relation between total and new productivity yielded a slope of 0.88 which suggests that at most 88% of the total productivity can be exported. Above results from the two seasons suggests that productivity in the Arabian Sea is heterogeneous in space and time but still this basin is capable of high export production and thus plays a significant role in global carbon cycle.

The first result from the equatorial Indian Ocean suggests that total N-uptake is very less in this basin: it varied from 0.66 $mmolNm^{-2}d^{-1}$ to 2.23 $mmolNm^{-2}d^{-1}$ in the pre-monsoon season. The mean N-uptake was 1.32 $mmolNm^{-2}d^{-1}$ (105.6 $mgCm^{-2}d^{-1}$). New production along 77°E transect was 0.20 $mmolNm^{-2}d^{-1}$ (16 $mgCm^{-2}d^{-1}$), almost half of the same 0.43 $mmolNm^{-2}d^{-1}$ (34.4 $mgCm^{-2}d^{-1}$) along 83°E transect. Urea was the most preferred from of nitrogen for phytoplankton followed by ammonium. Nitrate was the least preferred. The *f*-ratio was also very low though it showed considerable spatial variation: it varied from 0.14 to 0.40. The *f*-ratio was low (mean = 0.18) along 77°E transect but was relatively high (mean = 0.29) along

83°E. In the equatorial Indian Ocean upper mixed layer had greater control on the productivity; since this layer was devoid of any nutrients, the productivity was less. Also due to strong stratification the export production was low.

The first comprehensive estimates of nitrogen based productivity from a large area in the Southern Indian Ocean suggest that Antarctic coastal zone, STF and equatorial Indian Ocean was relatively more productive than other parts of the Southern Ocean. Euphotic zone integrated total N-uptake rate varied from 1.73 $mmolNm^{-2}d^{-1}$ (138 $mgCm^{-2}d^{-1}$) to 12.26 $mmolNm^{-2}d^{-1}$ (981 $mgCm^{-2}d^{-1}$) in the Southern Indian Ocean; the highest rate was measured in the Antarctic coastal zone (69°S). New productivity varied from 0.92 $mmolNm^{-2}d^{-1}$ (73.6 $mgCm^{-2}d^{-1}$) to 7.7 $mmolNm^{-2}d^{-1}$(616 $mgCm^{-2}d^{-1}$). The Antarctic coastal zone, equatorial region and STF had more new production compared to other regions of the Southern Ocean. The mean Column N-uptake rate at two equatorial stations sampled during this study was ~8 $mmolNm^{-2}d^{-1}$. The *f*-ratio was almost the same (0.45) at both stations. Though a large part of the southern Ocean, HNLC region, is less productive, it can have high export production, almost 50% of the total. The *f*-ratio varied from 0.27 to 0.63 in the Southern Ocean with a mean of 0.50 and with an upper limit of 0.63. Compared to other data from similar regions the present study shows a shift in productivity regime from regenerated nutrient based production to nitrate based production. This means a slightly greater export production in this region than before. Again, a significant correlation between total and new productivity can provide a significant input for the estimation of carbon fluxes over a large region using satellite data.