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PRODUCTIVITY OF THE INDIAN SEAS

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ABSTRACT

The productivity of the Indian Seas and adjacent ecosystems such as estuaries, mangrove swamps, coastal environment and also the upwelling areas have been discussed in the light of data collected over the years by different expeditions and also by the studies conducted intensively in localised regions. The general level of productivity shows much variation both in space and time. The estuarine areas and upwelling regions are found to have a higher production rate. There is also a seaward decrease in the production. The region-wise annual production for west and east coasts of India and the Indian Ocean in general have been quantitatively estimated from the carbon production tracing through the yield ratio based on the ratio obtainable in the intensively exploited waters. The possible exploitable yield from the Exclusive Economic Zone comprising an area of about 2 million sq. km has also been estimated both in terms of carbon production and potential resources. The productivity of special ecosystems such as mangrove swamps and coral reefs have also been discussed in general.

INTRODUCTION

THE INDIAN OCEAN including Antarctica has an area of about 75million km² which is roughly one fifth of the World oceans. But the fish production from this ocean is only about 4 million tonnes, *ie.* about one twentieth of the world annual catch. In terms of organic production and yield ratio Indian Ocean presents a very dismally low percentage as compared to that of Pacific and Atlantic Oceans. That means the yield ratio as percentage of carbon is roughly one third of the Pacific and one fourth of the Atlantic Oceans. This clearly indicates the wide gap in the potential harvestable stock especially in view of the fact that the average carbon fixation is almost similar for the Pacific, Atlantic and Indian Oceans with the western Indian Ocean indicating even slightly higher rate of fixation. This gap is mainly due to under-exploitation of several productive areas mainly the upwelling regions which produce majority of the pelagic stock comprising tunas, bill fishes, and middle level carnivores and herbivores. The recent studies conducted by UNDP pelagic fisheries project for the south-west coast has indicated a high potential for anchovies and other pelagics even for a restricted area. Considering various productivity parameters and stock assessments by different agencies, it has been fully established that the annual sustainable yield for 70% of the Indian Ocean area should be at least 11-12 million tonnes at the present level of world fishing. The EEZ comprising just over 2 million km² could provide an annual sustainable yield of 4 to 5 million tonnes.

Expeditions such as CHALLENGER, VALDIVIA, METEOR, MICHAEL SARS, CARNIEGIE, JOHN MURRAY and GALATHEA have explored the Indian Ocean prior to the International Indian Ocean Expedition (IIOE). Of these, JOHN MURRAY expedition was the first to compute the production of matter in terms of wet weight by using the nitrate data. But the Danish GALATHEA Deep Sea Expedition made significant contribution in this direction by introducing the most powerful tool of carbon isotope ever to be used in the study of marine photosynthesis (Steemann Nielsen, 1952; Steemann Nielsen and Jensen, 1957). The GALATHEA's coverage was on the western part of the Indian Ocean at the middle

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latitudes and the equatorial part as a section from Mombasa to Sri Lanka, the Bay of Bengal and Indo-Malayan waters. These were single observations and did not cover the peak periods in the respective regions. However, the International Indian Ocean Expedition in which thirteen countries and forty ships participated has provided a detailed picture of hydrography, productivity and resources of the Indian Ocean (Wyrtki, 1962; Ryther *et al.*, 1966; Shomura *et al.* 1967; Kabanova, 1968).

Prior to these major expeditions several localised attempts had been made by various authors to study the plankton of the west and east coasts of the Peninsula (Subrahmanyan, 1959). All these accounts are of a general qualitative nature indicating the peak period of plankton production and its seasonal cycle. The first attempt on a qualitative and quantitative study on the magnitude of standing crop and production of organic matter along with their relationship to fish landings based on intensive biological and hydrographical data collected over the years from the south west coast of India was made by Subrahmanyan (1959). But the methodology adopted and the tools available then were inadequate for an accurate estimation of the production of matter.

The average annual gross production for all seas is estimated to be about 55-70 g C/m^2. Assuming a 40 % loss through respiration and an area of 361 million square kilometers for all the oceans, the total net production per year for all the seas is estimated at about 1.2-1.5 x 10^{10} *tonnes of carbon (Steemann Nielsen, 1960).* This value has been subsequently modified to 2 x 10^{10} tonnes by Ryther (1963). This value is practically the same as that estimated for the production on land.

Of the 74.917 million km^2 which is conventionally taken as the Indian Ocean region, 3.1 million km^2 is considered as coastal and near-shore regions which sustain the major part of the fishery and have an annual net production of 560 x 10^6 tonnes. Druing the GALATHEA Expedition it was found that the rate of organic production was practically high anywhere in the tropics in shallow waters which was at variance with the observations of the earlier expeditions which indicated a comparatively low productivity in the tropical seas. But with intensive exploration during the International Ocean Expedition (1959-'65) it was revealed that some of the world's highest values of primary production are in the upwelling regions of Somalia and South of Arabia. Based on the measurements made by several vessels during different seasons Prasad *et al.* (1970) and Qasim (1979) estimated the production of the Indian Ocean at about 4 x 10^9 tonnes. But there is quite a large variation both in space and time in the Indian Ocean in general and coastal areas in particular (Ryther *et al.*, 1966). The reasons for this seasonal and spatial variations can be attributed to various factors.

FACTORS AFFECTING PRODUCTION

Taking all seas as a whole it is now almost conclusively established that the replenishment of nutrients in the productive layer is normally the key factor that determines the magnitude of the annual rate of organic production. This replenishment can be the result of regeneration *in situ* or due to upwelling and turbulence thereby nutrient rich subsurface water is carried into the euphotic zone.

In the open ocean the replenishment of nutrients is provided principally by water circulation. In contrast to the open ocean the nutrients distribution in the shallow coastal areas is primarily due to regeneration which takes place in the top layers of the bottom sediments. The highest rate of production is normally found in areas where there is no pronounced stratification of water masses.

Cushing (1969) stated that the productivity of the upwelling areas in tropics and subtropics is not so much from fertilization of the surface layers, but because the upwelling system is capable of supporting a temperate type of production cycle. Cushing (1971) observed that the most important areas in the Indian Ocean and in the Indonesian region, including the Southern China Sea, are those off Somalia and Southern Arabian Sea, which are comparable in intensity to any upwelling area in the world. He also stated that the region between Burma and the Andaman islands appears to be fairly rich during the north-east monsoon whereas that off the Malabar coast of India may be as rich and nearly as extensive as that of southern Arabia. Cushing and Dixon (1976) have indicated in the case of the Indian Ocean, the upwelling off southwest Arabia, in the Somali current and off the Malabar coast are tied to the timing of the south-west monsoon (April–September). The upwelling has an important bearing on the production, larval survival and fish yield (Banse, 1968).

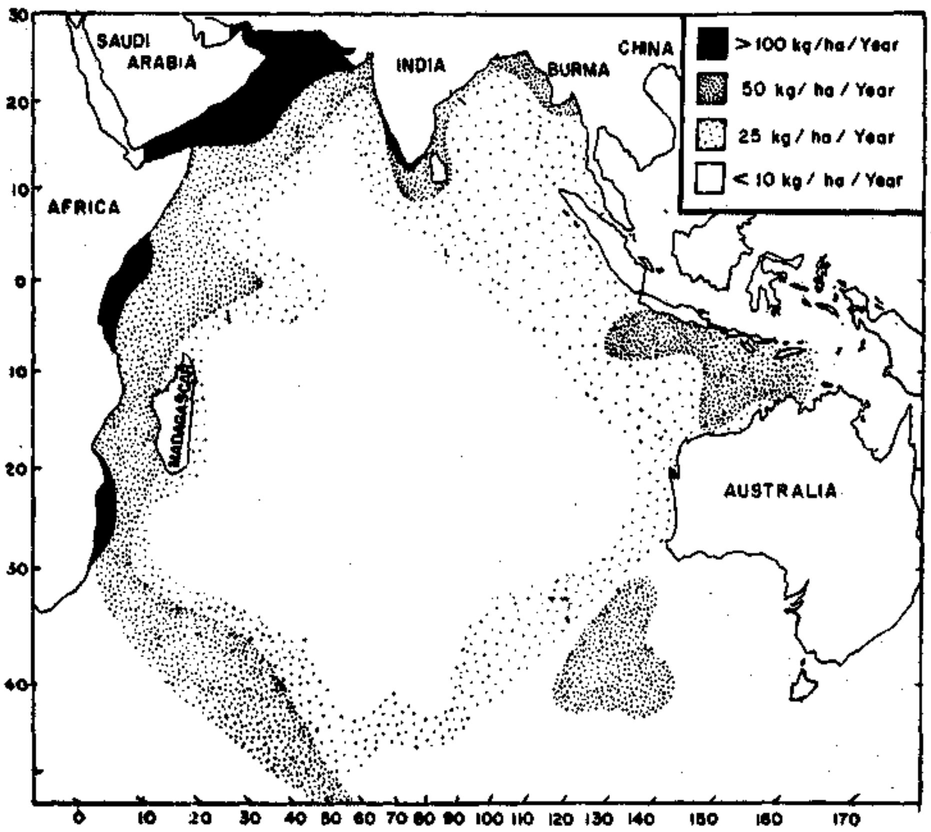

Fig. 1. Optimum yield estimated from primary production.

The other factors that determine the rate of production are light and temperature which are not limiting in the Indian seas. In addition, grazing, sinking and external metabolites also have some effect on the productivity.

Productivity in Different Environments of the Indian Seas

Backwaters

Considerable amount of work has been done by Qasim *et al.* (1969) Qasim (1973, 1979) and Gopinathan *et al.* (1984) in the Cochin Backwaters. These authors made use of the ^{14}C method concurrently with oxygen method. Gross and net primary production levels were also determined at various depths and community respiration rate was also computed. According to them the gross production ranged from 0.35–1.50 g C/m^2/day. The range in respiration was from 0.08-0.64 g C/m^2/day. The annual cycle of production showed three small peaks which were in the form of brief pulses showing no regular seasonal rhythm. These authors also found that three main ecological factors namely salinity, light and nutrients govern the rate of productivity in this ecosystem.

In the Goa estuarine complex Dehadrai and Bhargava (1972) determined the gross productivity by oxygen method which was found to vary from 135–550 mg C/m^3/day in Mandovi estuary and from 150-580 mg C/m^3/day in Zuari Estuary. Dehadrai (1970) reported that the average net production at the surface in Mandovi ranged from 95 to 450 mg C/m^3 day. The measurements in the Bombay harbour area near BARC indicated that the range of production varied from 15-499 mg/C/m^3/day (Krishnamurthy and Viswanathan, 1968).

In the Vellar-Coolrum estuarine system on the east coast near Porto Novo gross and net production at the surface ranged from 11.77-36.99 mg C/m^3/hr and 6.72 to 26.22 mg C/m^3/hr respectively (Venugopal, 1969). At 1.5 m depth the range in the production was much higher perhaps because of higher nutrient availability. The gross production ranged from 21.88 to 58.83 mg C/m^3/hr and net production 18.48-47.07 mg C/m^3/hr. In the Killai Backwaters Bhatnagar (1971) measured a gross production of 251.20 mg C/m^3/hr and net production of 225.44 mg C/m^3/hr with maximum values in August and the minimum in February being 47.62 and 38.09 mg C/m^3/hr. Both measurements are by oxygen technique and the ^{14}C technique also indicated almost the same range during February.

In the Vembanad Lake adjacent to Cochin Estuary, relatively higher rates of production are observed. The rate of production is uniformly high, exceeding 10 mg C/m^3/hr and in one area high values upto 3g C/m/^{2}day (highest single value recorded) with an average of 1.2 g C/m^2/day were recorded.) Qasim *et al.* (1969) have estimated that the gross production ranges from 273–293 g C/m^2/year with an average of 280 g C/m^2 /year, while the net production is 184–202 g C/m/^{2}year with an annual consumption by zooplankton herbivores of 30 g C/m^2 leaving a large surplus of basic food in the estuary. Inspite of seasonal and spatial variations, the estimated annual gross production for the entire Vembanad Lake comprising about 300 km^2 is about 1,00,000 tonnes of carbon (Nair *et al.*, 1975).

Mangrove areas

Mangrove swamps are specialised ecosystems flourishing in brackishwaters of the tropics and hence they are found all along the Indian coastline. Since they are away from the sea the wave action is minimal and substratum is silty. Untawale and Parulekar (1976) have studied the ecology of mangroves in the estuaries of Goa, but productivity values are not available for that region. For Pichavaram mangroves on the east coast at Porto Novo Krishnamurthy and Sundararaj (1973) have given an average primary production rate of 7.56 g C/m^3/day and a net production of 6.29 g

C/m^2/day. For mangroves of Cochin Backwater the values reported is 160–1485 mg C/m^2/day (Rajagopal, 1985). The mangrove ecosystem of the Andaman–Nicobar area has a very high production rate of exceeding 2 g and attaining upto 3.6 g C/m^2/day (Gopinathan and Rajagopalan, 1983).

The coastal environment

In the coastal environment, measurements have been made at Lawson's Bay by Subba Rao (1973), Mandapam (Prasad and Nair, 1963) and off Cochin (Nair *et al.*, 1969). In Lawson's Bay gross production ranged from 9.20 to 150.05 mg C/m^3/hr. During blooms the gross production increased 3–13-fold (Subba Rao, 1973). At Mandapam on the south-east coast, Palk Bay and the Gulf of Mannar show two types of environment. According to Prasad (1956) Gulf of Mannar has got a typical oligotropic environment, whereas Palk Bay has got a eutropic environment. The production values on the average is over 1.0 g C/m^2/day reaching upto 3.6 g C/m^2/day whereas in the Palk Bay during peak production periods values reaching 7 to 8 g C/m^2/day have also been recorded by ^{14}C technique. The inshore waters of Mandapam are extremely rich both in phytoplankton concentration as well in submerged vegetation comprising dense seagrass beds and a variety of algal flora and symbiotic zooxanthellae in the coral reefs. On the south-west coast, off Cochin, the 50 m depth zone is the most productive area with an average production rate exceeding 1 g C/m^2/day, decreasing seaward and the euphotic zone varies from 14 m in the nearshore waters to nearly 90 m in oceanic waters near the Laccadive sea.

Prasad *et al.* (1970) observed that rates of primary production on the continental shelf of the Indian seas are uniformly high during most part of the year. The mean net production is 0.51 g C/m^2/day. Hence they concluded that 6% of the eutropic coastal waters account for approximately one-seventh of the entire primary production in the Indian Ocean.

Ryther *et al.* (1966) observed that north of the equator in the Arabian Sea the level of primary production increases to the north and west reaching exceptionally high values off the coasts of Saudi Arabia and Pakistan. The highest measurements ever made in that region was 6.4 g C/m^2/day. The Anton Bruun survey indicated that 23 million km^2 comprising one-third of the Indian Ocean has an annual productivity of 3 x 10^9 tonnes of carbon which is 10–12% of Steemann Nielsen and Jensen's (1957) estimate of the range of production for the oceans as a whole. It is not surprising as the western Indian Ocean, when considered as a whole, is somewhat more productive than most of the large oceanic areas and is a region of contrast containing some of the richest and the most infertile waters (Ryther *et al.*, 1966.)

Radhakrishna *et al.* (1978) observed that primary productivity at the surface in the northern Arabian Sea varied widely ranging from 0.18–65.11 mg C/m^3/day and averaged 8.4 mgC. Exceptionally high values of 281 mg C/m^3/day was recorded near Bombay. High values were encountered close to the shore along the Kutch and Saurashtra coast near Dwaraka point off Porbander. Surface productivity varied from 1.12–65.11 mg C/m^3/day in the shelf region and from 0.18–17.88 mg C/m^3/day offshore. Integrated values for daily productivity in the euphotic column was about 0.7 g C/m^2.

Radhakrishna (1975) again measured primary productivity at twelve stations in the Bay of Bengal and two stations in the south-east Arabian Sea during March–April,

1975. The column production varied from 0.063–0.485 g C/m²/day for offshore stations (>10 m) whereas nearshore stations had showed a unit volume production of 110 mg C/m³/day which was the highest value recorded from the Bay of Bengal. However, the same station showed only an integrated value of 0.25 g C/m²/day. He has come to the conclusion from the observation that primary productivity in the Bay of Bengal is relatively low as compared to the Arabian Sea which has been attributed to the topographical feature as the narrow continental shelf and heavy cloud cover. As is well known, upwelling in the Bay of Bengal is less intense and limited compared to the Arabian Sea. Steemann Nielsen and Jensen (1957) has also pointed out that the low productivity of the Bay of Bengal is due to the high run off from the Gangetic and Brahmaputra river systems which discharge high quantity of terregenous organic matter which affects light penetration. Radhakrishna (1975) has also suggested that mixing processes being weak lessens the transfer of subsurface nutrients to the euphotic zone as there is greater degree of stratification due to the river discharge.

The same author reported from the Bay of Bengal during the post-monsoon (August–September) period a production of 0.22 g C/m²/day as compared to 0.29 on the shelf and 0.32 at the slope. At almost all stations productivity at the surface was maximum. He has also pointed out that the post-monsoon period is more productvie compared to the pre-monsoon season.

Measurements of productivity has also been made for seagrass beds, coral reefs and atolls. For coral reefs and atolls flow respiratory technique has been used in Gulf of Mannar, Palk Bay and Pamban island reefs, Mandi reef, Minicoy reef, Andaman reef and Kavaratti reef (Pillai and Nair, 1972; Qasim *et al.*, 1972; Balasubramanyam and Wafer, 1975). The gross and net primary production in the lagoon at Kavaratti were found to be 12.92 g C/m²/day and 3.38 g C/m²/day. The Gulf of Mannar, Minicoy and Andaman reefs indicated a production rate of 7.3, 9.1 and 3.9 g C/m²/day respectively. Bhargava *et al.* (1978) observed an average production of 7.5 mg C/m³/day in the south east Arabian Sea near Lakshadweep during October–December period with an integrated value of 0.21 g C/m²/day with higher values exceeding an average of 0.8 g C/m²/day in August–December. These authors conclude that from the hydrographic point of view the period when upwelling ceases and the waters are relatively infertile during October. The average productivity values in the Andaman Sea (Bhattathiri and Devassy, 1981) were 5.3, 12.4 and 2.4 mg C/m³/day during the pre-monsoon period. The column productivity values varied from 0.12 to 0.62 and 0.20 to 1.2 g C/m²/day during 1979 and 1980. During 1963 the values were between 0.01 and 0.27 g C/m²/day. Thus the respective average productivity was maximum during 1980. Kabanova (1968) has found productivity at two stations in central Andaman Sea to be 0.114 and 0.177 g C/m²/day when the phosphate phosphorus was zero and nitrate nitrogen was between 1.5 and 2μg at/litre in the euphotic column.

Qasim *et al.* (1978) determined the biological productivity of coastal waters of India from Dabhol to Tuticorin, for an area of 43×10^3 km² and arrived at a figure of 0.33 g C/m²/day or 122 tonnes C/km²/year or 5 million tonnes of carbon for the entire year. After making a thorough comparative study of six different tropical environments in the Indian Ocean, Qasim (1973) has come to the conclusion that the rate of production near the shores is greater than in regions away from the coast and high instantaneous rates of production are generally recorded in upwelling areas during the monsoon period. Besides, primary production in the turbid and polluted environments is high and is largely contributed by nannoplankters and that estuaries are also greatly influenced by the monsoon cycle as the annual cycle of primary production and succession of phytoplankters are found to be related to the increased flushing caused by the monsoon.

Productivity and potential yield

Several attempts have been made to relate productivity parameters with that of potential yield or optimum sustainable yield (Subramanyan, 1959; Prasad and Nair, 1963; Nair *et al.*, 1969; Prasad *et al.*, 1970; Qasim *et al.*, 1978). It has been observed by Steemann Nielsen and Jensen (1957) that the landings of commercial fish catch in intensely exploited waters is about 0.4% of the organic matter produced by the phytoplankton. The computations made so far indicate that in the eastern Arabian Sea towards the coast of India that the average rate within 50 m depth is about 1.2 g C/m^2/day and for the outer shelf region. the rate is 0.5 g C/m^2/day. The net production on the west coast of India within 50 m comprising 114,520 km^2 has been estimated as 30 x 10^6 tonnes of carbon. Between 50 and 200 m (168,790 km^2) the net production is only 16 x 10^6 tonnes. Thus for the whole continental shelf area on the west coast of India the annual net production is computed at 46 million tonnes of carbon. Qasim's (1979) estimate for 43,000 km is 5 million tonnes of

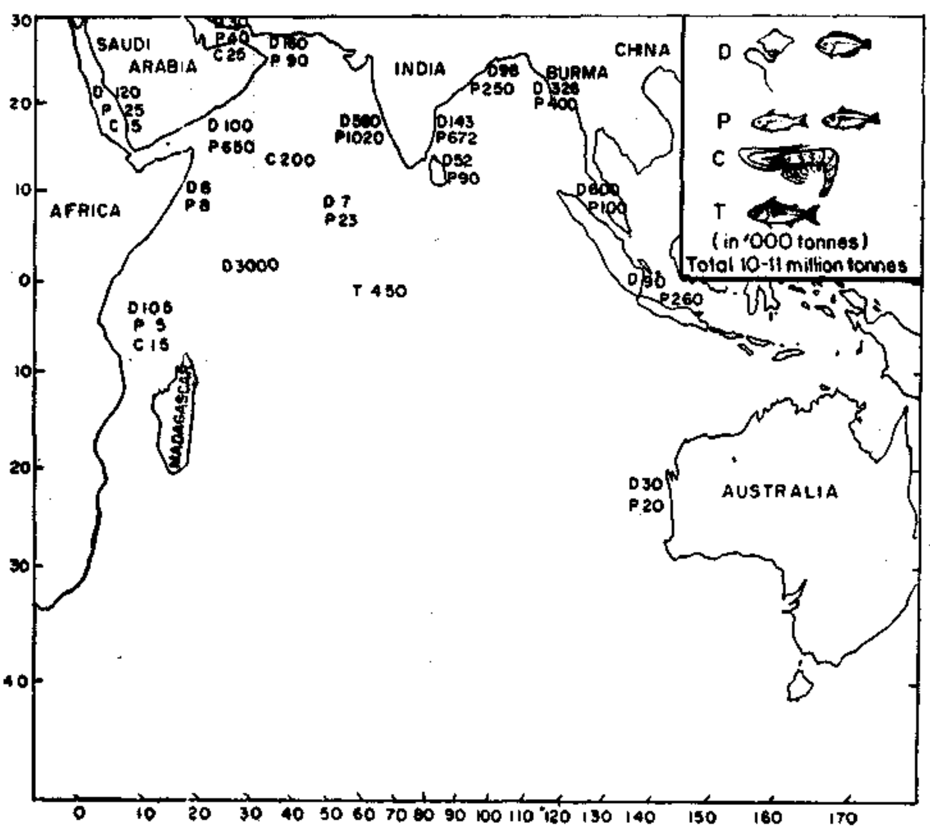

Fig. 2. Estimated potential annual yield from the Indian Ocean.

carbon. Prasad *et al.* (1970) estimated the net primary production for part of the Indian Ocean covering an area of 51 million km² as 3.9 x 10^9 tonnes of carbon per year which is in close agreement to the estimate of Koblentz-mishke *et al.* (1970) which is 4.1 x 10^9 tonnes. For the Exclusive Economic Zone comprising an area of about 2 million km² the estimated productivity is 2.8 x 10^8 tonnes of carbon (Gopinathan, M.S.). In view of the expanse of the Exclusive Economic Zone and rather diffused distribution of the resources an optimum yield of 0.4% of organic production is unrealistic. So a maximum sustainable yield of 0.2% would be a more realistic estimate which would amount to just about 5 million tonnes of fish. Among this, pelagics such as tunas, bill fishes and anchovies which occupy lower level in the trophic chain, mid water resources such as myctophids, Nemipterus and deep sea prawns could be the major components.

Estimation of the harvestable yield by using the ecological efficiency factor has been developed by Schaefer (1965) which has been successfully used by Prasad *et al.* (1970) and Qasim *et al.* (1978). According to Qasim *et al.* (1978) the average sustainable yield per year has been estimated as 0.8 million tonnes for the coastal waters from Dabhal to Tuticorin. As the present exploited yield from the coastal waters is in the order of 0.6 million tonnes the existing yield for Kerala coastal region appears to be greater than the annual sustainable yield and further increase in the exploitable yield that seems possible is only of the order of 0.2 million tonnes. But exploitation for the entire Exclusive Economic Zone holds out a promise of a three fold increase from the present yield of 1.6 million tonnes.

In recent years the technology of remote sensing also has been used in selected areas to study the bioproductivity by estimating the chlorophyll concentration by air borne Ocean Colour Radiometer and satellite data from LANDSAT and NIMBUS-7 CZCS along with sea truth data collected during overpasses. Though relationships have been established for chlorophyll gradients, accurate values for organic productivity through chlorophyll estimates are not yet possible to be computed. This may be possible with more observations from the data collected by the Indian Remote Sensing satellite to be launched shortly and through larger coverage of near and offshore areas during its overpasses in the coming years. The recent coverages by the exploratory surveys of the Fishery Survey of India vessels and FORV SAGAR SAMPADA on resources of these seas along with synoptic observations on environmental parameters through satellite data from the Indian Ocean waters are expected to yield more reliable information on the abundance and distribution of resources as well as the environmental changes that determine their distribution.

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