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2 Primary production

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ABSTRACT

Studies on primary production of the Indian Seas in general and adjacent ecosystems such as estuaries, mangroves, mud banks and coastal environments in particular are briefly discussed, in the light of the data collected over the years by various Expeditions and also by the investigations conducted in localised regions. The results indicated that the general trend of primary production vary both in space and time and also a seaward decrease in the production. The factors affecting and favouring the primary production of the Indian Seas is also presented. The annual production rates of west coast and east coast and potential estimates of resources derived from primary production is also discussed. The annual carbon production for the EEZ of India has been computed as 283 million tonnes and potential harvestable resources available in this region derived as 5.5 million tonnes, based on primary production. Future investigations on productivity through chlorophyll analysis are also projected.

Introduction

Primary production may be defined as the amount of organic materials which by the activity of organisms in unit time is synthesized in unit volume of water or in unit area, extending from the sea surface to the bottom of the euphotic zone. The floating micro-algae remove dissolved carbon-di-oxide and micro-nutrients from the water and using solar energy convert them into complex organic compounds of high potential energy with the help of chlorophylls.

The word 'production' is synonymously used for standing crop as well as primary production which is basically a measure of the photosynthetic activity of autotrophic organisms. Various methods, both direct and indirect, are employed for the estimation of primary production of an area. Of these methods, light and dark bottle oxygen technique (Gaarder and Gran, 1927), ^{14}C technique (Steeman Nielsen, 1952) and chlorophyll estimation (Strickland and Parsons, 1972) are the most popular.

Work undertaken during Expeditions of *Challenger, Valdivia, Meteor, Michael Sars, Carneigii, John Murray, Galathea, Vityaz and International Indian Ocean Expedition* have thrown light on various resources in the Indian Ocean and adjacent areas. Of these, the Danish *Galathea* Expedition made significant contributions in this direction by introducing the advanced technique of ^{14}C (carbon isotope) to be used in the study of primary production (Steeman Nielsen and Jensen, 1957).

Prior to these Expeditions, several localised attempts have been made by various authors, most of which are of a general qualitative nature indicating the peak periods of phytoplankton 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 with fish landings based on biological and hydrological data collected over years from the west coast of India was made by Subrahmanyan (1959). But the methodology adopted and the results obtained were inadequate to give an accurate picture of the production of organic matter from the west coast of India. Later, Prasad and Nair (1963), employing the ^{14}C technique made measurements of primary production in the Gulf of Mannar and Palk bay regions of the east coast and Prasad *et al.* (1970) estimated the quantitative assessment of the potential resources available from the Indian Seas based on primary production.

It is well known that three factors viz., light, nutrients and primary production are of importance for determining the biological productivity of the sea. Light penetration of the waters determine the depth of the euphotic zone while the nutrients indicate the fertility of the waters to promote productivity and the production at primary level is dependent on the availability of phytoplankton.

Euphotic Zone

The investigations so far revealed that the average depth of the euphotic zone along the west coast is 60 m. According to Qasim (1982) the depth of the euphotic zone in the northern Arabian Sea is 40 m and that of the southern part is 60 m. However, recent investigations on board FORV *Sagar Sampada* indicated 75 m depth of euphotic zone in the north-west coast in the oceanic waters while at the Wadge Bank area of south west coast, it was found to be at 45-50 m.

Taking into consideration various environmental factors that influence the primary production, it is generally accepted that light is never a limiting factor in the Indian Seas. But due to turbidity the light penetration and in turn the depth of the euphotic zone is limited to 1 - 1.5 m as was observed in the Cochin backwaters (Qasim et al. 1969) and also in the mud bank area of Alleppey (Nair *et al.* 1984). However, in the nearshore waters of the marine environment, the euphotic zone extends to about 40 m, while in the offshore waters, it extend upto 50 to 60 m and in the clear blue waters of the oceanic regions, especially near the Lakshadweep and Andaman Nicobar Islands, it extends upto 85-90 m (Nair *et al.* 1973).

Factors affecting/favouring primary production

It is an established fact that the replenishment of nutrients in the production layer is normally the key factor that determines the magnitude of primary production. This replenishment may be the result of regeneration or due to vertical mixing process like upwelling and turbulance by which the nutrient rich sub surface waters are carried into the euphotic zone. In the open ocean the replenishment of nutrients is brought about principally by water circulation. The highest rate of production is normally found in areas where there is no pronounced stratification of water masses. The other important factor that determines 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 rate of production.

Temperature plays an indirect role on primary production by setting up a thermocline in the Oceans above which forms the mixed layer. According to Steeman Nielsen and Jensen (1957), the replenishment of nutrients in the open ocean is provided primarily by water circulation whereas in shallow coastal waters, it is provided by decomposition taking place in the upper layers of the bottom sediments by micro-biological processes which are dependent on temperature. Salinity variations have also some effect on the rate of photosynthesis. Salinity appears to be the controlling factor for the primary production in the estuarine system. In the inshore and oceanic environments also sudden fall in salinity during monsoon months associated with low temperature and high nutrient enrichment favour the production of primary organic matter.

The phenomenon of upwelling on the west coast of India has a pronounced effect on the rate of primary production. The IIOE results as well as several other publications (Shomura *et al.* 1967; Prasad *et al.* 1970) indicated that the rate of primary production is of a high order in areas of upwelling. It was found to be more than 2-3 times during the south west monsoon than the north east monsoon and generally Arabian Sea was found to be more productive than Bay of Bengal.

Primary production in various ecosystems of the Indian Seas

1. Backwaters and estuaries

Cochin backwaters and the entire estuarine system has been studied by various authors (Qasim *et al.* 1969; Gopinathan *et al.* 1984) for the estimation of primary production. These authors made use of ^{14}C technique concurrently with oxygen method and found that the gross production ranged from 0.35 - 1.50 $gC/m^3/day$. The annual production rate of this estuarine system was about 300 gC/m^2. It is observed that three main ecological factors namely, light, salinity and nutrients govern the rate of primary production in this ecosystem.

In the Vembanad lake, adjacent to Cochin estuary, relatively higher rate of production was observed. The rate of production was uniformly high, exceeding 100 $mgC/m^3/hr$. Nair *et al* (1975) have estimated the annual gross production for the entire Vembanad lake in the order of 1 lakh tonnes of carbon comprising about 300 km^2 area. In the Goa estuarine system Dehadrai and Bhargava (1972) determined the gross productivity by oxygen method which ranged from 135 to 550 $mgC/m^3/day$ in the Mandovi estuary and from 150 to 580 $mgC/m^3/day$ in the Zuary estuary. In the Vellar estuarine system on the east coast, the gross production ranged from 12-37 $mgC/m^3/hr$ (Venugopal, 1969) and in Killai backwaters, Bhatnagar (1971) measured a gross production of 251 $mgC/m^3/day$.

2. Mangrove areas

Mangroves are specialised ecosystems found all along the Indian coastline. The primary production rates of the mangroves of Cochin backwaters indicated a range of 160-1485 mgC/m3/day (Rajagopalan *et al.* 1985). For Pichavaram mangroves on the east coast, Krishnamurty and Sundararaj (1973) have given an average primary production rate of 7.5 $gmC/m^3/day$, indicating high production in the ecosystem. The mangroves of Andaman-Nicobar Islands have a very high production rate of exceeding 2.0 $gmC/.m^3/day$, attaining upto 3.6 $gmC/m^3/day$ in the pre-monsoon period (Gopinathan and Rajagopalan, 1983).

3. Mud banks

Unlike the rest of the west coast, where the maximum rate of production was during the monsoon months, the mud bank showed low values during these periods while during the pre-monsoon months, the same area revealed high rate of production. The rate of potential assimilation was uniformly high averaging to 35 $mgC/m^3/hr$ with the maximum during Feb-May when there was no mud bank prevailing in this area.

4. Coastal environment

In the coastal environment, measurement of primary production have been made at Mandapam, Lawson's Bay, Cochin and Tuticorin and in selected ecosystems of the west and east coasts of India. Investigations hitherto made on the productivity of the coastal environment revealed that the shallow inshore regions are highly productive with an average rate of production of 1.0 $gmC/m^2/day$. The season of upwelling which coincides with the monsoon is the most productive period with average rates exceeding 2.0 $gmC/m^2/$ day. Of course, there is spatial and seasonal variations in the pre and post monsoon periods depending on light penetration and depth of mixing. On the south west coast of India, the 50 m depth zone is the most productive zone with an average production rate exceeding 1.0 $gmC/m^2/day$, decreasing seaward.

Prasad *et al* (1970) observed that rates of primary production in the continental shelf of the Indian Seas are uniformly high during most part of the year. The mean net production was 510 mgC/m²/day. Hence they concluded that 6% of the euphotic coastal waters account for approximately one seventh of the entire primary production in the Indian Ocean.

Measurements of primary production has also been made for seagrass beds, coral reefs and atolls. For coral reefs and atolls flow respiratory technique has been employed (Pillai and Nair, 1972). The gross and net primary production in the lagoon at Kavarati were found to be 12.9 gmC/m²/day and 3.3 gmC/m²/day respectively. Gulf of Mannar, Minicoy and Andaman reefs indicated a production rate of 7.3, 9.1 and 3.9 gmC/m²/day respectively.

5. Oceanic environment

According to Qasim (1977), the west coast of India is an area of wide temporal and spatial fluctuations from the point of productivity. Bhargava *et al* (1978) while studying the productivity of the Arabian Sea mentioned average values ranging from 75 to 806 mgC/m²/day in different months. Silas (1975) reported the productivity in the shelf waters between 50 and 200 m along the west coast of India as 470 mgC/m²/day and for the offshore waters as 180 mgC/.m²/day. However, Radhakrishna *et al.* (1978) reported high values of 875 mgC/m²/day in the shelf and 607 mgC/m²/day in the offshore regions of the Arabian Sea. Further, Qasim *et al* (1978) have reported a maximum production value of 750 mgC/m²/day in the coastal waters of Karwar and Calicut.

Radhakrishna (1975) measured the productivity of the Bay of Bengal in selected areas and found that the column productivity varied from 63 to 485 mgC/m²/day for offshore stations where as nearshore stations had showed a unit volume production of 110 mgC/m²/day. He has come to the conclusion that primary productivity in the Bay of Bengal is relatively low as compared to the Arabian Sea which was attributed to the topographical features such as narrow continential shelf and also heavy cloud cover. As is well known, upwelling in the Bay of Bengal is less intense and limited compared to the Arabian Sea. Steeman Nielsen and Jensen (1957) have 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 system which discharge large quantities of terragenous organic matter which restricts light penetration.

Qasim *et al* (1978) determined the biological productivity of coastal waters of India from Dabhol to Tuticorin, for an area of 43 x 10^3 km^2 and arrived at a figure of 330 $mgC/m^2/day$ or 122 tonnes of carbon/km^2/yr or 5 million tonnes of carbon for the entire year. After making a thorough comparative study at six different tropical environments in the Indian Ocean, Qasim (1977) came to the conclusion that the rate of production near the shore 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.

Recent studies on board FORV *Sagar Sampada* conducted during the post-monsoon period indicated that shelf waters of the south west coast had the production rate of 190 $mgC/m^2/day$ and the offshore waters an average of 140 $mgC/m^2/day$. It was also noted that the regions of high concentrations of chlorophyll *a* are the coastal waters of Gujarat and Bombay in the north west coast and Wadge Bank area in the south west coast. Integrated values of chlorophyll *a* between 0 and 75 m depth along the west coast showed that much of the chlorophyll *a* occurs below the surface. High concentrations of photosynthetic pigments were found between 20 and 30 m. Column production of chlorophyll *a* in the west coast indicated that the southwest coast showed higher values than the northern part. However, according to Qasim (1982), the average production in the northern Arabian Sea is higher than the average for the entire west coast implying that the northern region is by and large more fertile than the southern region.

Productivity and potential yield

The shelf areas of the Indian Seas which sustain the bulk of the fish production at present are on the whole, having a high rate of primary production. Because of the constant replenishment of nutrients in the surface layers, the shallow waters are generally more productive. An average rate of 0.5 to 1.0 $gmC/m^2/day$ is observed in the shallow areas most of the time. Rates exceeding 2.0 $gmC/m^2/day$ are found during the south west monsoon period. In the eastern Arabian Sea towards the Indian coast, the average rate within 50m depth is about 1.2 $gmC/m^2/day$ and for the outer shelf region, the rate is 0.53 $gmC/m^3/day$. The net production (taken as 60% of the gross production) for the shelf area on the west coast of India, upto 50 m depth has been computed as 30 x 10^6 tonnes of carbon and between 50 and 100 m, the net production is only 17 x 10^6. Thus for the whole continental shelf area upto 100 m, the annual net production is computed as 47 million tonnes of carbon. The rate of primary production for the east coast of India are 0.65 $gmC/m^2/day$ on the shelf and 0.20 $gmC/m^2/day$ outside the shelf and the annual estimate of net production is 17 million tonnes of carbon, totalling to 64 million tonnes of carbon from the entire continental shelf area upto 100 m depth of the Indian Seas (Nair and Pillai, 1983) (Table - 1).

Table - 1 Estimation of Primary Production in the Indian Seas

Area	Production Upto 50m	mgC/m2/day upto 100 m	Net Production upto 50 m	(Tonnes) upto 100 m	Total
West Coast of India	1200	530	30×10^6	17×10^6	47×10^6
East Coast of India	680	200	10×10^6	7×10^6	17×10^6
Continental shelf upto 100 m	-	-	-	-	64×10^6
Exclusive Economic Zone (2.02 mill. sq.km.)	-	-	-	-	283×10^6

Several attempts have been made to relate primary production with that of potential yield or optimum sustainable yield. It has been observed by Steeman Nielsen and Jensen (1957) that the landings of fishery resources in intensively exploited waters is about 0.3 to 0.4% of the organic matter, produced by the phytoplankton. Accordingly, the potential harvest of resources from the whole Indian coasts is about 3 million tonnes. Actually we are exploiting about one third only from the coastal region; hence there is scope for further exploitation of the resources.

In view of the declaration of 200 miles Exclusive Economic Zone, having a total area of 2.02 million sq. km, it would be worthwhile computing the annual production rate within this area and the potential harvestable resources available. The different gradients within the shelf and outside the shelf when integrated give a total production of 283 million tonnes of carbon (Fig.1). In view of the distance involved and the sparseness of distribution, a minimum possible exploitation of just 0.20% could be expected from the entire EEZ of

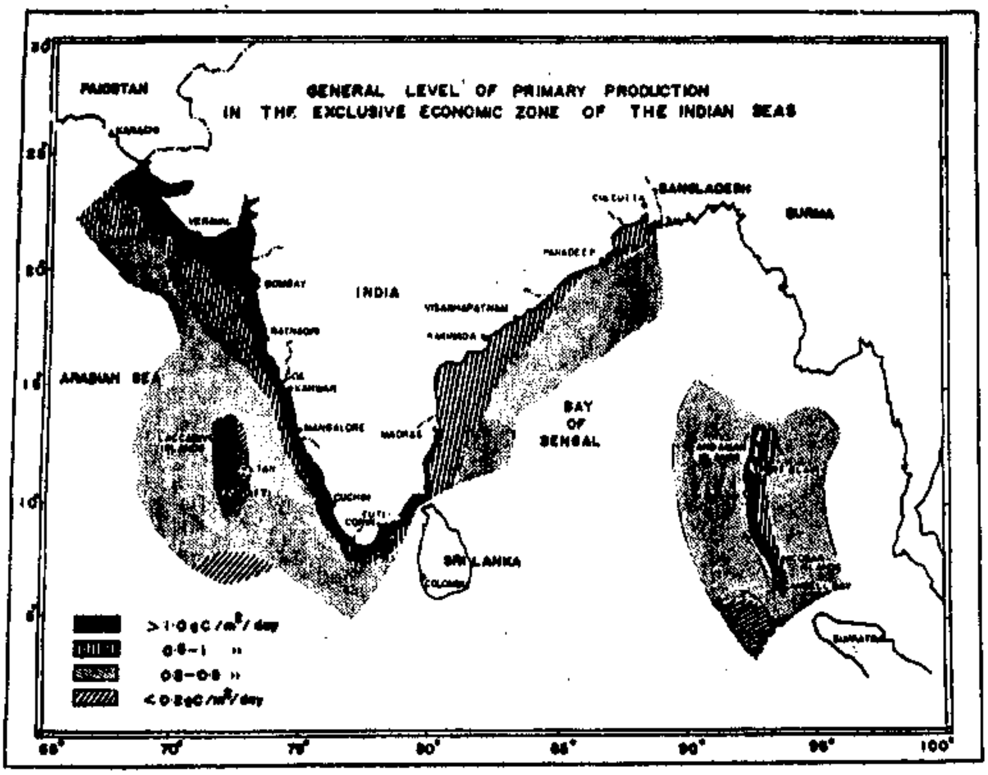

Fig.1 General level of primary production in the Indian EEZ

India. Therefore the exploitable yield of the harvestable resources from the EEZ would amount to about 5.5 million tonnes (Gopinathan, 1981), both pelagic (70%) and demersal (30%) resources. Since the present yield is only 2.4 million tonnes, there is vast scope for further exploitation.

In recent years, the technology of remote sensing has been used in selected areas to study the bioproductivity by estimating the chlorophyll concentrations along with sea-truth data collected during over passes of satellites. 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 IRS P4 and future Satellites proposed to be launched and through larger coverage of near and offshore regions during the Satellites overpass in the coming years (Pillai and Gopinathan, 1996).

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