

Primary Productivity of the Arabian Sea

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Abstract

Reversal of surface circulation during the monsoons, patchy nutrient distributions and high light intensity drive phytoplankton production processes in the tropical Arabian Sea. Available data are discussed in the light of these driving phenomena with particular reference to nutrient limitation and the effect of high light intensity on extracellular production by phytoplankton and the fate of such products in the sea. An attempt is made to relate production rates with zooplankton biomass and fishery potentials in this region.

INTRODUCTION

The Arabian Sea extends from the coast of Africa in the west to the Indian coast in the east and from about 25°N to just south of Goa. The sea has a surface area of 3.8×10^6 km² and an average depth of 2700 m. This region of the Indian Ocean is an area of negative water balance where annual evaporation exceeds precipitation particularly in the region off the Arabian Peninsula where deficit values greater than 100 cm yr⁻¹ may occur (Venkateshwaran 1956). This leads to high salinity surface water in the northern and central Arabian Sea to a depth of 125 m ($\Sigma_t = 25.0$). This depth also encompasses the euphotic zone, where phytoplankton growth is expected to occur. Thorning-Smith (1971) has attempted to classify phytoplankton in the entire Indian Ocean region according to their major hydrological distributions.

Among factors that affect phytoplankton distributions and productivity in the Arabian Sea, the first is temperature of the seawater and, consequently, thermohaline circulation. As seen from the variation in surface isotherms in Figs. 1A, B and C the temperature ranges from 25°C in November to less than 28°C in May although the lowest surface temperatures are found in August particularly off Somalia and Southern Arabia in August with the establishment of the upwellings in these regions.

Using temperature and salinity data surface circulation of the Arabian Sea (Figs. 2A & B) shows the monsoon reversal typical of the northern Indian Ocean. In February-March there is a southerly flow off Somalia and a series of gyres in the Arabian Sea and Bay of Bengal. By August the monsoon winds drive a northerly flow off Somalia and a strong southerly flow off the west coast of India. The Somali and Arabian coast upwellings are established by June of most years followed by an upwelling off the southwest coast of India by July/August.

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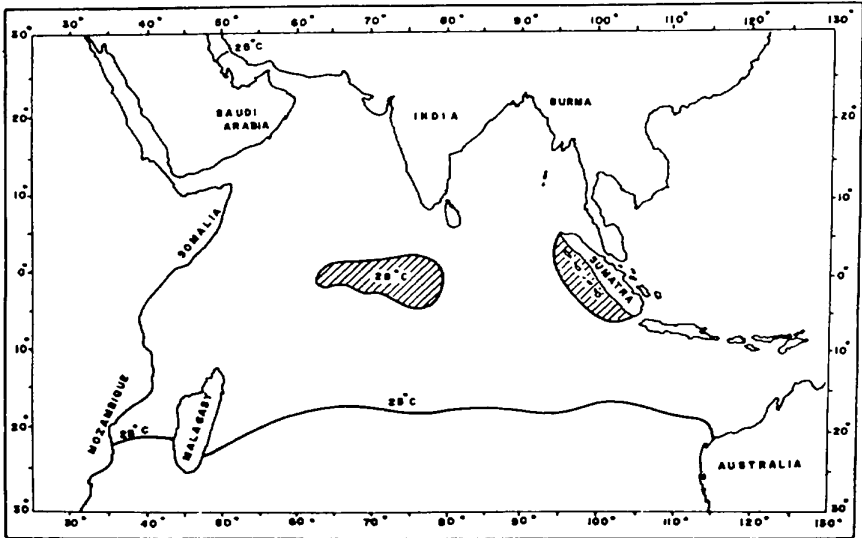


Fig. 1A. Distribution of surface isotherms in November. Source: Tchernia (1980).

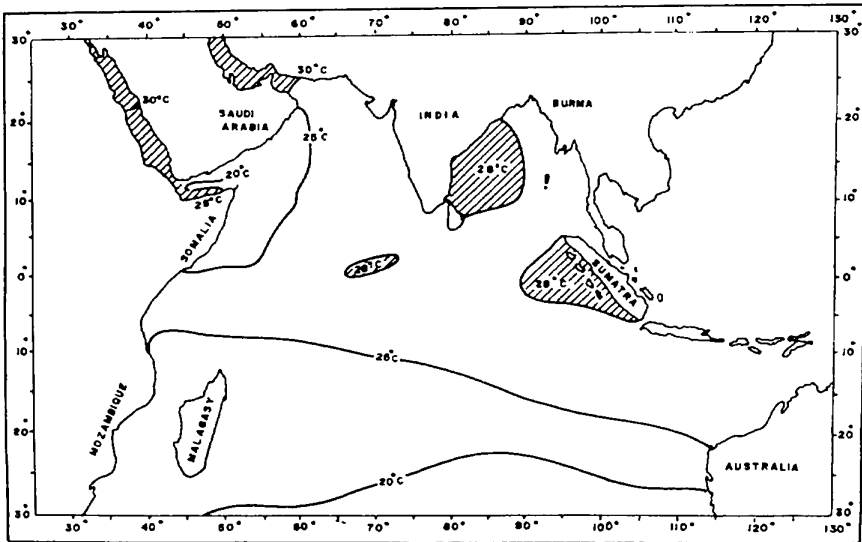


Fig. 1B. Distribution of surface isotherms in August. Source: Tchernia (1980).

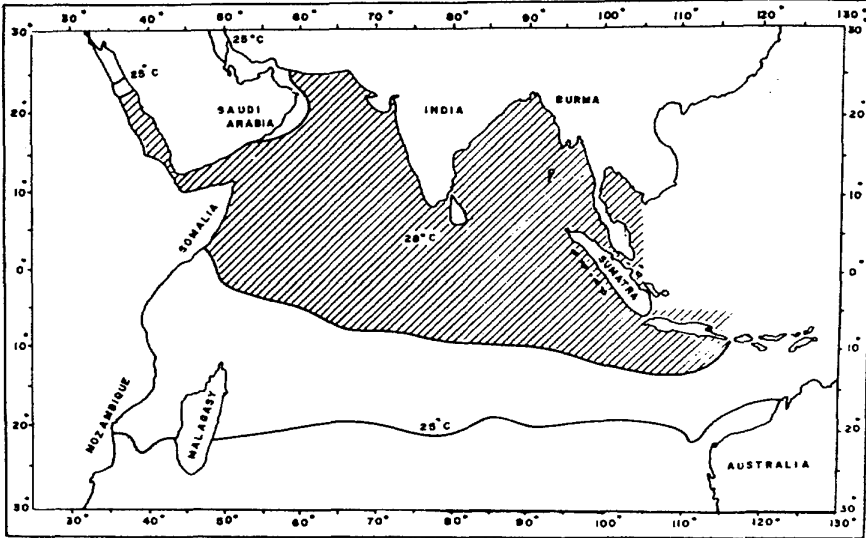


Fig. 1C. Distribution of surface isotherms in May. Source: Tchernia (1980).

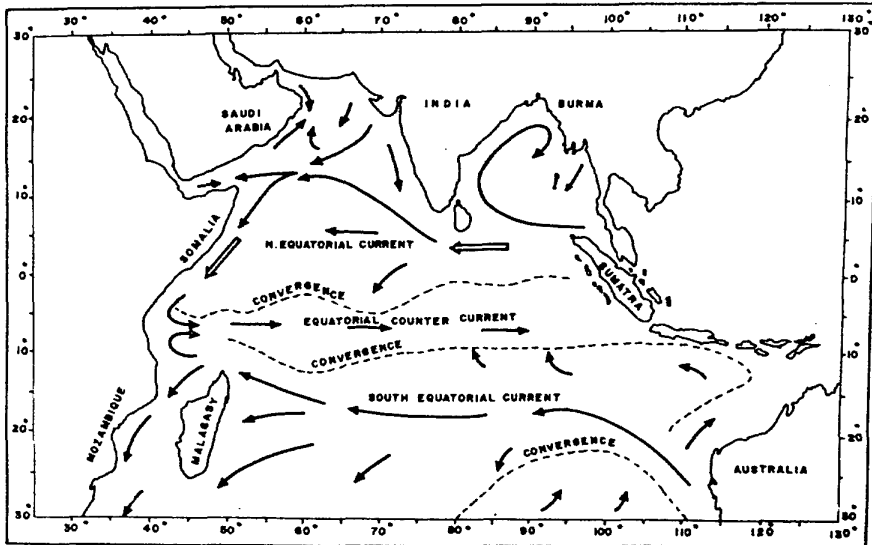


Fig. 2A. Direction of surface currents from February-March.

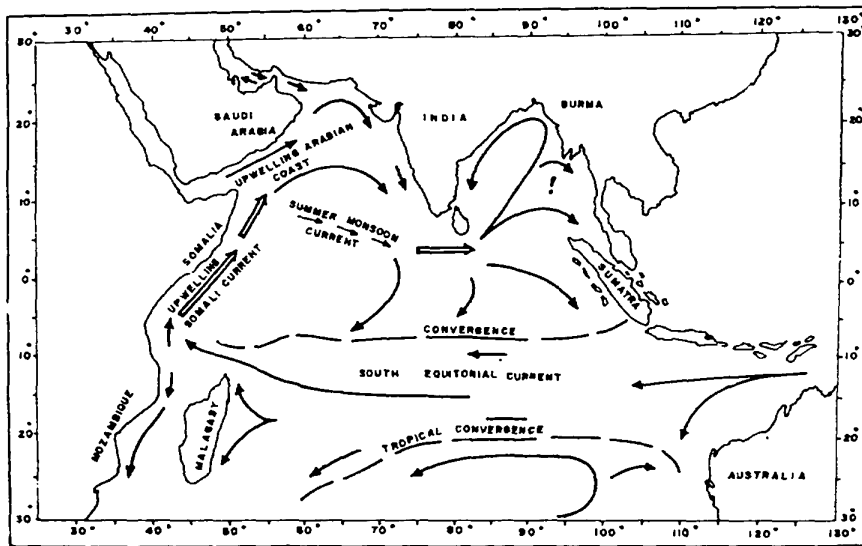


Fig. 2B. Direction of surface currents from August-September.

These data led Wrytki (1973) to identify 3 zones in the Indian Ocean; (1) the seasonally changing monsoon gyre north of 10°S, (2) the central Indian Ocean anticyclonic gyre characterized by low nutrient content waters and low primary productivity, and (3) Antarctic circumpolar water with very high nutrients and high productivity.

The distributions of the major macro-nutrients, $\text{NO}_3\text{-N}$ and $\text{PO}_4\text{-P}$ (Figs. 3A & B), in the surface 100 m of the Indian Ocean show a significant positive correlation with regions of high productivity. Phosphate-P values vary from 0.2 $\mu\text{M/l}$ to 1.0 $\mu\text{M/l}$ and are high at river mouths and in coastal areas but $\text{NO}_3\text{-N}$, except for the very high values in the northern Bay of Bengal (Fig. 3A), is undetectable in the surface layers and has been earlier considered limiting to primary production, at least in the Arabian Sea. Once the upwelling systems off Somalia and the Arabian coast are established, surface $\text{NO}_3\text{-N}$ may reach 10 $\mu\text{M/l}$ and $\text{PO}_4\text{-P}$ upto 2 $\mu\text{M/l}$ (McGill 1973) with consequent high primary production. Recent evidence (Wafar *et al.* 1986) indicates other nitrogenous compounds such as urea, ammonia and nitrite are also readily absorbed by tropical phytoplankton and a close coupling between zooplankton-excreted nitrogen and phytoplankton productivity within the oceanic well-mixed layer may determine local primary productivity. Below the thermocline, $\text{NO}_3\text{-N}$ values rise rapidly upto 25 $\mu\text{M/l}$. In most cases in the Arabian Sea the mixed layer coincides with the euphotic zone and phytoplankton growth is limited by nutrient availability.

The third variable influencing phytoplankton productivity and distribution is light intensity. On clear days noon intensities of upto 600 $\text{g Cal/m}^2/\text{day}$ have been recorded (Qasim *et al.* 1968), although an average value lies closer to 400 $\text{g Cal/m}^2/\text{day}$. In the monsoons with their heavy cloud cover intensities upto 270 $\text{g Cal/m}^2/\text{day}$ are common, and available light, particularly at the surface

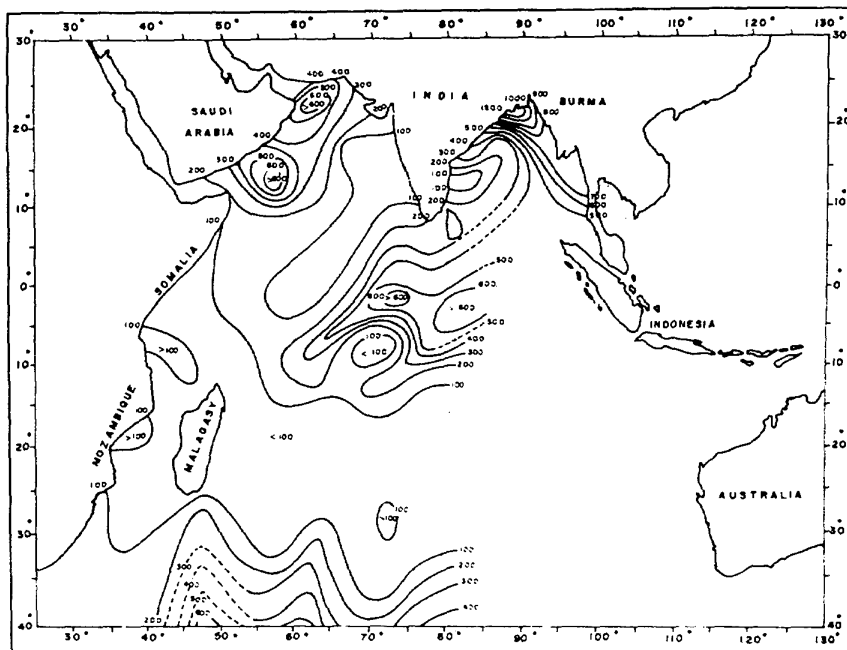


Fig. 3A. Distribution of nitrate-N in 100 m water column from surface. Integrated values in mg-at/m^2 . Source: Qasim (1977).

is inhibitory in most cases. The euphotic depth, defined as the depth to which 1 per cent of surface light penetrates, varies from 10 m nearshore to greater than 100 m in the central gyre (Fig. 4), although shallow euphotic zones have also been noted occasionally in the open ocean generally associated with *Trichodesmium* blooms.

The effect of inhibiting surface intensity is reflected in the non-homogenous vertical distribution of phytoplankton (Fig. 5). Both chl *a* and ATP show pronounced subsurface peaks and this is also true of photosynthetic carbon assimilation. The data of Wafar *et al.* (1986) suggests that the stimulation of carbon assimilation in oceanic samples by added nitrogen in the forms of nitrate, nitrite or ammonia is less at the surface than in subsurface samples due to inhibiting surface intensity. Thus, as is expected, availability of light and inorganic or organic nitrogen determine phytoplankton distribution and productivity and this is also true of phytoplankton exudation.

As shown in Table 1, phytoplankton exudation is high at the surface and decreases with decreasing available light at greater depths in the water column. The high standard deviations in the distribution of both chl *a* and exudation values reflect the patchy distributions of organisms, and the difference in mean values of both variables although not statistically significant are real. In near-shore regions such as the estuary of the Zuari river and Dona Paula Bay ($15^{\circ}30'N$ $72^{\circ}45'E$) where phytoplankton are not limited by nutrient concentrations, there is a seasonality in extracellular

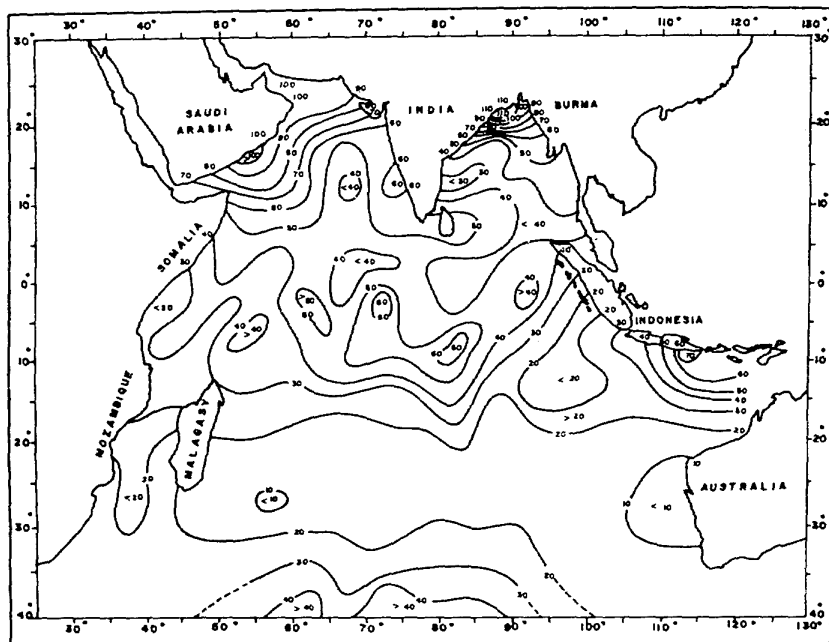


Fig. 3B. Distribution of phosphate-P in 100 m water column from surface. Integrated values in mg-at/m^2 . Source: Qasim (1977).

production both in quantity and quality. Shailaja & Pant (1986) have shown that in premonsoon April/May (Table 2) total extracellular production is high and glycollate forms almost 30 per cent of the exudate whereas in June/July extracellular production is less, probably due to decreased light intensity and change in phytoplankton species in the Bay, and amino acids and sugars form a significant part of exuded materials. Thus the seasonal rainfall changes assemblages of natural phytoplankton communities and influences both particulate and extracellular production in near shore localities.

TABLE 1. Particulate and extracellular production per unit of chl *a* at different depths within the euphotic zone

Iz	Particulate prodn/chl <i>a</i> /hr	Extracellular prodn/chl <i>a</i> /hr
I100%	1.44 ± 1.00	0.65 ± 0.64
I60%	2.54 ± 1.71	
I30%	1.5 ± 1.00	0.23 ± 0.28
I16%	1.22 ± 1.00	
I1%	0.37 ± 0.31	0.02 (negligible in most cases)

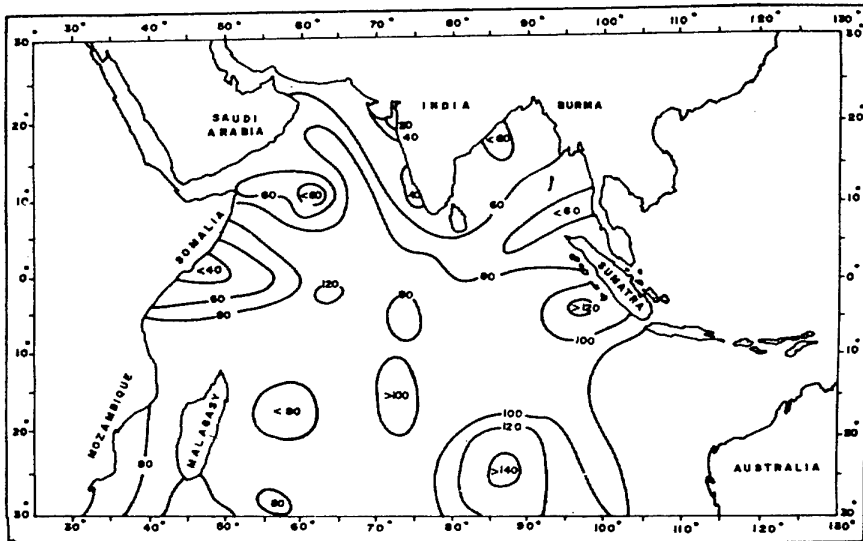


Fig. 4. 1% of surface illumination. Isolines join points of equal euphotic depths.
Source: Qasim (1977).

TABLE 2. Surface particulate and extracellular production in two tropical environments

	Arabian sea	Dona Paula	
		Pre-monsoon	Monsoon
Particulate prodn/chl <i>a</i> /hr	1.44	2.0	3.4
Extracellular prodn/chl <i>a</i> /hr	0.65	0.61	0.14
Extracellular prodn as % of total fixation	45	25	4

Although exudates represent a loss of energy of phytoplankton, they form a link between algae and bacteria as shown by work in temperate seas (Bell & Sakshaug 1980; Lancelot 1979). Recent information from tropical Dona Paula shows that 80 per cent of the exuded material is taken up by bacteria, irrespective of season. Of this uptake almost two thirds is retained in bacterial biomass the rest being respired. In comparison with temperate systems, tropical estuaries such as Dona Paula show a greater percentage of bacterial uptake and faster uptake rates. Bacterial particulate production comprises an average 30 per cent of phytoplankton carbon assimilation in the Dona Paula Estuary — and pelagic Arabian Sea values are likely to be similar.

The distribution of year-round averages of primary particulate production in the Arabian Sea support Wrytki's (1973) division of the Indian Ocean into the northern monsoonal-gyre area with high nutrients and production, the central gyre which is characterized by low nutrients and production, and the rich southern region with high nutrients and production in the Antarctic Ocean.

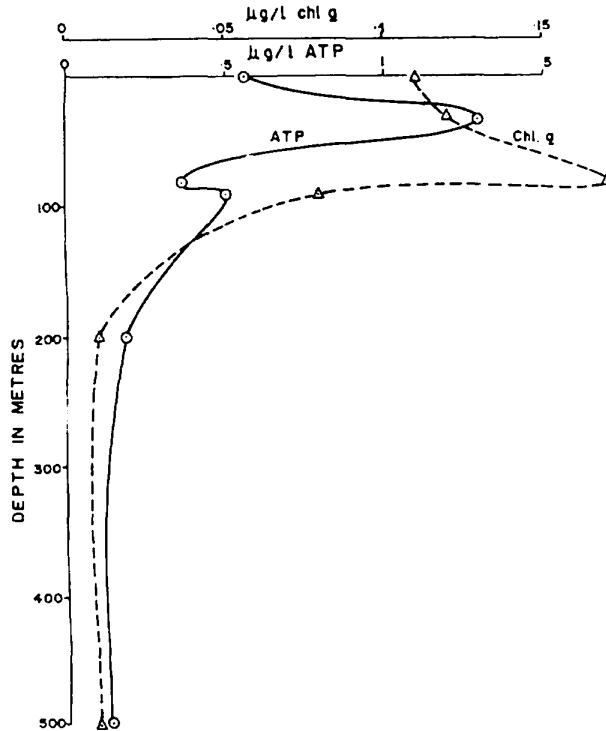


Fig. 5. Depth distribution of ATP and chlorophyll *a* at a representative station in the Northern Arabian Sea.

Koblentz Mishke *et al.* (1970) have summarized that the over all year round production of 222 mgC/m²/day in the Indian Ocean is twice that in the Pacific and 1.2 times that in the Atlantic oceans. In the tropical regions of the Indian Ocean, particularly along the Indian coast, year-round averages of high production match similar chl *a* distributions (Figs. 6A and B). There is, however, a considerable variation in primary production with season.

As shown in Figs. 7A, B and C premonsoon values of production seldom exceed 600 mgC/m²/day and the open ocean average is 190 mgC/m²/day in the monsoons, on the other hand, the range is from 500 to 1000 mgC/m²/day with high values in the upwelling regions such as the southwest coast upwelling off the Indian coast. During all three seasons, however, the areal distribution of primary production is patchy. Considering the positive correlation between nutrients and phytoplankton and chlorophyll *a* and primary production it is of interest to examine the reasons for the observed patchiness.

In the nitrogen-limited surface waters of the Arabian Sea any process that adds nitrogen to the euphotic layers will increase production. In the first instance land run-off or river discharge leads to pockets of high production near the coasts. The second reason for the patchy distributions is the

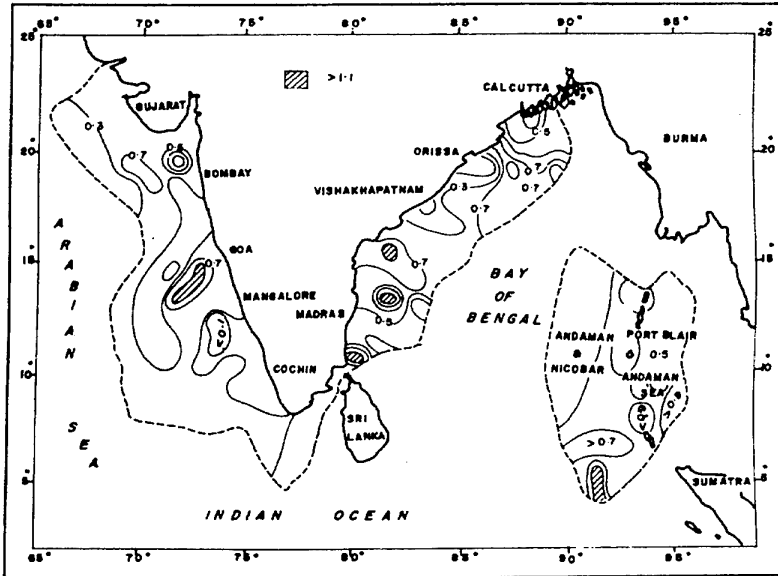


Fig. 6A. Primary production in the euphotic zone (column) of the Indian Ocean. Source: Qasim (1977).

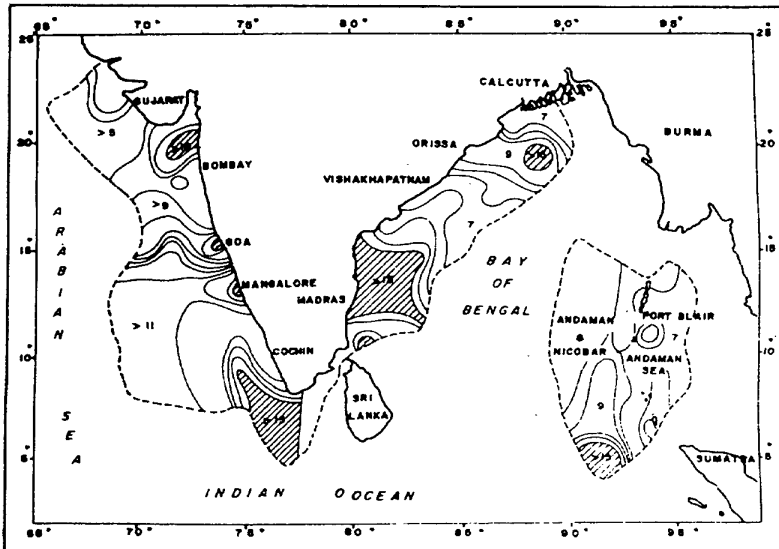


Fig. 6B. Chlorophyll *a* in the euphotic zone (column) of the Indian Ocean. Source: Qasim (1977).

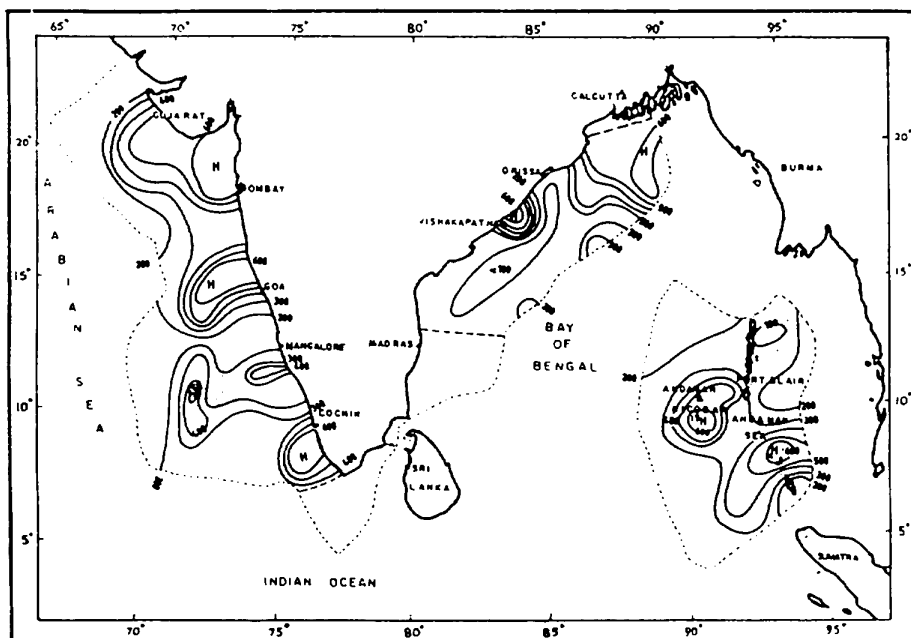


Fig. 7A. Primary productivity column in $\text{mgC}/\text{m}^2/\text{day}$ during pre-monsoon (February-May).

establishment of the major systems such as the Somali and Arabian coast upwelling where vertical velocities of water movement are in the range of 7×10^{-3} cm/sec (Swallow & Bruce 1966). The replacement of nutrient-poor surface water with subsurface water of high phosphate-P and nitrogen-N results in an upsurge of productivity. A third causative factor is the occurrence of large patches of *Trichodesmium* from December to April in the Arabian Sea. The decay of these blooms can cause the addition of upto $260 \mu\text{M}/\text{m}^2$ of $\text{NO}_3\text{-N}$ and $1200 \mu\text{M}/\text{m}^2$ of $\text{PO}_4\text{-P}$ (Devassy *et al.* 1979) and it is not surprising that a number of other algae and zooplankton succeed the blooms.

Recent evidence suggests the existence of mesoscale eddies in the Arabian Sea during the north-east monsoon between December to February. The data of Varma *et al.* (1980) and Das *et al.* (1980) show alternate surface flows derived from calculations of dynamic topography and Gopal Krishna *et al.* (1987) have calculated vertical flows of 10^{-4} cm/sec or less in such upwelling and downwelling areas which are much less than the strong southwest monsoon systems. Cyclonic circulations which add subsurface nutrients to the euphotic zone, result in higher production. Numerical abundance of zooplankton correlates well with mesoscale eddies (Madhupratap & Haridas 1986) in the Bay of Bengal, Andaman sea and the central Indian Ocean.

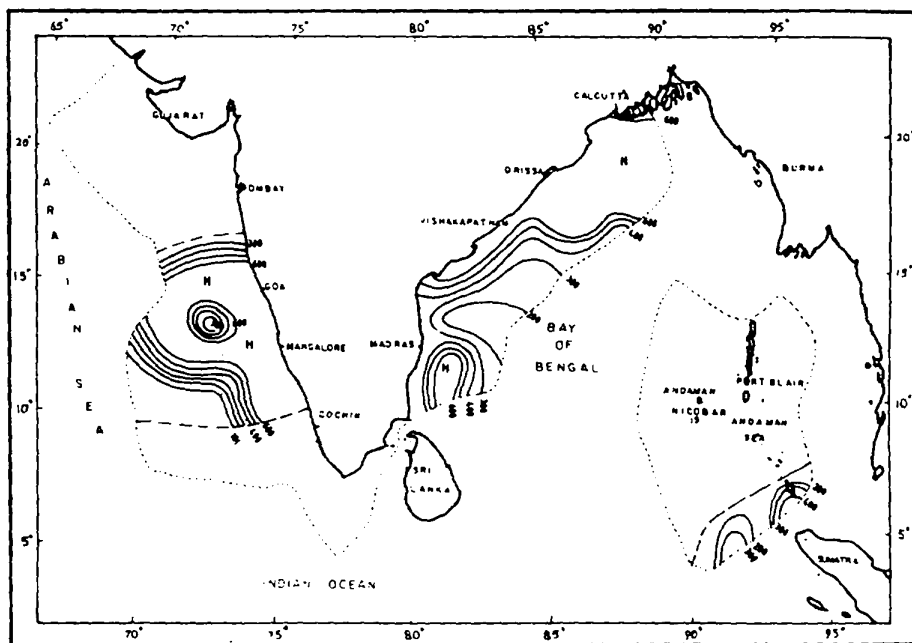


Fig. 7B. Primary productivity column in $\text{mgC}/\text{m}^2/\text{day}$ during monsoon period (June-September).

The yearly average of zooplankton production (Fig. 8) shows a close coincidence with similar primary productivity averages as is expected. Secondary production ratios (Moiseev 1971) and an observed generation time of 14 days together with pooled zooplankton data show a calculated zooplankton production rate of $4 \text{ mgC}/\text{m}^2/\text{day}$. In the area off the southwest coast of India which supports 75 per cent of the total pelagic fish landings of the country, very high production rates of between 20 to $40 \text{ mgC}/\text{m}^2/\text{day}$ have been reported (Qasim 1977).

Potential fish catch calculated from the primary and secondary production values given above and linear food chain models of the type phytoplankton-zooplankton-fish result in values between 11 million (Prasad *et al.* 1970) to 17 million tonnes per annum (Qasim 1977) in the Indian Ocean. The present catch is about 3.6 million tonnes and has remained at this level for the last 6 years indicating that presently used fishing techniques have reached saturation level. Any further increase in yield must depend on modified fishing such as mid-water trawling or other methods. In any case, the current levels of exploitation represent less than one third the projected catch in the Indian Economic Zone at the minimum estimate, and suggest that the actual yield may be doubled without harm to the ecosystem.

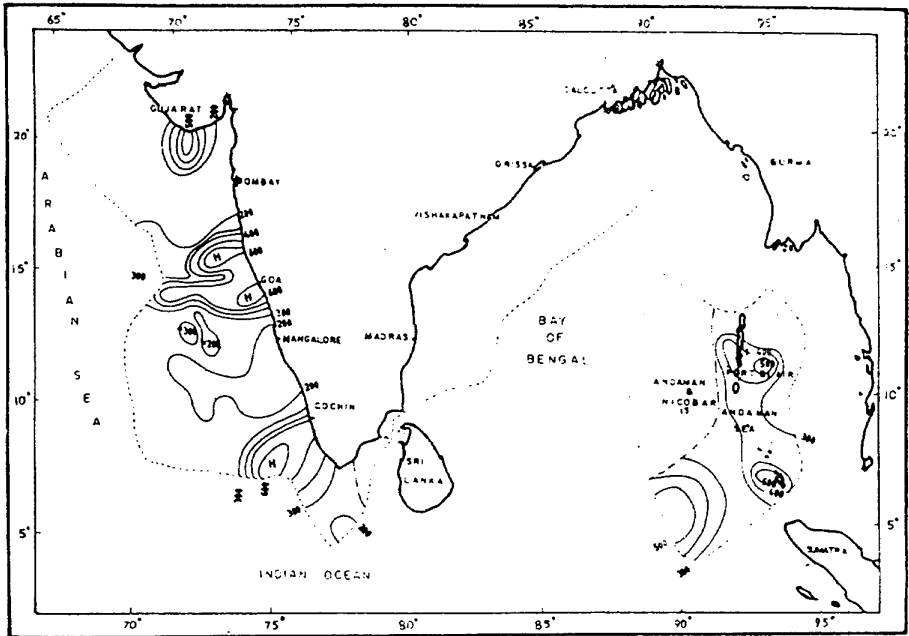


Fig. 7C. Primary productivity column in $\text{mgC}/\text{m}^2/\text{day}$ during post monsoon period (October-January).

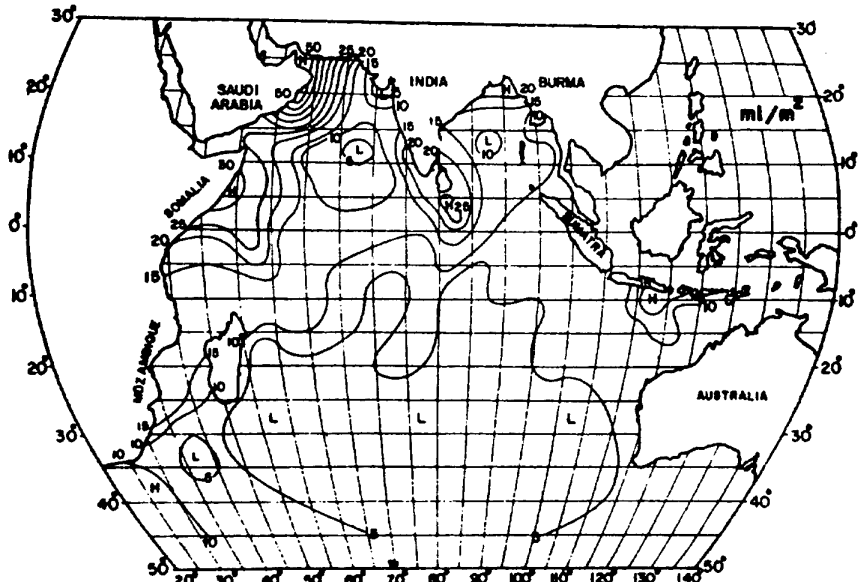


Fig. 8. Zooplankton biomass (ml/m^2) covering the full year based on day and night samples. Source: Qasim (1977).

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