

Biological diversity in the seas around India: Present status and major threats

S Z QASIM and T W KUREISHY*

Department of Ocean Development, Lodi Road, New Delhi 110 003, India

*National Institute of Oceanography, Dona Paula, Goa 403 004, India

Abstract. The seas around India (Arabian Sea and the Bay of Bengal, including the Laccadive and Andaman Seas) form the exclusive economic zone of the country. In terms of the general oceanographic features, these regions of the northern Indian Ocean have several unique features which have a marked influence on productivity processes governing the floral and faunal distribution and abundance. The biological diversity of phytoplankton, zooplankton, benthos and fisheries have been dealt with in brief in this paper, but the other ecosystems namely the seaweeds, mangroves and coral reefs have not been attempted because of maintaining brevity of the article. The different groups of marine flora and fauna have been described in the light of their general distribution, production processes and yields. The paper attempts to include conservation measures of fishery in some regions and indicates the need for management policies because of intensive fishing activities in some States.

Certain types of man-made pollution are affecting the marine environment and particularly the coastal regions. Special mention may be made of 'oil pollution' particularly along the west coast of India in the light of 513 million tonnes of oil being transported across the Arabian Sea every year. Other pollutants such as, sewage, heavy metals and pesticides also affect the marine environment in varying degrees. The current status of marine pollution of the coastal waters of India calls for constant vigil and monitoring in order to keep our seas clean.

Keywords. Biological diversity; phytoplankton; zooplankton; benthos; fishery management; marine pollution.

1. Introduction

While evaluating the biological diversity in the seas around India, it seems a difficult task to draw boundaries; for the marine ecosystems though divided into various ecological areas such as estuarine, coastal and open ocean, are somewhat interdependent on each other. Any attempt, therefore, to describe the biological diversity of one, must take into consideration the various processes governing the biological productivity of the different ecosystems. Hence in discussing the biological diversity certain important environmental parameters which have a direct impact on the assessment of biological productivity of the area have also to be incorporated.

The seas around India in the present context have been taken as the Arabian Sea, and the Bay of Bengal including the Laccadive and the Andaman Seas which form a large part of the exclusive economic zone (EEZ) of India. Some of the general hydrographic conditions and oceanographic features occurring beyond these regional boundaries have also been incorporated, because these have a marked influence on the biological productivity processes.

2. General hydrographical features of the area

The northern Indian Ocean covering the Arabian Sea and the Bay of Bengal has a peculiar asymmetric configuration which has given rise to unusual oceanographic phenomena such as the monsoon gyre within which large differences occur in the hydrographical and hydrochemical conditions largely regulated by the meteorological and geographical features characteristic of each region.

The Arabian Sea is bordered on the northern, eastern and western sides by the landmasses of Asia and Africa. It is connected with the Persian Gulf through the Gulf of Oman by a 50-m deep sill at the Hormuz Strait. Similarly, a 100-m deep sill at the strait of Bab-el-Mandab separates the Arabian Sea from the Red Sea through the Gulf of Aden. The total area of the Arabian Sea between latitudes 0° and 25°N and longitudes 50° and 80°E is about $6.225 \times 10^6 \text{ km}^2$ (Qasim 1977). It is an area of negative water balance where evaporation exceeds the total precipitation. It is maximum (100–150 cm per annum) off the Arabian coast and decreases steadily towards southeast. A slight excess of precipitation over evaporation ($> 20 \text{ cm}$) occurs annually off the southwest coast of India (Venkateswaran 1956).

The Bay of Bengal occupies an area of about $4.087 \times 10^6 \text{ km}^2$ between latitudes 0° and 23°N and longitudes 80° and 100°E (Qasim 1977). In contrast to the Arabian Sea, the Bay of Bengal is a region of positive water balance where precipitation and river runoff far exceed the evaporation. The annual excess of precipitation over the evaporation has been estimated to be about 70 cm.

A large number of rivers flow into the northern Indian Ocean. The annual runoffs from the Brahmaputra, the Ganga and the Irrawadi have been estimated to be 630, 490 and 440 km^3 , respectively (Baumgartner and Reichel 1975), and the contribution from the other rivers along the Indian coast is about 720 km^3/yr (Rao 1977). A value of 175 km^3/yr can be calculated from the Indus (Leopold 1962) bringing the total runoff from these rivers to about 2500 km^3/yr . If the contribution from all the other rivers, discharging into this region, is taken as 500 km^3/yr , in the absence of any reliable data, a total of 3000 km^3/yr is obtained. This represents about 9% of the total annual global river runoff of about 32,000 km^3 (Garrels and Mackenzie 1971). As the Arabian Sea, Bay of Bengal, Laccadive and Andaman Seas, combined together, occupy an area which is barely 3% of the total areas of the oceans (Sverdrup *et al* 1942), it can be concluded that the northern Indian Ocean receives thrice as much river runoff per unit area as compared to all the oceans put together. Evidently, the river runoff is not uniformly distributed throughout the northern Indian Ocean as the Bay of Bengal and the Andaman Sea receive much more runoff than do the Arabian Sea and the Laccadive Sea.

Solar heating and wind-induced turbulence produce a warm, isothermal, well-mixed surface layer throughout the region, generally 50–100 m in thickness. This layer is well oxygenated and is poor in inorganic micronutrients due to their utilisation by the photosynthetic organisms. Below the surface layers, a sharp decrease in temperature is observed. The feature, known as the thermocline inhibits any significant exchange of waters between the underlying and the overlying layers. As a result of high rate of organic production at the surface and limited ventilation below the thermocline, oxygen is severely depleted in the subsurface layers thus leading virtually to anaerobic conditions in a large body of water at the intermediate depths. This feature differentiates the northern Indian Ocean from most other oceans (Sen

Gupta and Naqvi 1984) and has a great impact on the primary productivity processes in these areas.

Along the Indian coast, the currents usually follow the general clockwise pattern during the southwest monsoon and anticlockwise pattern during the northeast monsoon. In January, when the northeast monsoon is at its peak, the currents flowing along the coastline have a southerly component on the east coast of India and a northerly component on the west coast of India. In June–July, as the southwest monsoon reaches its peak, the flow generally gets reversed (Varadachari and Sharma 1967). The coastal areas of the Arabian Sea have some major zones of upwelling during the southwest monsoon (Currie *et al* 1973). Off the Arabian Coast it is particularly observed to occur nearly 400 km offshore and flows parallel to the coast for nearly 1000 km. This area shows the maximum abundance of zooplankton in the Indian Ocean. Off the southwest coast of India, the upwelling starts much before the southwest monsoon and is reported to continue till September (Sharma 1968). This reportedly brings the 20° isotherm up by about 100 m resulting in the oxygen-depleted water to invade the shelf of the west coast. These changes favour the occurrence of very rich zooplankton and large shoals of fish particularly sardines and mackerel (Rao 1979). Along the east coast of India too, specially off the Vishakapatnam coast, some upwelling takes place which is associated with rich phytoplankton blooms (Murty and Varadachari 1968) even though the immense river runoff may partially compensate for the offshore drift of surface waters (Sen Gupta *et al* 1977).

These features play a very important role in governing the primary and secondary production rates in these areas. The other features governing the productivity patterns, such as the nutrient distribution in this region, have been extensively reviewed by Qasim (1982).

3. Primary production—Phytoplankton

The inorganic carbon is converted into organic compounds by many kinds of marine organisms using external sources of energy. Some pioneering work on the productivity measurements using radiocarbon technique in the Indian Ocean was done during the International Indian Ocean Expedition (IIOE) and subsequently during *R V Gaveshani* cruises. Based on the data from these two sources, Qasim (1977) had estimated a total of 4.42×10^9 tonnes of carbon/year being produced in this region. The other comprehensive work on the primary production of the Indian Ocean is that of Kabanova (1968) who has shown that the average surface production in the region is 3.5 mg C/m³/day in the winter and 30 mg C/m³/day in the summer. The average column production has been estimated to be 0.19 g C/m²/day in the open ocean in the winter and from 0.5–1.0 g C/m²/day in the summer. Qasim (1977), while summarizing the production levels in the euphotic zone (figure 1), and column production (figure 2), concluded that productivity of the Indian Ocean appears to be almost 75% higher than that of the Pacific and approximately 17% greater than that of the Atlantic.

The major factors affecting the production of organic carbon by phytoplankton are light, uptake and availability of nutrients and grazing by zooplankton and other organisms. The principal taxa of primary producers are diatoms, dinoflagellates, coccolithophores, silicoflagellates, blue-green algae and bacteria. In general, the

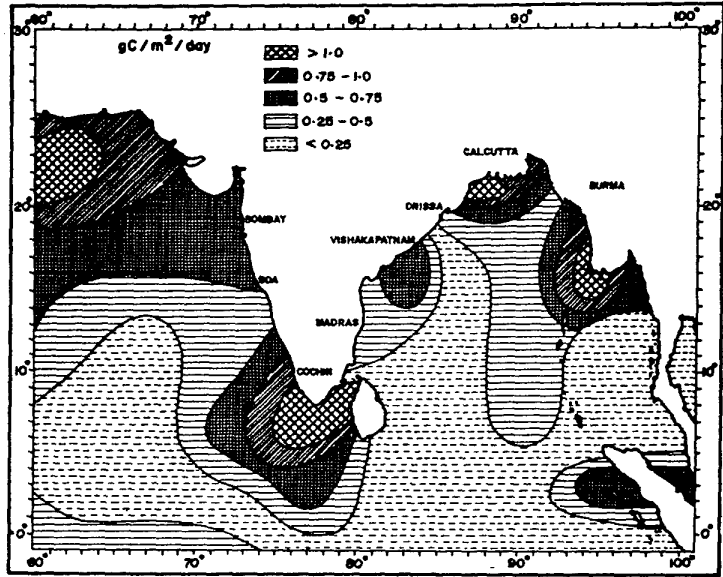


Figure 1. Rate of primary production in the euphotic zone (column) of the northern Indian Ocean. Source: Qasim (1977).

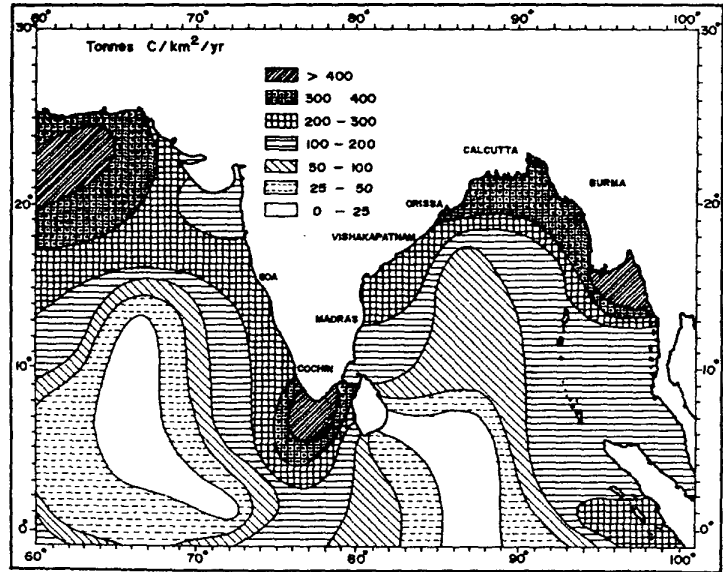


Figure 2. Annual levels of primary production in the column of water of the northern Indian Ocean. Source: Qasim (1977).

composition of phytoplankton in the sea water varies in time and space. Similar is the case with the Arabian Sea and Bay of Bengal. It is also known that generally phytoplankton abundance decreases from coastal to oceanic waters by several thousand cells per litre to a few hundred cells per litre. The fertility of sea water also affects the composition of phytoplankton with diatoms dominating the nutrient-rich coastal waters while dinoflagellates becoming more abundant in nutrient-impoverished oceanic waters.

In general, the information on the phytoplankton of the Indian Ocean is scanty. However, based on the work carried out by some of the workers during the IIOE, it can be concluded that a predominance of dinoflagellates exists in any particular phytoplankton collection. The total number of species established from these studies include dinoflagellates—55 sp, diatoms—35 sp, cyanophytes and other flagellates—100 sp. However, very few of these species occur everywhere. Based on the extensive work carried out in the Indian waters, Subrahmanyam and Sarma (1960) listed 37 phytoplankton organisms, reproduced by Krey (1973) and these have been given below, as mass forms in the Indian Ocean.

(a) Bacillariophyceae: *Asterionella japonica*, *Bacteriastrum hyalinum* var. *princeps*, *Biddulphia heteroceros*, *B. mobiliensis*, *Chaetoceros affinis*, *C. brevis*, *C. cinoressus*, *C. contortum*, *C. curvisetus*, *C. laciniosus*, *C. lauderii*, *C. lorenzianus*, *C. pelagicus*, *C. socialis*, *Coscinodiscus asteromphalus*, *C. oculus-iridis*, *Fragilaria oceanica*, *Guinardia flaccida*, *Lauderia annulata*, *Leptocylindrus danicus*, *Nitzschia seriata*, *N. sigma* var. *indica*, *Rhizosolenia alata*, *R. robusta*, *R. stouterfothii*, *Skeletonema costatum*, *Schroderella delicatula*, *Thalassiothrix frauenfeldii*, *T. longissima*.

(b) Dinophyceae: *Ceratium fusus*, *C. macroceros*, *C. tripos*, *Dinophysis caudata*, *Glennodinium lenticula* f. *asymmetrica*, *Noctiluca miliaris*, *Peridinium depressum*.

(c) Myxophyceae: *Trichodesmium erythraeum*

There is very little variation in the list of species from region to region and season to season, but the relative cell numbers may vary considerably. Krey (1973) classified the Indian Ocean region into different biogeographic units based on the predominance of the groups of species. These units are:

(i) Central areas of Arabian Sea and Bay of Bengal: Dinoflagellates along with cyanophytes dominate this region followed by diatoms and coccolithophores.

(ii) North-eastern region of Somali current: Diatoms dominate followed by cyanophytes.

(iii) Mozambique current region: Diatoms dominate followed by dinoflagellates and coccolithophores.

(iv) Equatorial current region: Dinoflagellates and coccolithophores dominate followed by diatoms and cyanophytes.

Among the areas mentioned above, the last 3 do not directly come under the purview of the present discussion. However, these areas do have a marked influence on the distribution of phytoplankton in the northern part.

The concentrations of phytoplankton in the regions such as the central area of the Bay of Bengal, or the central water mass of the Indian Ocean vary between the eutrophic (highly productive) to oligotrophic (low productivity). Andaman Sea and the Central part of the Arabian Sea are good examples where phytoplankton may vary from 500–1000 cells/litre. In some regions of the Andaman Sea, the concentration of phytoplankton may reach 6000 cells/litre. However, in the oligotrophic regions, this concentration may become below 500 cells/litre and sometimes may come to below 100 cells/litre.

4. Zooplankton

The distribution of zooplankton in the Arabian Sea and the Bay of Bengal can best be understood if we take almost the entire Indian Ocean with its various zoogeographic regions. These regions can conveniently be classified as the Arabian Sea and Bay of Bengal (limit placed at 10°N); equatorial region (between 10°–35°S), Somali current region, Agulhas current region, the entire Indian Ocean up to Subtropical convergence; and the Antarctic part of the Indian Ocean (Rao 1979). It may look a very large area not falling under the region under consideration, but as mentioned earlier and pointed out by Rao (1979), although these geographical areas are characterised by special faunal associations, they also share taxa with the adjacent areas. The boundaries between these regions offer no barriers, for the majority of the species which migrate or are brought within and out of these regions are largely dependent on the prevailing current patterns.

It is also seen that depending upon the various factors which limit the distribution of species such as the temperature and salinity, certain areas could best be delineated on the basis of communities of species rather than the indicator species. Rao (1979) points out that when we consider large areas, temperature becomes an important factor in limiting the species distribution, but in regions where temperature variations are minimal, salinity may act as a limiting factor.

The importance of southwest and northeast monsoons in the distributional pattern of zooplankton in the Arabian Sea and the Bay of Bengal cannot be overlooked and hence the various zoogeographic regions may be described in relation to the two monsoon cycles. There is a shift in the zooplankton population either to the east or to the west depending upon the prevailing monsoon or by its reversal. The Somali current transports both north and south of the equator, water masses from below. Its effect is further enhanced by the Mozambique and the Agulhas currents.

Distribution of zooplankton biomass is shown in figure 3 which has been taken from Rao (1979). In general the areas close to the northern Arabian Sea has the highest biomass. The other regions of high biomass are the southwest and southeast coasts of India and the area adjacent to Sri Lanka extending upto the equator. The northern Bay of Bengal also has moderately high values (15–20 ml/m²). The total zooplankton biomass for the Indian Ocean has been estimated to be about 5.19×10^9 tonnes/year (Prasad *et al* 1970). Based on the zooplankton biomass, secondary production rates have been computed and these are presented in figure 4 (Qasim 1977). The pattern is quite similar to the biomass distribution. However, almost the entire Bay of Bengal and southwest coast of India have a uniform rate of secondary production of 5–10 mg C/m²/day.

It is extremely difficult to attempt to describe the zoogeography of various species individually, hence the distributional pattern of various zooplanktonic group has been attempted by Rao (1979) for the entire Indian Ocean. The unique hydrographical conditions of the Bay of Bengal sustains peculiar associations of hydromedusae. The surface water of the Bay of Bengal has high temperatures and a decreasing salinity gradient from south to north because of the extensive freshwater discharge. Moreover, it lies above the relatively cold water of slightly > 19°C. Neritic species such as the cosmopolitan *Liriope tetraphylla* and *Cunina tenella* are widely distributed in these surface waters. Some of the other species from the Bay of Bengal such as *Pandeopsis scutigera*, *Phialucium condensum*, *Helgieirrata musifera* are found in the

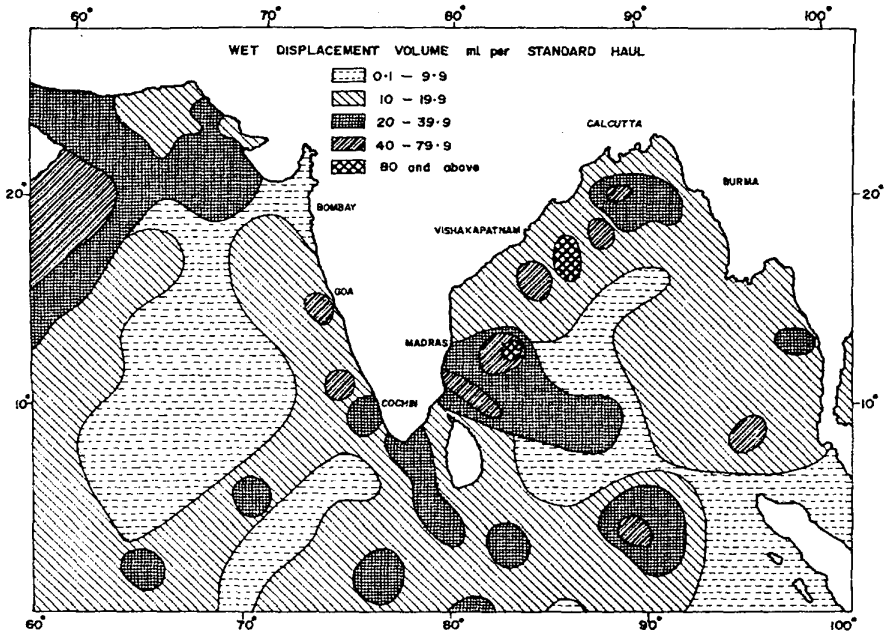


Figure 3. Distribution of zooplankton biomass in the northern Indian Ocean. Source: Rao (1979).

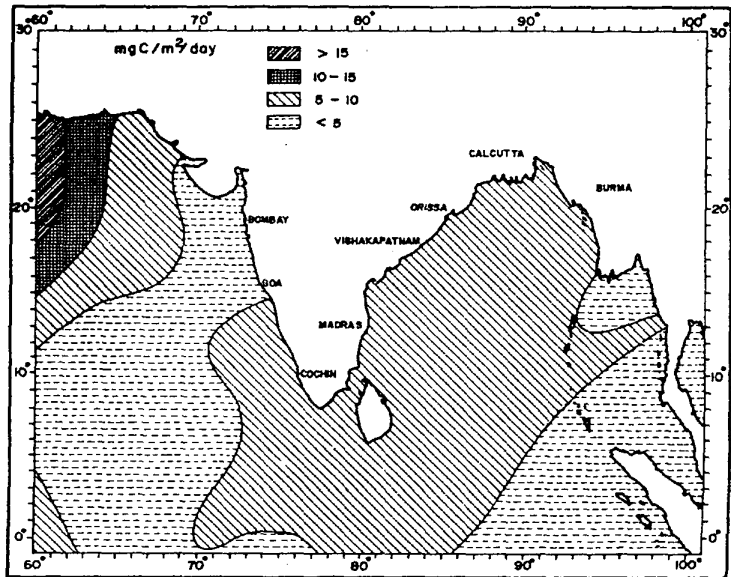


Figure 4. Secondary production in the northern Indian Ocean calculated from zooplankton biomass. Source: Qasim (1977).

coastal and estuarine areas of the Arabian Sea. However, the more abundant species in the Arabian Sea are *Aglaura hemistoma* and *Solmundella bitentaculata* (Vanucci and Navas 1973).

Distribution of Cladocera is found to be patchy and seasonal. *Evadne tergestina* has been found to occur in the central Arabian Sea during the inter-monsoonal period. In March and April, this species is found all over the Bay of Bengal. *E. spirifera* is observed in the northern Arabian Sea in May and November. *Penilia avirostris* is mainly found in the neritic waters of India.

The areas with the highest copepod densities occur over wide regions in the northern Arabian Sea. The Wadge Bank, the Gulf of Mannar, some areas off Madras, the northern Bay of Bengal including the Orissa coast and some patches along the equatorial regions also show high densities. The central Arabian Sea and many regions of the Bay of Bengal show low densities. It is also observed that during the northeast monsoon, the density of copepods is higher along the west coast of India than during the southwest monsoon when low densities are noted during the northeast monsoon and it is suggested that, though primary production values are the highest during the southwest monsoon, there is some time-lag in the appearance and assemblage of zooplankton populations (Rao 1979). It is indeed not possible to describe the distribution of the various species of Copepoda in the area under consideration as it would include nearly 60-70% of the various copepod species.

During the southwest monsoon, high densities of euphausiids have been observed off the Arabian coast and off Madras extending upto hundreds of miles offshore. Except for a small area of low density, the whole of the Bay of Bengal shows quite a high density for euphausiids. During the northeast monsoon, very low densities are observed off Bombay and Gujarat and also in the Bay of Bengal. In fact, the earlier high occurrence of this group totally disappears from the Madras area. Brinton and Gopalakrishnan (1973) indicated the characteristic presence of *Euphausia diomedea*, *E. distinguenda*, *Pseudeuphausia latifrons* and *Stylocheiron indicum* off the area north of 10° including the Bay of Bengal and the Arabian Sea.

Pillai (1973) characterised 36 species of mysid in the Indian Ocean. The chaetognath fauna is rich in the western Arabian Sea and in the whole of Bay of Bengal during the southwest monsoon. There is an apparent shift westward of the chaetognath abundance during the northeast monsoon with the result that high densities are observed along the west coast of India. The typically Indo-Pacific species like *Krohnitta pacifica*, *Sagitta bedoti*, *S. neglecta*, *S. pulchra* and *S. robusta* are mainly confined to the northern Indian Ocean (taken as north of 10°S).

The distribution of the planktonic molluscs resembles that of the copepods and chaetognaths because of the monsoonal changes. The appendicularians have a very different distribution.

Fenaux (1973) found 23 species of appendicularians in the Arabian Sea. In the Bay of Bengal, however, one or two species form the bulk, i.e. *Oikopleura longicauda* represents 50% of the total number collected. This was followed by *O. rufescens* 14% and *Megalocercus huxleyi* 8%. He also noted that starting with 21 species from the south, only 2 species remain in the northern part of the Bay of Bengal mainly because of the prevailing low salinity.

The account summarised above gives only the general pattern of distribution of the major group of zooplankton in the northern Indian Ocean. From this it can be concluded that the most fertile regions, where diversity is maximum, are the areas of divergence and upwelling.

5. Benthos

The relevance of benthic standing crop (macro and meio) in the assessment of the potential demersal and crustacean fisheries is by now a well established feature. Parulekar *et al* (1982) in an exhaustive review of the benthos have described in detail the biomass of both macro and meio benthos in the Indian seas. The annual benthic production is given in figure 5. The biomass in the Indian seas varies from 0.01–601 g^{-2} . The average biomass is 10.61 g^{-2} in the Arabian Sea, 7.32 g^{-2} in the Andaman Sea, 5.32 g^{-2} in the Bay of Bengal and the lowest 0.74 g^{-2} in the Lakshadweep Sea. The latitudinal variation in the biomass production shows a regional pattern. In the northern parts of the Arabian Sea and Bay of Bengal, the biomass shows a high mean values of 38.5 and 45 g^{-2} , respectively. These are followed by a decrease upto 19°N in the Arabian Sea and upto 15°N in the Bay of Bengal. Beyond this, while consistently high values of 15–30 g^{-2} are persistent in the southern parts of the Arabian Sea, a substantial decrease has been observed in the Bay of Bengal where values as low as 0.34 g^{-2} are commonly observed.

Macrofauna largely contributes to the standing crop of the northern part of the Arabian Sea and the Bay of Bengal. In other parts, the macrofaunal dominance decreases and meiofauna increases upto 6°N. In the overall area surveyed by Parulekar *et al* (1982) the meiofauna formed nearly 70% of the standing crop in all the regions except for the Bay of Bengal where its contribution was about 56%.

Depthwise contribution of macrofauna was 56% along the shelf while on the slope and in the deep sea, it is the meiofauna which forms 78–83%. Parulekar (1985) has given the standing crop of benthos in the different ecosystems as follows:

	Arabian Sea (g^{-2})	Lakshadweep Sea (g^{-2})	Bay of Bengal (g^{-2})	Andaman Sea (g^{-2})
Shelf	0.01–98.8	–	0.07–80.9	0.03–9.8
Slope	0.05–44.1	0.01–2.5	0.05–60.2	0.1–28.2
Deep	0.01–119.6	0.01–2.5	0.7–5.2	1.0–19.5

6. Fisheries

The commercially exploitable fisheries can be regarded as the final links in the food chain, starting from sun's energy and its conversion by plant communities into organic matter and ending up with exploitable fish, crustaceans and molluscs. The exploitable stocks are referred to as 'tertiary production' and they include the herbivores, and the 1st, 2nd and 3rd stage carnivores. From the standing stock it is possible to estimate the 'potential' and 'annual sustainable yield'.

Qasim (1977) had calculated the tertiary production as 0.1% of the primary production and the same has been given in figure 6. It comes to about 4.42×10^6 tonnes of carbon/year live or 44.2×10^6 tonnes of live weight/year. From this figure, he further calculated the potential yield from primary production as 15 million tonnes of harvestable resources/year.

Tertiary production can also be calculated as 10% of the secondary production and this has been given in figure 7. The total tertiary production calculated from secondary production, comes to 6.93×10^6 tonnes carbon/year or 69.3×10^6 tonnes live weight of which the potential yield amounts to about 17.3 million tonnes. Explaining this

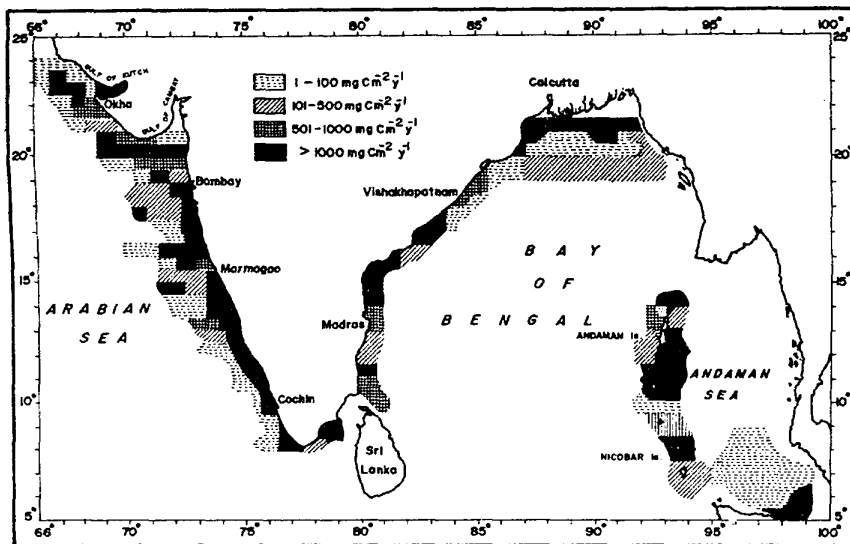


Figure 5. Annual benthic production in the Indian Seas. Source: Parulekar *et al* (1982).

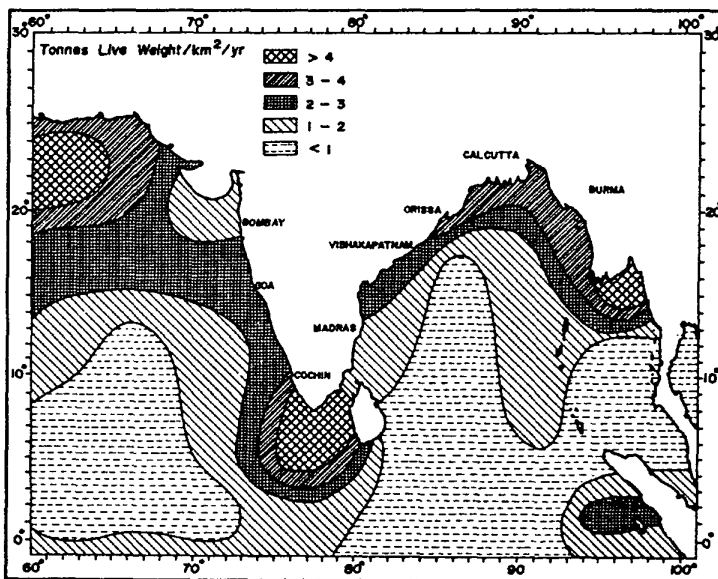


Figure 6. Tertiary production in the northern Indian Ocean calculated as 0.1% of primary production (column). The values have been multiplied by a factor of 10 to give the live weight of animals. Source: Qasim (1977).

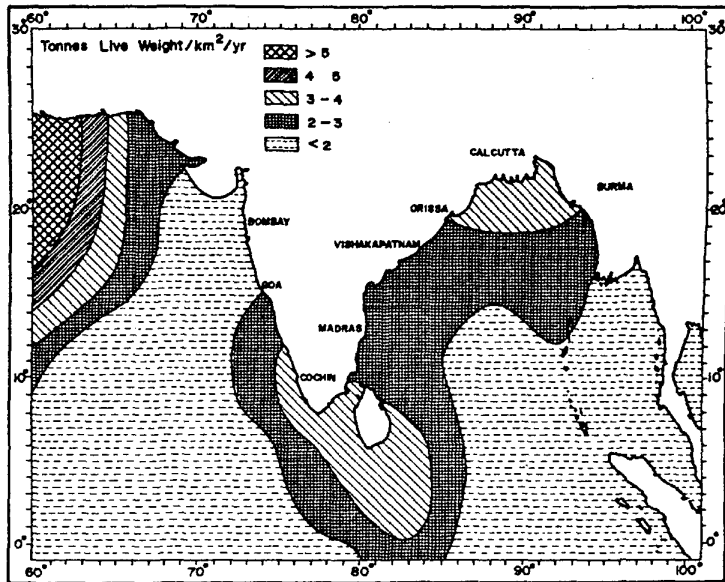


Figure 7. Tertiary production in the northern Indian Ocean calculated as 10% of secondary production. Source: Qasim (1977).

discrepancy obtained in the potential yield, Qasim (1977) explains that apart from the known pathways, there are many unpredictable links in the food chain through which the food energy can easily be lost. This would explain the differences obtained in the calculated values of potential yields.

Gulland (1971) estimated the available fish resources or the exploited stocks using the data of catch and effort, length and age composition etc. The unexploited stocks were estimated from the data obtained from exploratory fishing and from the studies on eggs and larvae and the echo-surveys. The potential yield of different exploitable populations at different trophic levels was estimated from the data of primary production, taking the ecological efficiency at each trophic level from 10–20%. Using the various types of estimates, the potential yield of different categories of fishes is given in figure 8. Included in this figure are the potential and the exploited fishery resources of the area under review. The pelagic fisheries resources have been taken from the data given by Prasad and Nair (1973). Moiseev (1971) in an exhaustive review of the living resources of the world oceans has also dealt with some of the aspects of exploitable resources of the Indian Ocean.

Rao (1973) in a very informative review has described the major exploited marine fisheries resources of India. He has also described the various groups of fishes, their occurrence, habitat and yield. Cohen (1973) has however dealt with the zoogeography of fisheries in the Indian Ocean based on their possible habitats such as tropical shores which may contain between 3000 and 4000 species, tropical continental shelf, continental slope and abyssal region, tropical epipelagic, deep water pelagic areas etc. He has at length described the number of species found in each category of

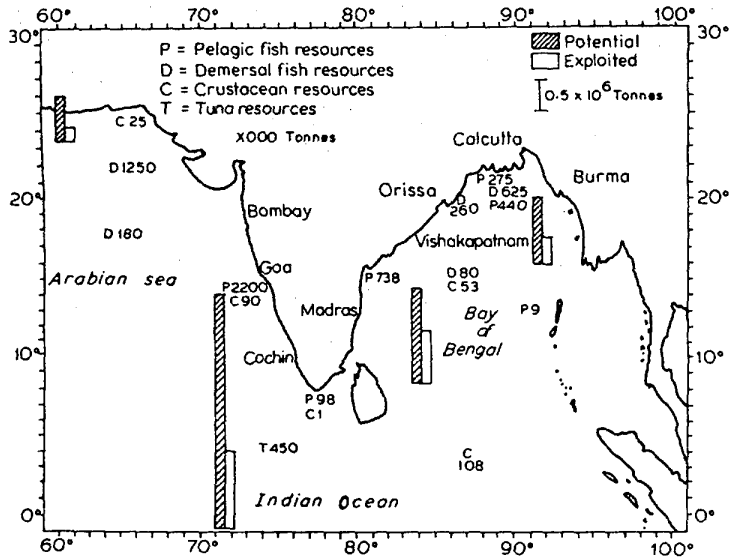


Figure 8. Potential yield of various exploitable resources from different areas of the northern Indian Ocean (in numbers) and the total potential and exploited yields (in histograms), (modified from Qasim 1977).

fishes in the Indian Ocean. He concluded that the Indian Ocean itself does not appear to be an area endemic by itself or a natural zoogeographic unit because there are very few species found in this ocean which are not found in the Pacific. There are, however, certain endemic areas like the Arabian Sea. The eastern Indian Ocean shares much of its fauna with the western Pacific. More widespread species seem to be the rule as far as the pelagic fishes are concerned. However, certain exceptions have been found in the distribution of deep water species. Their distribution largely depends on the characteristics of water masses.

Pathmarajah (1982) has described the presence of different species of marine organisms in various ecosystems of the Indian Ocean. He gives the details of fish species and their approximate distribution. These have been reproduced in table 1.

It is really not possible, within the scope of this article, to go into the details of the distribution of various species in the northern Indian Ocean. From the data available of the commercial catches, it can be concluded that a 'monospecific' trend in the fishes prevails as far as the landings go. *Sardina longiceps*, *Rastrelliger kanagartha*, *Acanthocybium solandri* (seer fish), *Harpodon nhereus* (Bombay duck) etc. are clear examples of this trend. Therefore, we have a situation where a single species clearly dominates the catch landings all along the Indian coast depending upon the season, area and the fishing gear employed.

7. Major threats, conservation status and measures

The exploitation of biological resources results from the removal, at the apex of the food pyramid of the natural communities such as fishes, crustaceans, cephalopods,

Table 1. Fish species present in the Indian Ocean and their approximate distribution.

40 metre depth zone:	Scavengers, snappers, sharks, rays.
Coral rubble and rocky bottom:	Lutjanids, serranids, sharks, denticids, carangids, caesio, spiny lobsters.
Smooth sea floor:	Mullidae, nemipterus, sauridae, sparids, lutjanids, serranids, lethrinids, sand lobster, portunid crab.
Greater than 100 m:	Pristipomoides, carangids, panulirus, scuridae, polysteganus, sparids, epiniphelids, sharks.
Deep Ocean waters:	Tuna, billfish, squids, cuttlefish, sharks, skipjack, dolphin fish, auxis, euthynnus, scomberomorus, acanthocybium, clupeoid, carangids, barracudas.
Epipelagic:	Sardines, scombroids, carangids, scads.
Mesopelagic/Bathypelagic:	Lantern fish, gonostomidae.
Others:	Include red oceanic swimming crab, mantis shrimp, porcupine fish, dolphins, marine turtles.

East-west distribution of major species

Pelagic:	Oil sardine*, lesser sardine ⁺ , other clupeoids ⁺ , Bombay duck*, half beaks, gar fishes, carangids, flying fish, ribbon fish ⁺ , mackerel*, seer, tunny, Indian pellona, leiognathidae.
Demersal:	Elasmobranchs ⁺ , eels, catfish ⁺ , tuna, perches, lizard fish, anchovy, red mullet, polynemids, sciaenids ⁺ , silver bellies ⁺ , lactarius, pomfrets, soles, prawns, shellfish, cephalopods, crustacea, pomadasyidae.

* Dominant on the west coasts.

+ Dominant on the east coasts.

From Pathmarajah (1982)

molluscs, whales etc. In order to conserve and avoid over exploitation of resources, it seems desirable (i) to evaluate the pattern of distribution of the forage organisms both qualitatively and quantitatively, (ii) to determine the regional productivity and the variability which exist from one region to the other and (iii) the variability in relation to physical, chemical and biological factors. In recent years, it has been very strongly recommended that the exploitation of the oceans should be judicious and wise, and the seas must be managed properly rather than taking them as 'free hunting grounds'. For example, Qasim *et al* (1978), in a detailed study on the biological productivity of the coastal waters of west coast of India, found that the fish yield along Maharashtra, Goa and Karnataka coasts was less than the optimum and that along the Kerala coast, there appeared to be overfishing. Based on this, they predicted an increase in fish yield from Maharashtra, Goa and Karnataka, but cautioned that, unless conservation measures were taken, there could be a substantial decline in the Kerala fishery. Later analyses (Qasim and Wafar 1985) of the fish yield from these States confirmed this. A comparison of the fish catch figures for 5 years preceding the prediction by Qasim *et al* (1978), and for the subsequent 5 years, showed that the average catch along Maharashtra, Goa and Karnataka did increase substantially. However, in Kerala, the average yield declined by 16% during the same period, and the yield for 1981 (0.35 million tonnes) was about 25% less than in the peak season (0.45 million tonnes) of 1973. In fact, the decrease of fish yield in

Kerala began as early as 1973-74 and is still continuing. Principles of conservation can probably be better understood from the practices on land. The marine ecosystems are very complex and unseen by our naked eyes. Hence, investigations are very often difficult in the ideal way. This has led to the suggestion that mathematical simulation, predicting the behaviour of the ecosystem subjected to changes in one or the other parameters has to be attempted. Assessment of the effect of anthropogenic activities on the ecosystem is also to be properly made.

Fishery management plays an important role in the maintenance of stocks. Basically a stock is a community of fish or shellfish, that under normal circumstances, is capable of maintaining itself without too much influx of the other communities or any other external pressures such as the overexploitation, deterioration of the environment etc. These have a direct effect on the communities. Moiseev (1971) has dealt with some of the problems of international fisheries.

As mentioned earlier, the biological processes in the sea start from the sun's energy being converted by plant communities into organic matter and ending up in exploitable resources of fish, crustaceans and molluscs. Probably the greatest threat posed to the marine environment and subsequently to any of the processes which govern the biological productivity is 'pollution'. The influence of pollution on any level of productivity, whether primary, secondary or tertiary, disturbs the entire food chain. The effects of pollution on the coral reefs, and our coastal areas including the estuaries are a subject of discussion in other articles of this volume. However, mention must be made of the various levels and types of pollution, threatening the marine environment around India.

The seas around India have become quite vulnerable to man's destructive forces of pollution. India has a long coastline of more than 6000 km, and an exclusive economic zone of an area of about 2.015×10^6 km². About 170 million people of India, or roughly about 25% of the total population live in coastal areas. The people depend directly or indirectly on the coastal resources and in turn generate and add to the tune of 3.9 km³ of sewage to these areas annually (Sen Gupta and Qasim 1985). Domestic sewage, in small proportions, fertilises the sea water and increases the rate of productivity, but over fertilization adds pressures on this environment because of eutrophication which leads to excessive growth of algae and this becomes detrimental to the systematic productivity processes. In other words, excessive amounts of sewage (nutrients) change the algal community and induce artificial diversity of species ranging from one to a few species. In such situations, commonly the herbivorous species thrive. Often the blooms of the blue-green algae or nanoplankton, totally unsuitable as food of the grazing animals may create environmental problems. Thus, the changes in the plant population indirectly cause changes throughout the ecosystem, and even in the availability of organisms which form higher links in the food chain. From such an analysis it is clear that if primary production is in a form which can be readily consumed, it will favour the production of higher forms of life. If it remains unconsumed, as it has been noticed in the case of *Noctiluca*, *Gonyaulax*, *Trichodesmium* etc., it can create serious problems.

Moreover, an excess of sewage discharge also affects the oxygen concentrations in water and may lead to anaerobic conditions. Thus, in the Arabian Sea where low concentrations of oxygen are endemic (Sen Gupta and Naqvi 1984), the additions of large volumes of sewage may alter the oxygen concentrations at the surface where it may presumably become difficult for some of the living organisms to survive.

Apart from sewage, the industrial and solid wastes going into the coastal waters of India have been estimated to be 0.39 km^3 and $33 \times 10^6 \text{ m}^3$ per annum, respectively. About 20,000 and 31,000 tonnes of pesticides and detergents, respectively, are annually added to the coastal waters. The rivers bring in additional quantities of wastes to the coastal waters (Sen Gupta and Qasim 1985). Such enormous additions will undoubtedly burden the marine environment.

The effects that these pollutants may have on the biota in terms of directly or indirectly altering the components of the ecosystems seems to be profound. These could be manifested in the form of impairment of biological activity within a community or in an individual. They may alter the entire faunal distribution apart from making them unfit for human consumption. One cannot go into the detail of such effects. However, mention may be made of 'oil pollution'. The Arabian Sea has become very vulnerable to oil pollution because it has perhaps the busiest oil transportation route not far away from the shores of India. It has been estimated that nearly 513 million tonnes of oil are transported across the Arabian Sea to the different parts of the world annually (Sen Gupta 1984). The spillage of oil originating from the ballast, bilge and cooling water amounts to nearly 2.1 million tonnes (Sen Gupta 1984). Added to this are the harbour activities and the oil exploitation programme in the Bombay High oilfields. Although the northern part of the Bay of Bengal is relatively free from oil transportation, the southern part does come under the tanker route to the far east.

It may be mentioned here that when an oil spill, large or small occurs, the volatile fractions evaporate and the remaining part of the oil gets degraded either microbiologically or as a result of photo-oxidation. The heavier fractions of the oil remain floating and these, most often form lumps or tar balls. These tar balls first get settled at the bottom but during the monsoon months they get stirred up by the turbulent sea depending upon the current pattern and the prevailing wind, are washed ashore on the beaches, thus affecting the intertidal fauna (Nair *et al* 1972). The thin film of the oil on the other hand, which gets spread over the sea surface, not only acts as a solvent for other organic pollutants, but it reduces the penetration of sunlight considerably for the photosynthetic activity of phytoplankton.

Other pollutants such as the heavy metals (mercury, cadmium and lead) also occur in varying degrees in the seas around India. However, they have not so far posed any serious threat. Off Bombay, as an isolated case, the concentration of mercury has been reported to be quite high, but otherwise in an extensive work carried out by National Institute of Oceanography, the concentrations of these 3 toxic metals—Hg, Cd and Pb—in the biota of the Indian seas do not show alarming trends. In fact, the concentrations are below the permissible limits indicated by WHO in fishes taken for human consumption.

Marine environment around India, needs detailed investigations, constant vigil and monitoring. With increasing industrialization along the coast, the need for an effective check and appropriate legislation cannot be over emphasized. The role of the various Pollution Control Boards existing in different States becomes very important in striking a balance between development and marine water quality and aesthetic value of the coastline. The role of the Coast Guards Organisation in keeping a constant vigil of the Exclusive Economic Zone (EEZ) becomes extremely important in identifying the culprit, particularly the defaulting oil tankers which do not follow the prescribed maritime conventions. A high degree of preparation and competence

is urgently needed by the various scientific bodies such as the National Institute of Oceanography and coordinating bodies like the Department of Ocean Development to protect the fauna and flora in the seas around India, so that the sea could continue to meet our social, economic and recreational needs for a long time to come. What we need today is a proper structure to keep our seas clean.

References

- Baumgartner A and Reichel E 1975 *The world water balance*, (Amsterdam: Elsevier) p 179
- Brinton E and Gopalakrishnan K 1973 The distribution of Indian Ocean euphausiids; in *The Biology of the Indian Ocean* (eds) B Zeitzschel and S A Gerlach (Berlin: Springer Verlag) pp 357-382
- Cohen D M 1973 Zoogeography of the fisheries of the Indian Ocean; in *The Biology of the Indian Ocean* (eds) B Zeitzschel and S A Gerlach (Berlin: Springer Verlag) pp 451-463
- Currie R I, Fisher A E and Hargreaves P M 1973 Arabian Sea upwelling; in *The Biology of the Indian Ocean* (eds) B Zeitzschel and S A Gerlach (Berlin: Springer Verlag) pp 37-52
- Fenaux R 1973 Appendicularians from the Indian Ocean, the Red Sea and the Persian Gulf; in *Biology of the Indian Ocean* (eds) B Zeitzschel and S A Gerlach (Berlin: Springer Verlag) pp 409-414
- Garrels R M and Mackenzie F T 1971 *Evolution of sedimentary rocks* (New York: Norton) p 397
- Gulland J A 1971 *The fish resources of the ocean*, (West Byfleet, Surrey, England: Fishing News Books Ltd.) p 255
- Kabanova J G 1968 Primary production of the northern part of the Indian Ocean; *Oceanology* 8 214-255
- Krey J 1973 Primary production in the Indian Ocean; in *The Biology of the Indian Ocean* (eds) B Zeitzschel and S A Gerlach (Berlin: Springer Verlag) pp 115-126
- Leopold L B 1962 Rivers; *Am. Sci.* 50 511-537
- Moiseev P A 1971 *The living resources of the world oceans* (Jerusalem: Keter press binding) p 334
- Murty C S and Varadachari V V R 1968 Upwelling along the east coast of India; *Bull. Natl. Inst. Sci. India* 38 80-86
- Nair S A, Devassy V P, Dwivedi S N and Selvakumar R A 1972 Preliminary observations on tar like material observed on some beaches; *Curr. Sci.* 41 766-767
- Parulekar A H, Harkantra S N and Ansari Z A 1982 Benthic production and assessment of demersal fishery resources of the Indian Ocean; *Indian J. Mar. Sci.* 11 107-114
- Parulekar A H 1985 Benthic explorations and potential demersal fishery resources of the Indian Ocean; in *The Oceans: Realities and Prospects*. (ed) R C Sharma (Delhi: Rajesh publications) pp 123-129
- Pathmarajah M 1982 *Pollution and the marine environment in the Indian Ocean* (UNEP Regional Seas Reports and studies) No. 13 UNEP, p 153
- Pillai K 1973 Mysidacea of the Indian Ocean; *International Indian Ocean Expedition, Handbook of International Zooplankton Collection, Indian Ocean Biological Centre* 6 126
- Prasad R R, Banerjee S K and Nair P V R 1970 A quantitative assessment of the potential fishery resources of the Indian Ocean and adjoining seas; *Indian J. Anim. Sci.* 40 73-98
- Prasad R R and Nair P V R 1973 India and Indian Ocean fisheries; *J. Mar. Biol. Assoc. India* 15 1-19
- Qasim S Z 1977 Biological productivity of the Indian Ocean; *Indian J. Mar. Sci.* 6 122-137
- Qasim S Z, Wafar M V M, Sumitra Vijayaraghavan, Joseph P Royan and Krishnakumari L 1978 Biological productivity of the coastal waters of India from Dabhol to Tuticorin; *Indian J. Mar. Sci.* 7 84-93
- Qasim S Z 1982 Oceanography of the northern Arabian Sea; *Deep-Sea Res.* 29 1041-1068
- Qasim S Z and Wafar M V M 1985 Marine resources in the tropics; in *Tropical resources—Ecology and Development* (ed) J I Furtado (London: John Wiley and Sons) (in press)
- Rao K V 1973 Distribution pattern of the major exploited marine fishery resources of India; in *Proceedings of the Symposium on Living Resources of the Seas around India*, (Cochin: Central Marine Fisheries Research Institute)
- Rao D P 1977 *A comparative study of some physical processes governing the potential productivity of the Bay of Bengal and the Arabian Sea*, Ph.D. thesis, Andhra University, Waltair
- Rao T S S 1979 Zoogeography of the Indian Ocean; in *Zoogeography and diversity of plankton* (eds) S Van Der Spoel and A C Pierrot (Netherlands: Butts. Bunge Sci. Pub.) pp 254-292
- Sen Gupta R, De Souza S N and Joseph T 1977 On nitrogen and phosphorus in the western Bay of Bengal; *Indian J. Mar. Sci.* 6 107-110

- Sen Gupta R 1984 Studies on oil pollution in the Indian Ocean; *Indian Foreign Rev.* **11** 26-28
- Sen Gupta R and Naqvi S W A 1984 Chemical oceanography of the Indian Ocean, north of the equator; *Deep-Sea Res.* **31** 671-706
- Sen Gupta R and Qasim S Z 1985 The Indian Ocean—An environmental overview; in *The Oceans: Realities and Prospects* (ed) R C Sharma (Delhi: Rajesh Publications) pp 7-40
- Sharma G S 1968 Seasonal variation of some hydrographic properties of the shelf waters off the west coast of India; *Proc. Natl. Inst. Sci. India* **38** 263-277
- Subrahmanyam R and Sarma A H V 1960 Studies on the phytoplankton of the west coast of India, III: Seasonal variation of the phytoplankton and environmental factors; *Indian J. Fish.* **7** 307-336
- Sverdrup H U, Johnson M W and Fleming R H 1942 *The Oceans, their physics, chemistry and general biology*, (New Jersey: Prentice Hall) p 1087
- Vanucci M and Navas D 1973 Distribution of Hydromedusae in the Indian Ocean; in *The Biology of the Indian Ocean* (eds) B Zeitzschel and S A Gerlach (Berlin: Springer Verlag) pp 273-281
- Varadachari V V R and Sharma G S 1967 Circulation of the surface water in the North Indian Ocean; *J. Indian Geophys. Union* **4** 61-73
- Venkateswaran S V 1956 On evaporation from the Indian Ocean; *Indian J. Meteor. Geophys.* **7** 265-284