

### 3. Primary production in some tropical environments

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#### Introduction

In this chapter 'primary production' refers to the photosynthetic production of organic carbon in which carbon dioxide is the only source of carbon. From this definition it is easy to distinguish the chemosynthetic uptake of carbon dioxide by microbial flora where no photosynthesis is involved.

During the last decade, a considerable amount of information has accumulated on the primary production of tropical and sub-tropical regions of the world and hence to present a comprehensive review on the subject would be beyond the scope of this chapter. It was, therefore, felt

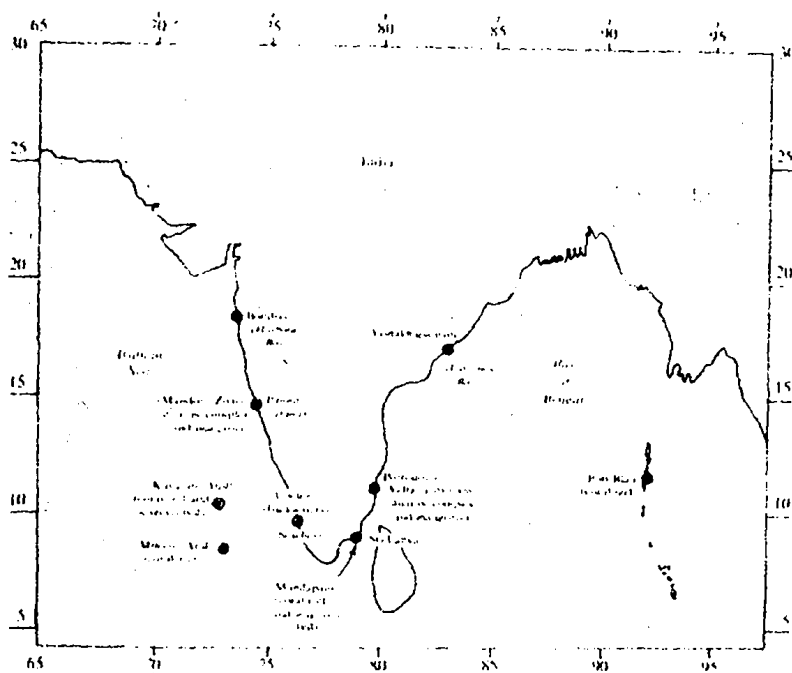


Fig. 3.1. Map of India showing the places where observations on primary production of different types of environment were made. The environments have been indicated in parentheses.

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that this review should be confined to the data which have appeared on certain environments from the Indian region, largely as a part of the International Biological Programme IBP/PM. The environments dealt with here are shown in Fig. 3.1 and consist of:

1. Coastal waters
2. Backwaters and estuaries
3. Coral reefs and atolls
4. Mangrove swamps
5. Seagrass beds
6. Sandy beaches

On problems related to the productivity of the Indian Ocean, the reader may refer to some of the earlier works (Kabanova, 1968; Humphrey, 1972; Krey, 1973; Aruga, 1973; Qasim, 1977).

The methods used for measuring primary production of the six environments noted above have been diverse and these will be mentioned briefly in different sections. From the data available, attempts have been made to assign specific levels and ranges of production in each environment.

#### **Coastal waters**

##### *West coast of India (Arabian Sea)*

During the period 1965-8, measurements of primary production, using the  $^{14}\text{C}$  technique, were made by Nair (1970) and Nair, Samuel, Joseph & Balachandran (1973) from Karwar to Cape Comorin. Tables 3.1 and 3.2 give the data from this region. As can be seen from Table 3.1, the rate of production near the coast (up to 50 m depth) ranged from 0.18 to 2.45 g C/m<sup>2</sup>/day. At the Wadge Bank, which is 38 m deep (the first station given in Table 3.1), the high production recorded was during the month of June (Nair *et al.*, 1973). Lower rates of production within the range 0.01-0.95 g C/m<sup>2</sup>/day, were in deeper waters (Table 3.2), except in September at two stations which were 60 m and 90 m deep. The values at these stations were exceptionally high and probably indicate bloom situations associated with upwelling.

The next set of  $^{14}\text{C}$  measurements was made from Cochin to Quilon from August to October 1967, along with submarine illumination and several other hydrographical factors (Radhakrishna, 1969). The carbon assimilation at different locations was found to range between 0.38 and 1.11 g C/m<sup>2</sup>/day (Table 3.3). Maximum carbon uptake was recorded at depths where the light intensity was about 50% of the incident illumination. The euphotic zone at the 13 stations ranged from 15.5 to 22 m and phosphate-phosphorus from 1.75 to 3.00  $\mu\text{g-at/l}$ .

Dehadrai & Bhargava (1972a) made measurements of chlorophyll *a* for

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Table 3.1. Rates of primary production at 15 stations along the west coast of India (Arabian Sea) within 50 m depth

Date	Position		Station depth (m)	Production (g C/m <sup>2</sup> /day)
	Latitude N	Longitude E		
1965				
5 June	8° 00'	77° 20'	38	2.09
15 December	13° 26'	75° 10'	40	0.95
16 December	Karwar Bay		7	1.39
1966				
3 February	9° 40'	76° 00'	40	0.18
6 September	9° 00'	76° 28'	25	1.24
1967				
7 August	14° 08'	74° 18'	30	0.61
6 September	9° 52'	76° 10'	18	2.37
7 September	9° 20'	76° 51'	50	1.18
7 September	8° 42'	76° 35'	35	1.26
9 September	7° 45'	77° 19'	50	0.48
9 September	7° 45'	78° 00'	47	1.43
1968				
20 July	8° 53'	76° 21'	50	1.12
21 July	10° 29'	75° 51'	37	0.89
22 July	11° 19'	75° 36'	28	1.34
24 July	12° 08'	74° 58'	37	2.45

From Nair (1970)

Table 3.2. Rates of primary production at 53 stations along the west coast of India (Arabian Sea) beyond 50 m depth

Date	Position		Station depth (m)	Production (g C/m <sup>2</sup> /day)
	Latitude N	Longitude E		
1968				
4 June	7° 30'	76° 00'	1500	0.33
6 June	8° 50'	75° 20'	1200	0.03
7 June	9° 30'	75° 10'	2000	0.13
12 October	9° 50'	75° 26'	2000	0.11
13 October	9° 20'	75° 39'	4000	0.16
14 October	8° 44'	75° 38'	350	0.05
15 October	7° 53'	77° 04'	550	0.53
16 October	8° 15'	75° 47'	1200	0.06
11 November	7° 56'	76° 55'	70	0.07
11 November	7° 52'	76° 38'	900	0.22
12 November	8° 32'	76° 00'	200	0.13
12 November	8° 32'	76° 21'	300	0.01
13 November	8° 43'	75° 26'	800	0.13
15 November			200	0.50

Table 3.2: (cont.)

Date	Position		Station depth (m)	Production (g C/m <sup>2</sup> /day)
	Latitude N	Longitude E		
1965				
24 November	11 26'	74 51'	82	0.11
25 November	12 20'	74 40'	58	0.05
25 November	12 40'	74 15'	86	0.27
27 November	13 30'	73 00'	1600	0.21
27 November	13 30'	73 30'	180	0.10
28 November	12 20'	74 21'	180	0.14
29 November	11 15'	74 34'	1200	0.04
14 December	11 10'	75 10'	60	0.57
19 December	12 30'	74 16'	180	0.04
1966				
6 January	14 09'	73 20'	160	0.25
7 January	13 35'	72 55'	1900	0.35
7 January	13 06'	73 33'	1800	0.28
8 January	12 27'	74 20'	120	0.25
5 February	7 50'	77 11'	300	0.13
7 February	9 30'	75 35'	1000	0.07
8 February	9 55'	75 09'	2000	0.39
21 April	11 15'	74 49'	260	0.45
22 April	11 40'	76 08'	1400	0.05
26 May	12 50'	74 05'	180	0.13
7 June	8 12'	76 44'	80	0.57
8 June	8 46'	76 10'	150	0.38
25 June	13 30'	73 34'	120	0.29
26 June	11 56'	74 11'	1700	0.22
7 September	8 00'	77 41'	60	4.55
7 September	8 00'	76 58'	90	4.55
8 November	16 30'	73 40'	110	0.11
8 November	16 29'	71 42'	300	0.12
6 December	11 15'	74 55'	120	0.09
1967				
9 March	9 21'	75 52'	188	0.05
18 April	10 27'	72 41'	1600	0.12
20 April	10 43'	74 26'	2160	0.21
8 June	10 28'	72 42'	1900	0.06
9 June	11 23'	72 46'	1900	0.04
6 August	12 44'	74 28'	56	0.18
31 August	11 16'	73 50'	2100	0.05
8 September	8 17'	75 44'	1400	0.40
9 September	7 45'	76 43'	183	0.42
10 September	7 27'	77 40'	117	0.95
10 September	7 32'	76 41'	850	0.95

From Nair (1970)

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Table 3.3. Rates of primary production at 13 stations from Cochin to Quilon along the west coast of India

Date	Position		Station depth (m)	Production (g C/m <sup>2</sup> /day)
	Latitude N	Longitude E		
1967				
21 August	9° 58'	76° 08.5'	21	0.43
21 August	9° 28.5'	76° 13'	25	0.38
21 August	8° 55'	76° 15'	43	1.11
11 September	9° 03'	76° 19'	41	0.97
12 September	9° 31'	76° 08'	46	0.90
12 September	9° 30'	76° 18'	24	0.76
27 September	8° 51'	76° 16'	58	0.74
27 September	9° 20'	76° 24'	28	0.93
12 October	8° 32'	76° 40'	76	1.07
13 October	8° 32'	76° 32'	61	0.38
13 October	9° 08'	76° 20'	42	0.87
14 October	8° 02'	76° 44'	127	0.95
16 October	8° 03'	76° 04'	1150	1.01

Modified from Radhakrishna (1969)

a period of 9 months (September 1969 to May 1970) in coastal waters, from Goa to Bombay. During the period November-January, chlorophyll *a* was found to increase at most locations and ranged from 2.4 to 18.8 mg/m<sup>3</sup>.

In addition to the data summarized above, a series of measurements was made from the western Indian Ocean during RV *Anton Bruun* cruises of 1963 and 1964 (Ryther *et al.*, 1966). But, since these measurements were not extended up to the coast, they have not been included here.

Recently the contributions of nanoplankton and microplankton have been studied in coastal waters of Cochin. The annual contribution of nanoplankton (algae smaller than 65  $\mu$ m) to the total photosynthesis was about 66.40% (Vijayaraghavan, Joseph & Balachandran, 1974).

#### East Coast of India (Bay of Bengal)

In the Palk Bay (near Mandapam), Prasad & Nair (1963) made a series of <sup>14</sup>C measurements. These have been given in Table 3.4. Maximum uptake was generally recorded at the surface, except in some instances when it was at a few metres below the surface. The values ranged between 0.10 and 8.68 g C/m<sup>2</sup>/day. During June and July, the values were found to be high.

In the nearshore waters, where the turbidity was high, the euphotic zone was about 6 m and the column production was relatively low. In clear

Table 3.4. Rates of primary production at 18 stations along the east coast of India, Palk Bay (Bay of Bengal)

Date	Place	Depth range investigated (m)	Production (g C/m <sup>2</sup> /day)
1961			
13 March	Mandapam	0-10	0.40
12 June	Mandapam	0-10	4.37
1962			
26 June	Mandapam	0-10	6.04
4 July	Mandapam	0-10	8.68
9 July	Mandapam	0-10	3.77
11 July	Thangachumadam	0-12	3.20
18 July	Uchippuli	0-12	3.22
1963			
20 February	9° 24' N, 79° 13' E	0-10	0.10
21 February	9° 44' N, 79° 16' E	0-10	0.17
11 June	Mandapam	0-10	1.07
17 June	Mandapam	0-10	2.21
1964			
26 August	Mandapam	0-8	1.40
26 August	Mandapam	0-8	1.68
2 September	Mandapam	0-8	1.11
2 September	Mandapam	0-8	1.03
16 September	Mandapam	0-8	1.02
9 October	Mandapam	0-10	1.30
13 October	Mandapam	0-7	0.74

From Nair (1970).

waters, the euphotic zone ranged from 15 to 40 m, depending upon the distance from the shore, and in these waters the daily production of the order of 3-5 g C/m<sup>2</sup>/day was often recorded (Nair, 1970).

The other relevant data on the productivity of the Bay of Bengal are from the Galathea Expedition (Steemann Nielsen & Jensen, 1957) and from the first cruise of RV *Anton Braun*. The former are from the deeper waters and the latter from shallow regions of the coast. In the deeper parts, the values ranged from 0.12 to 0.31 g C/m<sup>2</sup>/day, while in the shelf region the range was 0.01 to 2.16 g C/m<sup>2</sup>/day (Table 3.5).

A summary of the data collected from 73 stations of both west and east coasts of India has been attempted by grouping the values into four Indian States and three depth regions (Nair *et al.*, 1973). This has been presented in Table 3.6. The average primary production for the entire coastal waters of India up to 50 m depth is 1.19 g C/m<sup>2</sup>/day, from 50 to 200 m the average value is 0.25 g C/m<sup>2</sup>/day and from depths greater than 200 m it is 0.18 g C/m<sup>2</sup>/day (Table 3.6).

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**Table 3.5. Rates of primary production at 15 stations along the east coast of India (Bay of Bengal)**

Date	Position		Station depth (m)	Production (g C/m <sup>2</sup> /day)
	Latitude N	Longitude E		
1951				
23 April	14° 20'	82° 00'	3240	0.12
24 April	17° 10'	84° 30'	2860	0.25
26 April	20° 37'	87° 33'	62	0.60
2 May	19° 53'	89° 05'	1400	0.16
4 May	13° 58'	91° 05'	3000	0.24
5 May	10° 32'	90° 59'	850	0.31
1963				
27 March	11° 49'	92° 53'	87	0.01
28 March	11° 23'	93° 31'	80	0.36
1 April	15° 08'	94° 54'	29	0.25
1 April	15° 08'	94° 04'	58	0.25
5 April	19° 41'	93° 08'	38	2.16
5 April	19° 32'	92° 52'	55	0.24
22 April	20° 35'	87° 51'	80	0.83
28 April	17° 41'	83° 19'	65	1.53
28 April	17° 35'	83° 25'	67	0.11

The first six measurements are from the Galathea Expedition and the rest from the first Cruise of RV Anton Bruun. (I.I.O.F. Data sheets, Woods Hole Oceanographic Institution, 1964).

**Table 3.6. Average rates of primary production (g C/m<sup>2</sup>/day) obtained after pooling the data of 73 selected stations into four different states of India and three different depth regions**

States	Less than 50 m		50 to 200 m		Greater than 200 m	
	No. of stations	Average	No. of stations	Average	No. of stations	Average
Tamil Nadu	3	1.33	4	0.37	6	0.18
Kerala	10	1.22	13	0.25	22	0.17
Karnataka	6	1.08	4	0.19	3	0.28
Maharashtra	—	—	2	0.12	—	—

Modified from Nair *et al.* (1973).

From the above account it is clear that very few measurements have so far been made in the coastal waters of India. The available data do not cover all seasons and hence a correct picture of the primary production of coastal waters cannot be obtained. The Arabian Sea and the Bay of Bengal are greatly influenced by the monsoon system and hence uninter-

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rupted observations in different seasons are necessary for determining the overall productivity of shelf waters.

### Backwaters and estuaries

#### *Backwaters of Kerala*

The backwaters consist of a system of brackish-water lagoons and swamps, occupying an area of several hundred square kilometres in the central part of Kerala State, south-west India (Fig. 3.2). The entire region

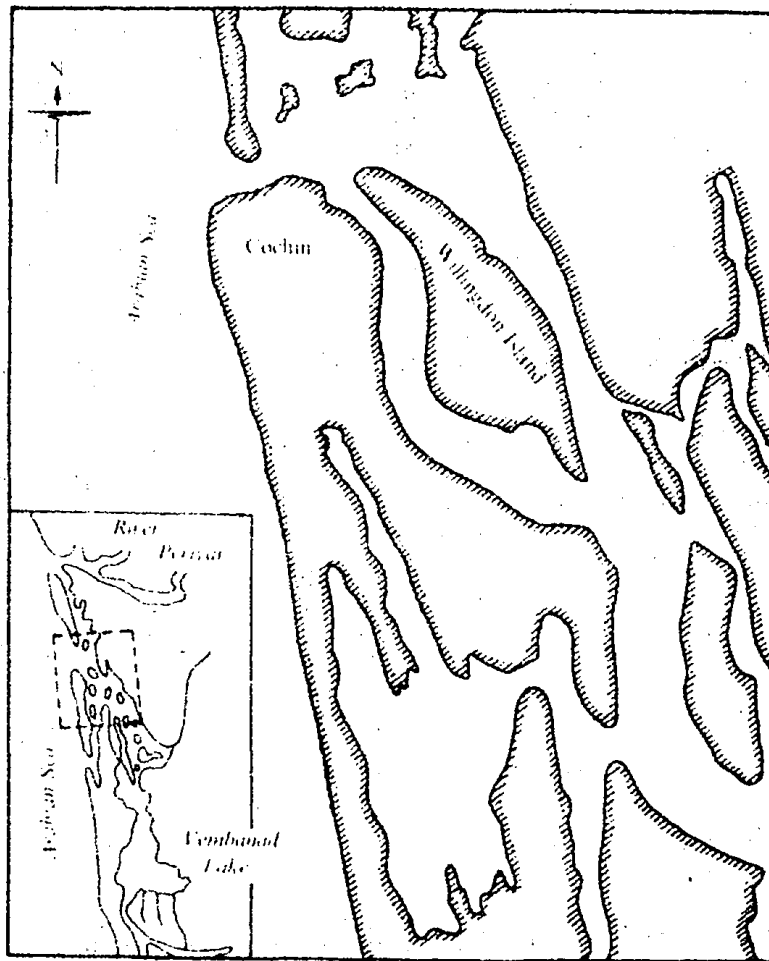


Fig. 3.2. Map showing a portion of Kerala backwaters. Inset shows the riverine and marine connections to the backwater system. The portion marked by dotted lines has been enlarged and termed Cochin Backwater. (From *The Biology of the Indian Ocean, Ecological Studies* 3, ed. B. Zeitzschel, Berlin: Springer-Verlag.)



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is a centre of human activity and a number of drains, factory effluents and sewage outlets flow into the backwaters making it in certain parts intensely polluted. The northern part of the backwaters, which has been studied fairly extensively, has been termed 'Cochin Backwater(s)'. This region has also been referred to as a tropical estuary. Much of the earlier work carried out on the backwater has recently been reviewed (Qasim, 1973). However, in view of several additional investigations made during the last few years, the earlier review needs up-dating.

The hydrography of Cochin Backwater is greatly influenced by two main factors: (1) the short-term changes induced by the tides (Qasim & Gopinathan, 1969) and (2) the seasonal changes brought about by the monsoon (Sankaranarayanan & Qasim, 1969). Heavy rainfall and land runoff also affect the hydrography of coastal waters of Kerala (Derbyshire, 1967). However, the first point worth noting in the hydrography of the backwater is that a clear stratification begins to exist in the water column during the months of heavy rainfall (June to September), which makes the surface water quite distinct from the bottom water. This stratification can easily be identified from the vertical gradients of temperature, salinity and oxygen. The stratification gets broken in October-November and then the water becomes well mixed. The other point of interest is the seasonal cycle of nutrients in the backwater. All the three major nutrients (phosphate-phosphorus, nitrate-nitrogen and silicate-silicon) attain maximum concentrations during the monsoon months and their high occurrence seems to be associated with land runoff. In other words, the backwater gets maximum enrichment from May to September when the rainfall is maximum.

Light penetration in the backwater, because of high turbidity, gets considerably reduced. The euphotic zone varies from 2 to 6 m during the year with the attenuation coefficient ( $k$ ) ranging from 0.60 to 3.00 (Qasim, Bhattathiri & Abidi, 1968). Sedimentation of suspended material is maximum during the pre-monsoon (January to April) and post-monsoon months (September to December). Most of the settled material gets resuspended during the monsoon months (May to August) and with the strong ebb currents gets transported into the sea (Gopinathan & Qasim, 1971).

Measurements of primary production in the backwater were made using the  $^{14}\text{C}$  method concurrently with the light-dark bottle/oxygen technique throughout the year. Experiments were conducted *in situ* using a float from which bottles were suspended at various depths of the euphotic zone. Gross and net primary production rates were determined at various depths and these have been given in Fig. 3.3 for the three seasons. Because of high turbidity, primary production was non-existent at depths greater than about 4 m.

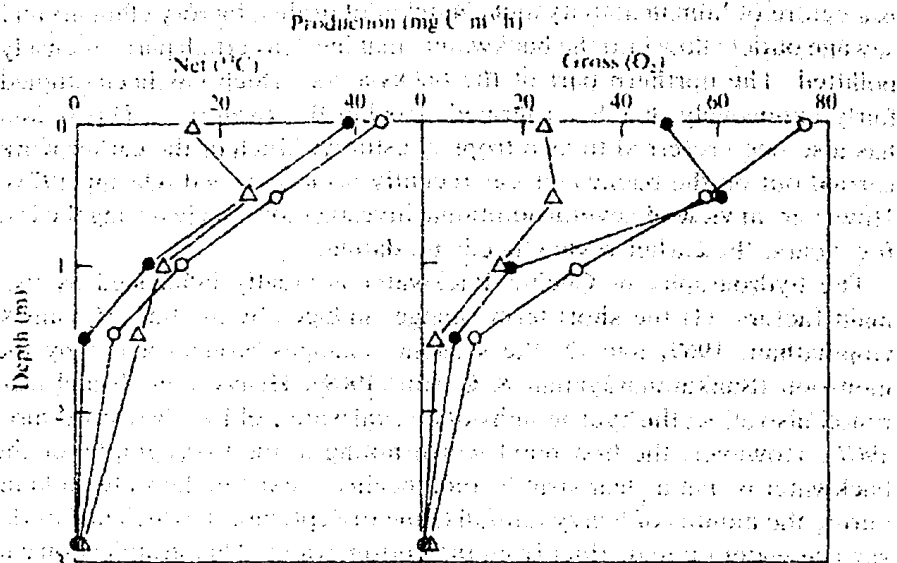


Fig. 3.3. Gross and net primary production in the backwater in relation to depth. Annual data have been pooled into three seasons each of four months. Monsoon season, closed circles; post-monsoon season, triangles; pre-monsoon season, open circles. (From *The Biology of the Indian Ocean, Ecological Studies* 3, ed. B. Zeitzschel, Berlin: Springer-Verlag.)

Monthly values of column production (gross and net) for the narrow euphotic zone have been given in Fig. 3.4. Community respiration was computed from the oxygen decrease in the dark bottle during light-dark bottle experiments. Gross production ranged from 0.35 to 1.50 g C/m<sup>2</sup>/day and net production from 0.25 to 0.88 g C/m<sup>2</sup>/day. The range in respiration was from 0.08 to 0.64 g C/m<sup>2</sup>/day (Qasim, Wellershaus, Bhattathiri & Abidi, 1969; Qasim, 1970a). The annual cycle of production showed three small peaks with approximately three-to-four-fold increase in April, July and October (Fig. 3.4). These peaks were in the form of brief pulses showing no regular seasonal rhythm.

In the Cochin Backwater, about 75% of the total primary production is contributed by nanoplankton and the rest (25%) by microplankton. The contributions of these two components of algae were determined by fractionating the water samples through different grades of bolting nylon and measuring the <sup>14</sup>C uptake, chlorophyll *a* concentration and cell numbers of each size group throughout the year (Qasim, Vijayaraghavan, Joseph & Balachandran, 1974).

Three main ecological factors, namely salinity, light and nutrients were found to govern the fate of primary production in the backwater. The influence of each of these factors was determined experimentally by exposing several species of unialgal cultures to varying salinities, light conditions and nutrients.

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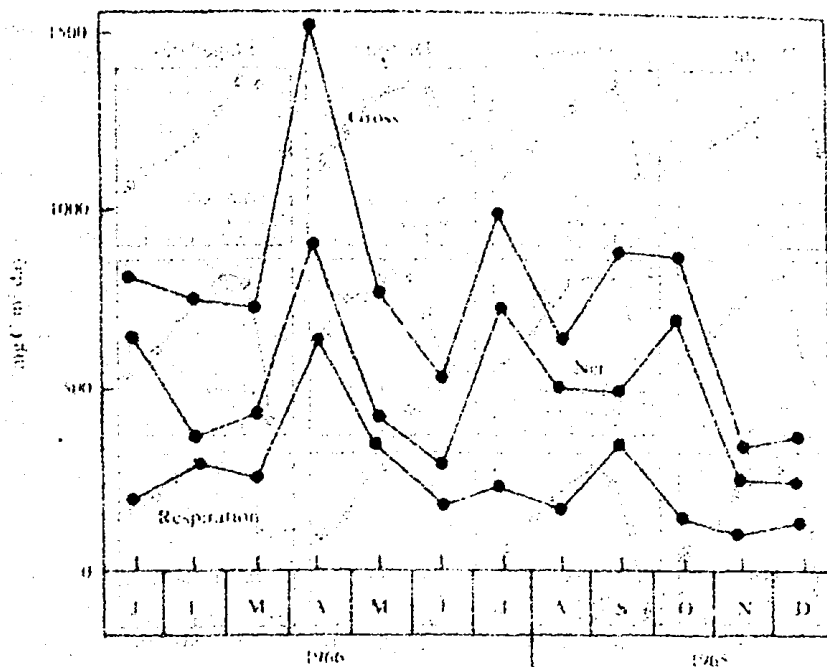


Fig. 3.4. Annual cycle of gross and net primary production in the backwater together with the seasonal changes in community respiration. The values of production and respiration refer to euphotic zone. (From *The Biology of the Indian Ocean, Ecological Studies* 3, ed. B. Zeitzschel, Berlin: Springer-Verlag.)

Fig. 3.5 gives the rates of photosynthesis of 12 organisms at different salinities. In all the organisms, maximum photosynthesis occurred at low salinities (Qasim, Bhattathiri & Devassy, 1972a). The ecological implications of the laboratory experiments were tested from the field data. In the backwater, maximum abundance of algae was found during a period when, because of heavy rainfall and land runoff, the salinity became low. This was confirmed once again by the total cell counts made throughout the year. Maximum numbers of algae were found in September when the salinity was low (Devassy & Bhattathiri, 1974). Many organisms were found to bloom successively at exceptionally low salinities. Such an adaptation in algae is probably to ensure that peak production occurs during a period when the nutrients in the environment are maximum. The enrichment in the estuary and in the waters of the south-west coast of India is associated with large dilutions during the monsoon months (Qasim, Bhattathiri & Devassy, 1972a).

Unialgal cultures of 11 different species were exposed to varying light intensities in an incubator provided with neutral density filters and their rates of photosynthesis were measured by  $^{14}\text{C}$  uptake. The saturation point ( $I_k$ ) in most of the organisms ranged between 11 and 17 kilolux. In

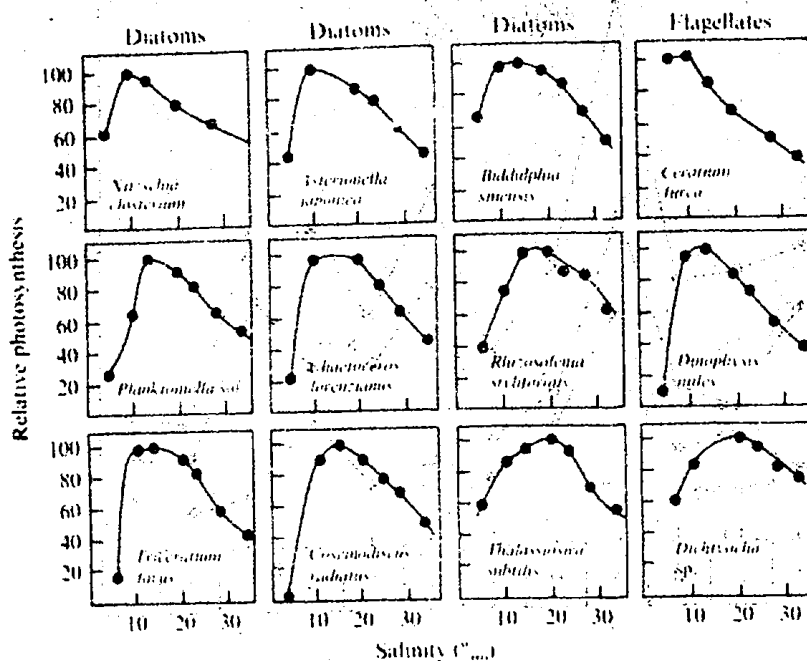


Fig. 3.5. Rates of photosynthesis ( $^{14}C$  uptake) as a percentage of maximum shown by unialgal cultures of diatoms and flagellates in relation to salinity. (From Qasim, Bhattathiri & Devassy, 1972a, *Marine Biology*, 12, 201.)

addition to the intensity effect, the influence of the wavelength of light was also determined by exposing each organism to a portion of the visible spectrum, starting with the longest wavelength. Sharp cut-type glass filters were used in a specially designed incubator for cutting off the transmittance of light (Qasim, Bhattathiri & Devassy, 1972b). In all the organisms, no wavelength-dependence of photosynthesis in saturation light was observed. All regions of the visible spectrum were found to be effective as long as there was enough light energy to stimulate photosynthesis. These observations indicate that marine planktonic algae are capable of adapting themselves to changing light conditions fairly rapidly. Such a chromatic adaptation is of a distinct advantage to the algae which have a floating existence (Qasim, Bhattathiri & Devassy, 1972b).

The nutrient requirements of different algae were found to be quite variable and high instantaneous concentrations of phosphate and nitrate alone did not give rise to a substantial increase in primary production. This was experimentally demonstrated by studying the growth kinetics of nutrient-depleted cells of a diatom, *Biddulphia sinensis*, and a dinoflagellate, *Ceratium furca*. The growth rate of both these organisms, as a function of phosphate and nitrate, followed the kinetics similar to that of the Michaelis-Menten equation for bacterial growth. The capacity of each

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organism to utilize phosphate and nitrate, when available either singly or in combination, was determined from the values of the half-saturation constant ( $K_s$ ).

Both the organisms (*Biddulphia* and *Ceratium*) were found to occur in the Cochin Backwater. The former became abundant during the monsoon months when the nutrients reached their maximum concentrations, and fairly high densities of the latter were recorded during the pre-monsoon months when the nutrients were low. *Ceratium* has a low  $K_s$ , and hence it is a better competitor at low concentrations of nutrients than *Biddulphia*. At high concentrations of nutrients, *Biddulphia*, which has a higher  $K_s$ , dominates over *Ceratium*. Thus, the study of the growth kinetics of the two organisms gave an explanation of the observed seasonal succession of the two species (for details see Qasim, Bhattachari & Devassy, 1973).

A simple model developed by Margalef (1967) was used to study the annual cycle of primary production and plankton succession in the Cochin Backwater. The increased flushing rate during the monsoon months seemed to govern the abundance of phytoplankton in the estuary. When flushing rate increased, the algal densities became very low. During the post-monsoon months, when the estuary remained relatively stagnant, the algal biomass was high (Wyatt & Qasim, 1973).

Besides phytoplankton, the other important component in the estuary is organic detritus. It plays a very significant role in the food chain of the estuary and leads to several additional pathways between primary production and animal nutrition (Qasim, 1970a, 1972a). The importance of detritus, its rate of sedimentation, its chemical composition and nutritive value have been described by Qasim & Sankaranarayanan (1972). The total quantity of settled detritus ranged from 67 to 1013 g/m<sup>2</sup>/day. Detritus is perhaps the most readily available food material in the estuary. It occurs at the bottom in coarsely particulate form and is derived from the dead material of plants and animals. Inorganic matter such as fine silt and sand particles form a substrate around which organic material adheres and forms larger aggregates of detritus. Caloric content of detritus ranges from 200 to 500 cal/g dry wt.

To determine the nutritive value of detritus, laboratory experiments were conducted on the energy conversion of a penaeid prawn, *Metapenaeus monoceros*, by feeding it on estuarine detritus. The shrimp readily consumed detritus and its energy budget was worked out after fourteen days of experiments. Measurements were made of energy utilized for growth,  $P$ ; intake of food or consumption,  $C$ ; and assimilation,  $A$ . Gross growth efficiency ( $P/C$  or  $K_g$ ) ranged from 10.5 to 35.2% (average 22%) and net growth efficiency ( $P/A$  or  $K_n$ ) ranged from 11.7 to 36.4% (average 24%). Food efficiency was inversely related to growth efficiency and the assimilation efficiency was of the order of 93% (Qasim & Easterson, 1974).

Seasonal changes in the zooplankton abundance in the estuary have been

studied by several authors in recent years. Copepods have been found to constitute the predominant component throughout the year (Tranter & Abraham, 1971; Pillai, 1971). Among copepods, the population of omnivores remains large in all the seasons. When the copepod biomass in the estuary was low, their population was heterogenous, i.e. the species diversity was greater (Pillai, Qasim & Nair, 1973).

#### *Mandovi-Zuari estuarine complex*

Two large estuaries, demarcated by the rivers Mandovi and Zuari, are found in Goa on the northern and southern sides of Panaji Island. About 14 and 11 km from their respective openings into the Arabian Sea, the two estuaries are connected by a natural canal, the Cumbarjua canal (Fig. 3.6). A large number of tributaries join the river Mandovi, whereas no major tributary meets the river Zuari. Both these estuaries are fed largely by the monsoon water. The average rainfall in Goa is 2611 mm per year, of which nearly 80% occurs from June to August. The Zuari estuary is broader and has a greater marine influence than that of the Mandovi estuary. The tides in the estuaries are of mixed, semi-diurnal nature with a range of about 2 m. The tidal influence is felt up to 35 km and 41 km upstream in Mandovi and Zuari respectively. The flow of water in the estuarine complex is largely dependent upon tidal conditions. During the flood tide, the water enters through Zuari and reaches Mandovi via the Cumbarjua canal. During the ebb, the flow is reversed (Das, Murty & Varadachari, 1972). The speeds of surface and bottom currents at the mouth of Mandovi estuary are 160 and 128 cm/s during the flood and 108 and 98 cm/s during the ebb respectively. These measurements were made in March using an Ekman-type current meter. In the two estuaries, the depth of water varies from 2 to 11 m.

In recent years, several communications have appeared on the hydrography of these two estuaries (Dehadrai, 1970*a, b*; Dehadrai & Bhargava, 1972*b*; Murty & Das, 1972). These authors reported several findings which are summarised below.

Light penetration, as measured by the Secchi disc, was found to vary considerably during the different months of the year. The euphotic zone ranged from 1 to 4 m. The range in surface temperature during the year was from 24 to 32 °C. The lowest temperature was recorded in December-January and the highest in April-May. The authors noted above have divided the year into three seasons, each of four months. Thus, the pre-monsoon season includes February to May; monsoon, June to September; and post-monsoon, October to January. Seasonal changes in the salinity were largely dependent upon the rainfall and land runoff. During the monsoon season, surface salinity varied from 0.12 to 30.20‰ in

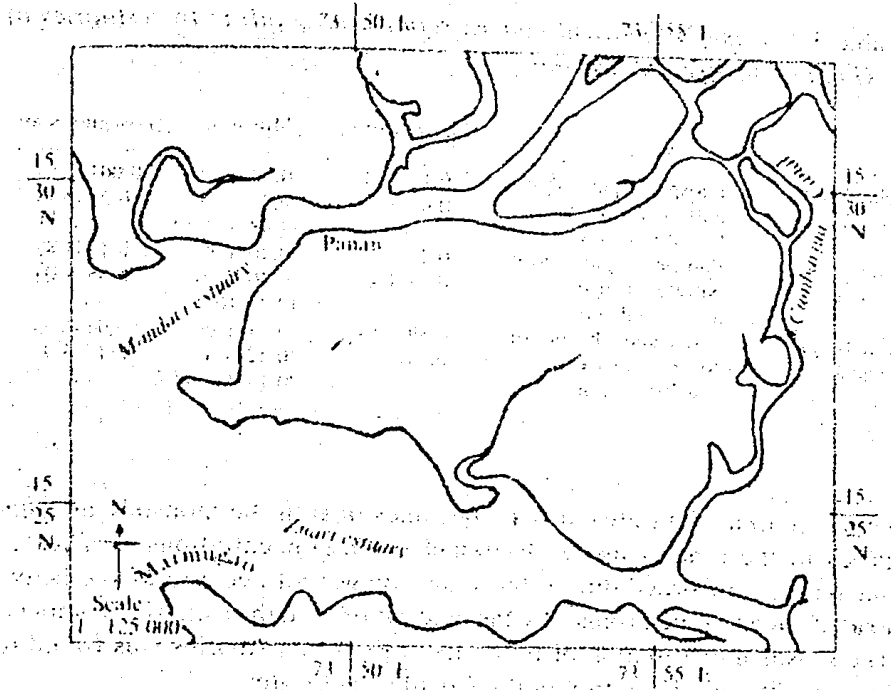


Fig. 3.6. Mandovi-Zuari estuarine complex of Goa with their marine and rivertine connections.

Mandovi, from 0.21 to 32.9‰ in Zuari and from 0.12 to 15.6‰ in Cumbarjua. Salinities at the bottom were slightly higher than at the surface but no stratification in the water column was recorded. In other words, the water throughout the year remains fairly well-mixed. This feature is unlike the Cochin Backwater where there is a clear stratification in temperature, salinity and oxygen during the monsoon months (June to September), which keeps the surface and bottom waters quite distinct. In the post-monsoon season, the ranges in salinity in Mandovi, Zuari and Cumbarjua were 40.54–33.58‰, 29.07–34.95‰, and 7.74–32.89‰ respectively and in the pre-monsoon the ranges in salinity were 22.81–36.19‰, 31.51–36.25‰, and 20.39–36.26‰.

From the above data it is clear that the Zuari estuary gets the maximum marine influence and the Cumbarjua canal the least.

During the year, three major nutrients, namely phosphate-phosphorus, nitrate-nitrogen and silicate-silicon, occur in varying proportions in the estuarine complex of Goa (Table 3.7).

The nutrient ranges given in Table 3.7 indicate that there is no major difference in their concentration in the three regions. Presumably it is the same water which flows from Zuari via Cumbarjua into Mandovi. The

Table 3.7. Range in nutrient concentrations in  $\mu\text{g-at/l}$  in the estuaries of Goa during different seasons

		Pre-monsoon	Monsoon	Post-monsoon
Mandovi estuary	Phosphate-phosphorus	0.11-1.78	0.04-1.75	0.001-1.52
	Nitrate-nitrogen	0.08-1.72	0.25-4.11	0.21-2.79
	Silicate-silicon	---	17.48-134.30	---
Zuari estuary	Phosphate-phosphorus	0.29-2.04	0.26-1.17	0.10-1.42
	Nitrate-nitrogen	0.25-1.47	0.36-4.56	0.35-8.01
	Silicate-silicon	---	12.43-89.98	---
Cumbarjua canal	Phosphate-phosphorus	0.39-1.91	0.13-1.26	0.004-1.45
	Nitrate-nitrogen	0.13-1.43	0.42-3.87	0.17-5.93
	Silicate-silicon	---	20.15-114.15	---

concentration of nitrate-nitrogen becomes high in the monsoon as compared to the other seasons. Extremely high concentrations of silicate-silicon were recorded during the monsoon period because of the heavy load of silt and sand brought by the land runoff into the estuarine complex. The seasonal distribution of nutrients in the Goa estuaries was found to be very different from that in the Cochin Backwater.

For the estimation of primary production in the Goa estuaries, both oxygen and  $^{14}\text{C}$  methods were employed (Dehadrai, 1970a, Dehadrai & Bhargava, 1972b). The values given by these authors are for the surface only. Gross production, as measured by the oxygen method, varied from 135 to 550  $\text{mg C/m}^3/\text{day}$  in Mandovi and from 150 to 580  $\text{mg C/m}^3/\text{day}$  in Zuari. Similarly,  $^{14}\text{C}$  assimilation (net production) for Mandovi and Zuari estuaries ranged from 95 to 274  $\text{mg C/m}^3/\text{day}$  and from 60 to 245  $\text{mg C/m}^3/\text{day}$  respectively. The ranges given above pertain to high tides only. During the low tides the ranges in  $^{14}\text{C}$  uptake were 44-122  $\text{mg C/m}^3/\text{day}$  for Mandovi and 22-82  $\text{mg C/m}^3/\text{day}$  for Zuari. Dehadrai (1970a) reports that the average net production at the surface in Mandovi ranged from 95 to 450  $\text{mg C/m}^3/\text{day}$ . The production was lowest during the monsoon months. No determinations of primary production were made in Cumbarjua canal.

Samples of phytoplankton were collected from the mouth of Zuari estuary using a net of 0.065 mm mesh width. Cell counts were found to be low and varied from 220 to 5800 cells/l. Two peaks in cell counts were recorded during the pre-monsoon and post-monsoon periods corresponding to the maximum values of primary production. The phytoplankton crop during the monsoon months was very low.

However, recent counts of plankton organisms made from the settled samples of water collected from Mandovi, Zuari and Cumbarjua have



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Table 3.8. Cell counts (cells/l) of surface samples from Mandovi, Zuari and Cumbarjua, 1972

	June	July	August	September
Mandovi	371000	35700	16700	14900
Zuari	387500	7200	3600	18600
Cumbarjua	430000	5000	89400	4000

failed to confirm the deductions made earlier (Bhattathiri, Devassy & Bhargava, 1976). The counts at the surface during June-September are given in Table 3.8.

Assimilation of  $^{14}\text{C}$  in Mandovi during the four months of monsoon (June-September) ranged from 56.0 to 540.0 mg C/m<sup>2</sup>/day. In Zuari, the range in the carbon uptake was from 108.0 to 502.0 mg C/m<sup>2</sup>/day and in Cumbarjua from 175.0 to 440.0 mg C/m<sup>2</sup>/day. Chlorophyll *a* values ranged from 1.60 to 12.70 mg/m<sup>3</sup> in Mandovi, from 1.90 to 12.40 in Zuari and from 2.20 to 12.60 in Cumbarjua (Bhattathiri, Devassy & Bhargava, 1976).

### Bombay harbour bay

This bay is connected with the Arabian Sea at its southern region and with the Thana Creek at its northern region. During the south-west monsoon, a large quantity of freshwater flows into the bay.

During 1964-5, measurements of primary production were made in this bay near the jetty of the Canada-India Atomic Reactor. Water samples from the surface were incubated *in situ* with  $^{14}\text{C}$  and the filters were counted using a liquid scintillation counter. Chlorophyll *a* concentrations were also determined from the surface samples (Krishnamoorthy & Viswanathan, 1968). Primary production was low in June because of high turbidity. The range in production during the year was from 0.015 to 4.99 g C/m<sup>2</sup>/day with a maximum in February. Chlorophyll *a* values ranged from 1.77 to 11.98 mg/m<sup>3</sup>. The minimum and maximum values of chlorophyll *a* were in August and December respectively (Krishnamoorthy & Viswanathan, 1968).

### Vellar-Coleroon estuarine system

This estuarine system is located on the east coast of India (Bay of Bengal) and connects the Porto Novo backwaters with the adjoining mangrove forests and swamps (Fig. 3.7). Several rivulets, canals and gullies join the forest and the backwater system. The vegetation in the area is thick with

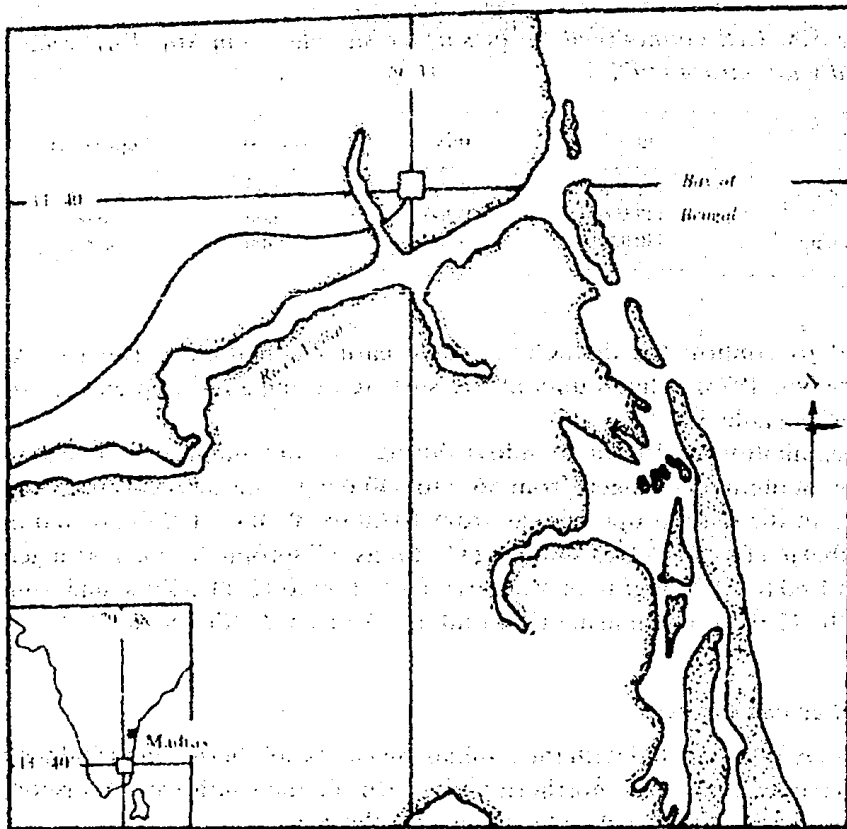


Fig. 3.7. Veilar-Coleroon estuarine system with its main connections with the Bay of Bengal. Inset shows its location on the east coast of India. (After Purushothaman and Venugopalan, 1972.)

mangrove trees and shrubs. The bottom sediment varies from fine silt, clay, coarse mud to fine mud. It becomes more sandy towards the sea. The tides in the region are of semi-diurnal type and vary from 0.5 to 1.0 m in range (Krishnamurthy, 1971; Krishnamurthy & Sundararaj, 1973).

In recent years, a series of papers has appeared on this estuarine system, describing primary production, plant pigments, dissolved silicon, environmental features and trace elements in the particulate matter (Venugopalan, 1969; Krishnamurthy, 1971; Bhatnagar, 1971; Purushothaman & Venugopalan, 1972; Jegatheesan & Venugopalan, 1973; Krishnamurthy & Sundararaj, 1973). The salient features of the estuarine system are recorded below.

During the year the temperature of water in the estuary varies from 24.8 to 32.6 °C, whereas the variations in salinity are very large, of the order of 0.5–28‰ or 1.00–34.30‰, depending upon the region under investi-

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gation. Maximum salinity values are recorded from May to July and minimum, because of the influence of the north-east monsoon, from November to December. The different nutrients have been reported to range as follows ( $\mu\text{g-at/l}$ )

Total phosphorus 0.72-3.34

Inorganic phosphate 0.19-1.59

Dissolved organic phosphorus 0.16-1.75

Ammonia and amino acids 0.34-3.60

Nitrite 0.11-0.25

Nitrate 2.85-6.94

Silicate 20.00-140

Similarly, the ranges in plant pigments were: chlorophyll *a*, 2.05-21.56  $\mu\text{g/l}$ ; chlorophyll *b*, 0.30-13.40  $\mu\text{g/l}$ ; chlorophyll *c*, 2.70-26.50  $\mu\text{g/l}$ ; carotenoids, nil-5.25 MSP/ $\text{m}^3$

Dissolved silicon in the Vellar river was found to be  $17 \times 10^3 \mu\text{g/l}$  and that in the sea water with salinity 35‰ it was 178  $\mu\text{g/l}$ . A linear inverse relationship was found between dissolved silicon and salinity.

Trace elements such as iron, copper, manganese, molybdenum, vanadium and cobalt were measured from the Vellar estuary from March 1971 to July 1972 and the seasonal cycle of each of these has been reported by Jegatheesan & Venugopalan (1973).

Measurements of primary production were carried out using the light-dark bottle oxygen method at five stations in Vellar estuary in February, March and April 1966. Incubations were made *in situ* both at the surface and 1.5 m depth. Gross and net production at the surface ranged from 11.77 to 36.99  $\text{mg C/m}^3/\text{h}$  and 6.72 to 26.22  $\text{mg C/m}^3/\text{h}$  respectively. At 1.5 m depth the range in the production was much higher, gross production was 21.88-58.83  $\text{mg C/m}^3/\text{h}$  and net production was 18.48-47.07  $\text{mg C/m}^3/\text{h}$ .

In February 1964, the  $^{14}\text{C}$  method was also used at four stations. The two marine stations gave the production values at the surface as 11.93 and 20.17  $\text{mg C/m}^3/\text{h}$ . The two estuarine stations, on the other hand, gave the primary production as 35.50 and 45.99  $\text{mg C/m}^3/\text{h}$  (Venugopalan, 1969).

Bhatnagar (1971) using the light-dark bottle oxygen method, reported very high values of primary production from the Vellar estuary (Kille Backwaters). According to him, maximum gross (251.20  $\text{mg C/m}^3/\text{h}$ ) and net photosynthesis (225.44  $\text{mg C/m}^3/\text{h}$ ) based on monthly mean values, were found in August 1968 and the minimum value of gross production was 47.62 and net production was 38.09  $\text{mg C/m}^3/\text{h}$  in February 1969. Chlorophyll *a* values during the period of investigation were 12.70  $\text{mg/m}^3$  (maximum) in July 1968 and 1.55  $\text{mg/m}^3$  (minimum) in November 1968.

A. Purushothaman & R. Natarajan (personal communication) have also estimated the primary production (using the oxygen method) and chlorophyll *a* of the estuarine system. The annual production rates (gross and net)

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at the mouth of Vellar estuary for the year 1969 were 598.30 and 379.70 g/m<sup>2</sup> C/m<sup>2</sup> respectively. The chlorophyll *a* at the surface varied from 1.30 to 19.20 µg/l.

#### Lawson's Bay

Lawson's Bay is an embayment on the east coast of India (Bay of Bengal). It is located along latitude 17° 44' N and longitude 82° 23' E, about 7.5 km away from Visakhapatnam harbour.

Primary production in the bay was measured using light-dark bottles by Subba Rao (1973). The samples were incubated under natural light in a trough for about 6 h. Gross production ranged from 9.20 to 150.05 mg C/m<sup>2</sup>/h. During blooms, gross production increased three- to thirteen-fold. The ratios of photosynthesis to respiration (*P/R*) ranged from 5.1 to 10.5. High *P/R* ratios coincided with the increase in production. Common organisms forming blooms were *Thalassiosira subtilis* and *Chaetoceros curvisetus*.

#### Coral reefs and atolls

Coral reefs are known to be among the most productive communities in the sea. The reefs of the tropical Indian Ocean include (a) fringing and barrier reefs, (b) sea-level atolls and (c) elevated reefs (Stoddart, 1972).

Reefs are either absent or poorly developed along the coasts of Somalia, India and Malaysia. They are, however, well developed in the Persian Gulf, Red Sea, the coasts of Kenya, Tanzania, West Malagasy and parts of Sumatra and north-west Australia. No barrier reefs are found on the continental shores except for a discontinuous submerged barrier in north-west Malagasy. Around the granitic Seychelles, the volcanic Comoros and Mascarenes, and the sedimentary Andamans and Nicobars, fringing reefs are well developed. Atolls having a dominant type of reef occur only next to fringing reefs in the Indian Ocean. One of the largest atolls in the world is 'Suvadiva' Atoll, Maldives (70 km × 35 km). Maldivian atolls have formations of faros or small atoll-shaped reefs around their margins. In the eastern Indian Ocean, elevated reefs are represented by Christmas Island and Ramanathapuram, and in the western Indian Ocean by raised atolls (Stoddart, 1972; Stoddart & Pillai, 1972).

Little work has been done on the primary productivity of coral reefs of the Indian Ocean. The available information is on fringing reefs located in the Gulf of Mannar, Andaman Sea, and on atoll reefs of Minicoy and Kavaratti in the Laccadives (Nair & Pillai, 1972; Qasim, Bhattathiri & Reddy, 1972).

The flow-respirometry technique of Sargent & Austin (1949, 1954) has

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**Table 3.9: Estimates of gross primary production of different coral reefs from the Indian region**

Location and date	Gross production (g C/m <sup>2</sup> /day)	Authors
Manauli Reef, Gulf of Matar, 5 March 1968	7.3	Nair & Pillai, 1972
Minicoy reef 2 April 1968	9.1	Nair & Pillai, 1972
Andaman reef 24 April 1968	3.9	Nair & Pillai, 1972
Kavaratti reef 6 November 1968	6.15*	Qasim, Bhattathiri & Reddy, 1972
Kathuyalimuni reef, Palk Bay April 1973	6.3	Rajasubramanian & Wafar, 1975

\* Uncorrected for diffusion.

**Table 3.10. Number of genera and species of reef-building corals (hermatypic) and non-reef-building corals (ahermatypic) recorded from the seas around India**

Region	Hermatypic		Ahermatypic	
	Genera	Species	Genera	Species
Maldives	47	124	19	42
Laccadives	26	69	3	4
Ceylon	27	70	12	20
Mandapam area	25	110	7	7
Tuticorin	14	16	5	8
Andamans	23	57	8	11
Mergui Archipelago	26	51	5	14
Other regions	12	3	13	26
Total*	149	253	27	89

\* From Pillai (1972). The values give the total number of genera and species recorded in all the regions put together, of which many were common to each region. The total number of genera was 76, and of species, 342.

been used in all the investigations to determine the primary productivity of the reef. The method involves the measurement of oxygen changes in water during its transport over the reef.

Table 3.9 gives the values of primary production in different reefs. All the reefs, except Andaman Reef, were found to be autotrophic; Pillai

Table 3.11: Range in the density of algae in three different coral reefs of the Bay of Bengal

Locality	Range in density of algae (wet weight, kg/m <sup>2</sup> )
Gulf of Mannar reefs	0.43-0.16
Palk Bay reefs	0.08-0.57
Pamban Island reefs	0.42-0.96

From Rao (1972).

(1972) gives the total number of genera and species of corals found in some of the reefs of India (Table 3.10). The mean densities of algae found in three fringing reefs were determined by Rao (1972). These are given in Table 3.11.

The descriptions of the reefs whose productivity has been measured are given below.

#### **Manauli Reef**

This fringing reef is situated along a small island in the Gulf of Mannar, 6 km away from the south-east coast of India. The width of the reef is about 100 m. The coral fauna recorded from the reef includes: *Echinopora lamellosa*, *Montipora foliosa*, *Favites abdita*, *Favia pallida*, *Porites* spp., *Acropora indica*, *A. surculosa*, *A. erythraea*, *A. hyacinthus* (Nair & Pillai, 1972).

#### **Kathuvalimuni Reef**

This reef is located in the Palk Bay near Mandapam and lies in an east-westerly direction. It extends about 4 km in length and runs parallel to the shore. The average width of the reef is about 300 m and the average depth over the reef is approximately 2 m. The major corals occurring in the reef are: *Acropora* sp., *Favites* sp., *Favia* sp., *Porites* sp., *Goniopora* sp., *Goniastrea* sp., and *Pocillopora* sp. (Balasubramanian & Wafar, 1974).

#### **Minicoy Reef**

This is an oval-shaped reef and forms a part of Minicoy Atoll, the southernmost atoll of the Laccadive Archipelago. The length of the atoll is 8 km and it has a maximum width of 4.5 km. The depth of the lagoon

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varies from 1 to 3 m. The corals forming the reef include: *Goniastrea retiformis*, *Platygyra lamellina*, *Favia pallida*, *Porites* spp., *Diploastrea heliopora*, *Lobophyllia corymbosa*, *Acropora* spp. and *Pocillopora damicornis* (Nair & Pillai, 1972).

#### Andaman Reef

This reef is of the fringing type and lies at 5 to 7 m depth near Port Blair. The dominant species of corals are: *Acropora assimilis*, *A. syringodes*, *A. squamosa*, *Pocillopora damicornis*, *Favites* spp. and *Porites* spp. The Andaman and Nicobar group of islands generally have luxuriant fringing reefs (Nair & Pillai, 1972).

#### Kavaratti Reef

This reef forms a part of Kavaratti Atoll of the Laccadive Archipelago and is located at latitude 10° 33' N and longitude 72° 36' E. The atoll, on its eastern side, has an island of 3.45 km<sup>2</sup> in area, a shallow lagoon about 4500 m long and 1200 m wide in the middle and a reef about 300 m wide bordering the western margin of the lagoon (Fig. 3.8). The productivity of this atoll has been studied more than those of the other reefs described above.

The beach slope of the lagoon has a luxuriant growth of turtle grass, *Thalassia hemprichii* and manatee grass, *Cymodocea isoetifolia*. Some of the algae found in the lagoon are:

Green algae: *Ulva lactuca*, *Enteromorpha prolifera*, *Chaetomorpha littorea*, *Cladophora fascicularis*, *Dictyosphaeria cavernosa*, *Boergesenia forbesii*, *Halimeda incrassata*

Brown algae: *Colpomenia sinuosa*

Red algae: *Fosliella lejolisii*, *Hypnea cervicornis*, *Spyridia filamentosa*, *Laurencia papillosa*, *Acanthophora spicifera*, *Leveillea jungermannioides*

The dominant species of corals in the lagoon are: *Acropora indica*, *A. conferta*, *Pocillopora damicornis*, *P. verrucosa*, *Porites* spp., *Fungia* spp. and *Goniastrea* spp. (Qasim, Bhattathiri & Reddy, 1972).

Blooms of the blue-green alga *Trichodesmium erythraeum* seem to occur around Kavaratti Atoll practically every year during the pre-monsoon season. In April 1968 a massive bloom of *Trichodesmium* was recorded and in 1969 also a similar bloom occurred during the same period (Qasim, 1970b, 1972b).

Primary production of the lagoon was estimated from a study of diurnal changes in the oxygen concentration at two stations which were about 1200 m apart. The formula of Kohn & Helfrich (1957) was used to deter-

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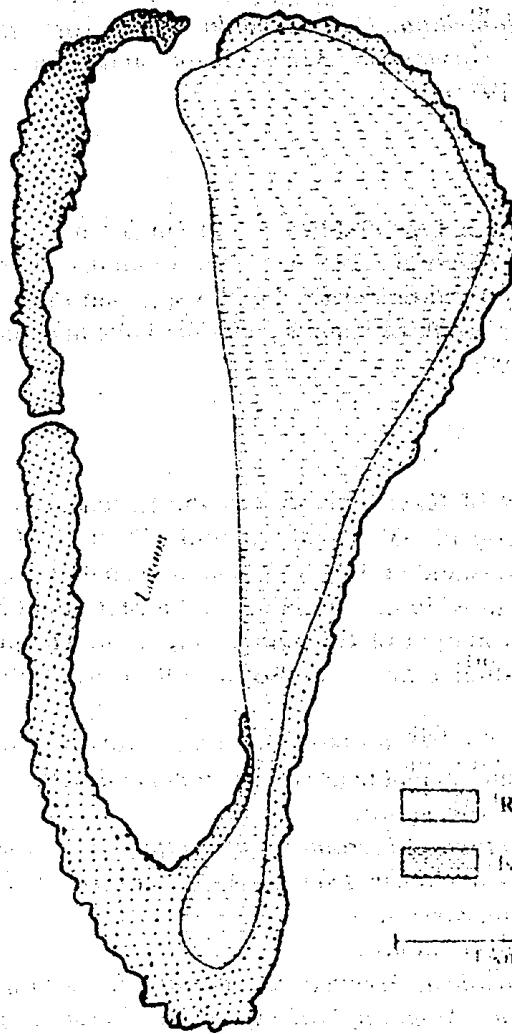


Fig. 3.8. Kavaratti Atoll of the Laccadive Archipelago showing the relative position of reef lagoon and island. (From Qasim & Sankatanarayana, 1970, *Limnology and Oceanography*, 15, 574-78.)

mine the rates of changes of oxygen concentration in ml/cm strip/s between the two stations. Gross and net primary production in the lagoon were found to be 12.92 g C/m<sup>2</sup>/day and 3.38 g C/m<sup>2</sup>/day (Qasim, Bhattachari & Reddy, 1972). Photosynthesis and respiration of some of the individual plants from the lagoon were also determined by oxygen changes, and in most species, photosynthesis for 12 hours exceeded their respiration for 24 hours. Similar experiments on three species of corals showed that their photosynthesis for 12 hours was much greater than their respiration



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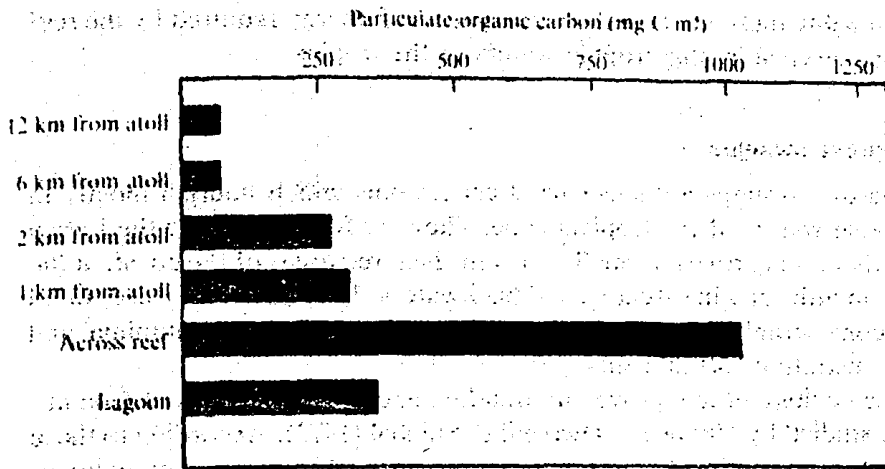


Fig. 3.9. Concentrations of particulate organic carbon at different sites. (From Qasim & Sankaranarayanan, 1970, *Limnology and Oceanography*, 15, 574-78.)

for 24 hours. The symbiotic zooxanthellae and the boring and attached algae occurring in the corals contribute largely to the high primary productivity of the reef.

Measurements of  $^{14}\text{C}$  uptake and chlorophyll *a* were made in the ocean water around Kavaratti Atoll. These gave extremely low values indicating that the water surrounding the reef community is low in its phytoplankton content. Particulate organic carbon, on the other hand, in the vicinity of the atoll was found to be high (Fig. 3.9). This indicates that a fairly large quantity of organic matter observed in the form of organic aggregates and microscopic particles is produced by the reef (Qasim & Sankaranarayanan, 1970). The total fractions of particulate matter added to the water as a result of its transport over the reef during day and night were also determined by the flow method (see Qasim & Sankaranarayanan, 1970). Production of particulate carbon was found to be  $0.101 \text{ g C/m}^2/\text{h}$  for the day and  $0.089 \text{ g C/m}^2/\text{h}$  for the night (average =  $0.095 \text{ g C/m}^2/\text{h}$ ). This amounted to 20% of the gross primary production of the reef and 95% of the coral respiration (Qasim & Sankaranarayanan, 1970).

Zooplankton biomass recorded at Kavaratti during a period of four months varied over a wide range. In October 1968, the nocturnal abundance of zooplankton in the sea and lagoon was very high (Tranter & George, 1972). From the difference between the biomass values of sea and lagoon, Tranter & George (1972) concluded that zooplankton organisms alone were unable to provide the total energy required by the reef. The extracellular products secreted by the zooxanthellae are of possible nutritional value to the host (Muscatine, Pool & Cernichiaro, 1972) and

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presumably these provide the extra source of energy required by the reef for its survival in oligotrophic waters of the tropics.

### **Mangrove swamps**

Mangrove swamps are specialized ecosystems which flourish mostly in brackish waters of the tropical zone. They are found all along the Indian coastline. Mangroves normally grow in sheltered areas of the coast, at the river mouths and in estuaries and backwaters. Very often they are found at a considerable distance from the sea where wave action is minimal and the substratum soft and silty.

The ecology of mangroves in Mandovi and Zuari estuaries of Goa has been studied by Untawale, Dwivedi & Singbal (1973). According to these authors, the dominant species of mangroves in the estuarine complex of Goa are: *Avicennia officinalis*, *Rhizophora mucronata*, *Sonneratia apetala* and *Bruguiera* sp. Although these four species are found all along the estuarine complex, the growth and density of plants differ markedly from place to place. In Cumbarjua canal, the height of the plants and their abundance were found to be much greater than anywhere else in the estuarine complex. The mangroves seem to appear in succession in the swamp. The red mangrove, *Rhizophora mucronata*, establishes itself first and begins to give firmness to the shifting mud with its supporting root system. It forms the first row at the water front. Soon afterwards, the black mangrove, *Avicennia officinalis*, appears and it begins to give out a special type of aerial roots - the pneumatophores. These roots quickly occupy a large area and help in trapping silt between them. This is followed by the development of a shoot system in the black mangrove. The root systems in these two mangroves give support to the plants and prevent erosion.

The mangrove swamps of Goa undergo well marked seasonal changes. Some of the environmental features such as temperature (water and soil), salinity, oxygen, sediment load and nutrients (phosphate and nitrate) and phytoplankton counts were studied by Untawale & Parulekar (1976) and these are shown in Fig. 3.10. Temperature differences during the year, both in water and soil, were of the order of 5 to 6 °C, but the seasonal variation in salinity was very large - from almost freshwater to sea water conditions (1-34.5‰). The range in oxygen was from 2.2 to 5.4 ml/l. The swamp is characterized by a very heavy sediment load and during the monsoon period the water has a thick suspension of sediment. The variation in the phosphate-phosphorus concentration during the year is somewhat greater than that of nitrate-nitrogen (Fig. 3.10). However, the swamp does not seem to get much enrichment from external sources. During the monsoon months, when the freshwater influence is maximum, the phosphorus and nitrogen values both at the surface and bottom remain relatively low.

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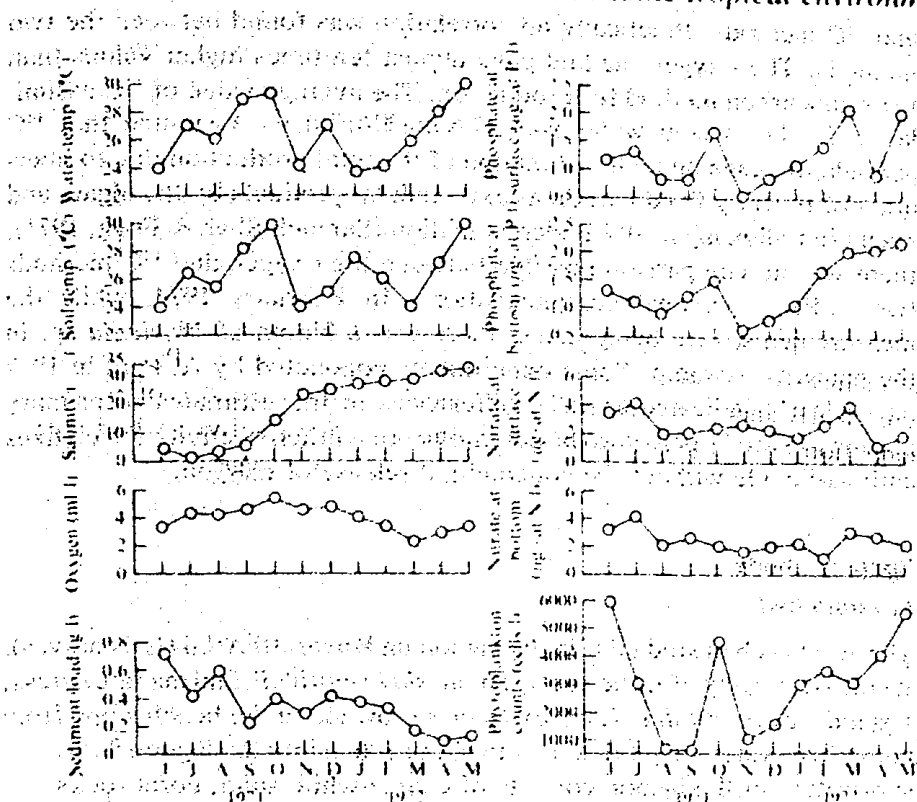


Fig. 3.10. Seasonal changes in the environmental features of a mangrove swamp at Goa. (From Untawale & Parulekar, 1976, *Mahasagar-Bulletin of the National Institute of Oceanography*, 9, 57-62.)

Similarly, during March–May, when the swamp becomes salt water dominated, there is no significant change in the nitrogen value although phosphorus values do show an increase (Fig. 3.10).

The swamp is generally characterized by a low phytoplankton crop (50–6000 cells/l). Maximum cell numbers are found in May and June and minimum in August and September (Fig. 3.10).

Krishnamurthy & Sundararaj (1973) report a high rate of production, by what they call a 'direct estimate of primary production', in the Pichchavaram mangrove (Porto Novo) made during March–April 1972. They give the average gross primary production in the mangrove region as 7.56 g C/m<sup>3</sup>/day and net production as 6.29 g C/m<sup>3</sup>/day. The chlorophyll *a* concentration reported by them varied from 4.10 to 39.80 mg/m<sup>3</sup>. It is, however, not clear what method these authors applied for measuring primary production of the mangrove swamp.

Recently Dr A. Pant (personal communication) measured the primary production in the water of a fringing mangrove in Goa using both oxygen

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and  $^{14}\text{C}$  methods. Practically no correlation was found between the two methods. The oxygen method gave almost ten times higher values than the radiocarbon method for production. The average value of  $^{14}\text{C}$  assimilation in the swamp water was  $37.8 \text{ mg C/m}^3/\text{day}$ . Assuming that  $^{14}\text{C}$  assimilation gave an underestimation of the total production due to liberation of recently fixed carbon as extracellular products by the algae, and even after allowing a 20% underestimation (Samuel, Shah & Fogg, 1971), there was no comparison possible between the oxygen and  $^{14}\text{C}$  methods (Dr A. Pant, personal communication). In February 1974, while the measurements were being made, there was a bloom of *Navicula* sp. in the mangrove swamp. Some experiments conducted by A. Pant in 1977 have clearly indicated that the differences in the estimates of primary production are largely due to bacterial photosynthetic activity which fixes carbon dioxide without the concomitant release of oxygen.

### **Seagrass beds**

#### **Kavaratti bed**

The seagrass bed studied is in the lagoon on Kavaratti Atoll (Laccadives). It consists largely of turtle grass, *Thalassia hemprichii*, and manatee grass, *Cymodocea isoetifolia*. The two species grow along the beach slope from about low water neap tide down to about 100 m into the lagoon floor. The substratum in the lagoon consists of coarse white sand, coral rocks and debris. At Kavaratti, the maximum tidal range is about 1.7 m. At low tide, the grass bed is partially exposed. The bed is a luxuriant community growing in oceanic conditions. Within the intertidal zone of the lagoon, there is a rich flora of algae (Qasim & Bhattathiri, 1971).

Primary production of the seagrass bed was studied from the diurnal changes in dissolved oxygen over the bed. Experiments were also conducted on some of the isolated plants to determine their rates of oxygen production and consumption. Gross production of the seagrass community was equivalent to  $11.97 \text{ g C/m}^2/\text{day}$  and respiration  $6.16 \text{ g C/m}^2/\text{day}$ . The daily net production of the community was  $5.81 \text{ g C/m}^2/\text{day}$  with a *P/R* ratio of 1.94 (Qasim & Bhattathiri, 1971).

The seagrass bed is autotrophic. Its presence is ecologically important to the atoll communities, for it offers shelter to a very large number of animals and serves as food either directly, or through detritus, to many animals.

#### **Mandapam bed**

This seagrass bed is found in the Gulf of Mannar (near Mandapam) and covers a distance of about 3 km. The average width of the bed is about

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200 m and the average depth over the bed is approximately 2 m. The seagrasses found in the bed are: *Cymodocea isoetifolia*, *C. serrulata*, *Halophylla ovalis*, *H. stipulacea* and *Diplanthera uninervis*. Of these, *C. isoetifolia* is the dominant species. The total quantity of seagrasses in the Mandapam bed has been estimated as 558 tonnes/km<sup>2</sup> (Rao, 1973).

Gross production of the bed, as determined by the oxygen changes, was 8.04 g C/m<sup>2</sup>/day and respiration 3.25 g C/m<sup>2</sup>/day. The P/R for July was 2.47 (Balasubramanian & Wafar, 1975).

### **Sandy beaches**

Under the International Biological Programme, a joint project between the Marine Laboratory, Aberdeen, Scotland, and the Regional Centre of the National Institute of Oceanography, Cochin, India, was started on the 'Production process and community interrelationship of two sandy beaches'. Investigations began in 1968 and two British scientists visited Cochin every year up to 1971 for about 2-3 months. The British side of the project was funded by the Royal Society of London, and the Indian side by the Council of Scientific and Industrial Research (CSIR). The beaches selected for the study were (1) at Cochin, situated just south of the entrance of Cochin Backwater where salinity values differ over a wide range during the year and (2) at Shertallai, an open sea beach approximately 32 km away from Cochin.

The monsoon brings about conspicuous changes in the profile of both the beaches resulting in active erosion followed by gradual accretion during the post-monsoon period and restoration of the stable profile of the pre-monsoon months. The composition of the macrofauna in both the beaches varies considerably. Perhaps the increase in exposure of the beach and the seasonal fluctuation in salinity have resulted in a less diverse and often a severely restricted fauna at Cochin. At Shertallai, five species of animals are frequently represented in the samples: the bivalve *Donax incarnatus*, the gastropod *Bullia melanoides*, crustaceans *Emerita holthuisi* and *Eurydice* sp. and the polychaete *Glycera alba*; although many more, like *Oliva gibbosa*, *Maetra alorina*, *Timoclea imbricata*, appear on the beach during certain seasons. The only species recorded from Cochin throughout the year is the *Eurydice* sp. However, *Donax incarnatus* and *D. spiculum* were recorded on the beach almost throughout the pre-monsoon period. *Donax incarnatus* collected at Shertallai attains a greater size than it does at Cochin. This seems to be directly related to the greater concentration of organic carbon and chlorophyll *a* at Shertallai than at Cochin.

The studies of Trevallion *et al.* (1970) and Ansell *et al.* (1972a) have made it possible to understand the population density and biomass of individual

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species composing the beach fauna. The ghost crab, *Ocypode ceratophthalma*, present almost throughout the year at Shertallai, was found at a density of 1-2/m<sup>2</sup> (based on the abundance of their burrow entrances). McIntyre (1968) observed a maximum of 9/m<sup>2</sup> of *O. macrodora* from a beach in south-east India. *Bullia melanoides* was recorded only at Shertallai, and the greatest numbers were in January and October, when 330-340 individuals/m transect appeared on the beaches representing up to 53 g wet body wt/m transect.

*Emerita holthuisi* and the two species of *Donax* were studied in detail (Ansell, Sivadas, Narayanan & Trevallion, 1972b, c). The numbers of *E. holthuisi* recorded at Shertallai reached 500/m transect and the wet biomass 0.23 g/m transect. One collection made in April at Cochin produced about 4000/m transect with a biomass of 0.35 g/m transect. The bivalves *Donax incarnatus* and *D. spiculum* were present in significant numbers on the beaches and formed a major constituent of the macrofauna. *D. spiculum* appeared at Shertallai from the beginning of the monsoon, but it was found in large numbers only during the period from August to November, numbers reaching 9000/m transect were recorded, with a biomass of over 300 g wet wt/m transect. At Cochin, the species occurred from January to May; the maximum numbers recorded were 6000/m transect, with a biomass of 200 g wet body wt/m transect. For *D. incarnatus*, the data were split into two parts, one dealing with the population recruited to the beach in 1967 and the other recruited in 1968. At Shertallai, two transects were sampled, and at the beginning of the year only individuals from 1967 settlements were present. In January, the transect A at Shertallai recorded 240-250 bivalves/m transect and transect B 660/m transect. The first indication of a 1968 settlement occurred in late January, although the major settlement came in only just prior to monsoon when in May maximum numbers of over 4000 bivalves/m transect were recorded from transect A. A detailed study of the length-weight relationship, growth, changes in body weight and reproduction of both *D. incarnatus* and *D. spiculum* has been made for Shertallai and Cochin samples (Ansell *et al.*, 1972c).

The low chlorophyll *a* content of the sand and the negligible <sup>14</sup>C uptake (the latter was estimated by the method given by Steele & Baird, 1968) no doubt showed that the interstitial or attached macro-organisms of the beaches at Shertallai and Cochin have essentially no primary production. Therefore the suspension feeders of the macrofauna of the intertidal sandy beach (*Emerita holthuisi* and the two species of *Donax*) may well have to depend upon the food resource of the surf water available mainly through the breakdown of plankton or through the degradation of animals higher in the food chain. For scavengers like *Bullia melanoides*, *Ocypode ceratophthalma* and *Eurydice* sp., the large quantity of fish offal and the

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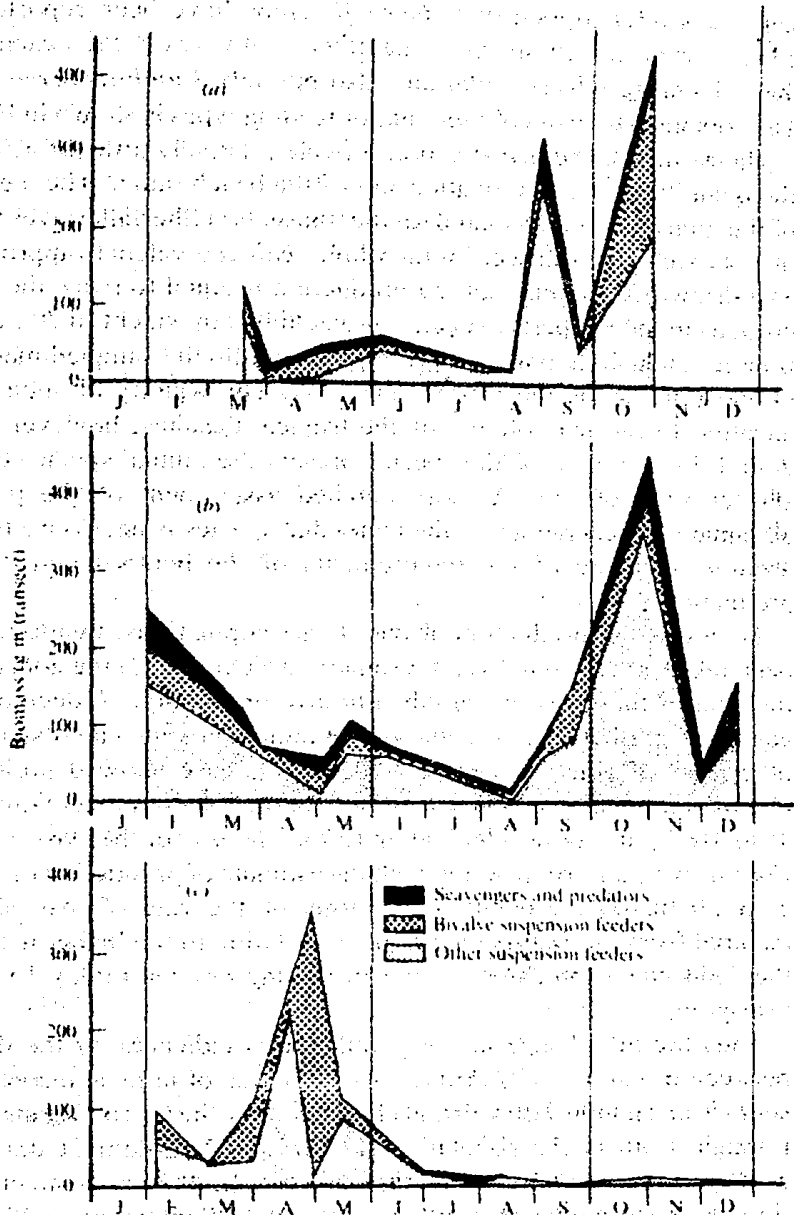


Fig. 3.11: Seasonal changes in three feeding types contributing to the total biomass of sandy beaches. (a) Shertallai beach, transect B. (b) Shertallai beach, transect A. (c) Cochin beach, during 1968. Deposit feeders present were too small in quantities to be shown. (From Ansell, Sivadas, Narayanan, Sankaranarayanan & Trevallion, 1972a, *Marine Biology*, 17, 57.)

bodies of the neglected part of the catch after the operation of the beach seine nets offer a good diet. *Ocypode* crabs have been reported to be a predator on *Donax* species. The other carnivores in the beach include the polychaete *Glycera alba* and also possibly *Lumbriconereis lutreilli*. The combined biomass of these major-feeding types is shown in Fig. 3.11.

The results of the investigation provide relatively little information on the quantitative trophic relationship of the beach fauna. The mean value of the total biomass calculated for the transects at Shertalla gives the value of 140 g wet wt/m transect for the whole year, equivalent to approximately 35 g dry wt. Assuming that the production is equal to twice the standing crop, as in the temperate species, it would be equivalent to 70 g dry wt/m transect annually, giving a total requirement by the sampled macrofauna of 700 g dry wt or 350 g C/m transect/yr. The validity of such a generalization to the macrofauna of the tropical beaches, however, remains doubtful since most of the species present are annual species or have a shorter span of life. A more detailed assessment of the population dynamics and energetics of the individual species is necessary to give an accurate estimate of the requirements of the benthos and its annual production.

To assess the production of the *Donax* populations, two factors have been taken into account: (1) the somatic weight and (2) the gonad weight, the sum of these two being taken to give production. A decrease in the gonad weight between successive sampling dates indicated spawning or other loss of gonad material, while an increase showed proliferation. Calculating by this method, production for the 1968 settlement ranged from 44 to 418 mg dry tissue/day and up to 736 mg/day for the 1967 settlement. For the two year-groups combined, the estimate of production ranged from 4 to 736 mg/day. Production in terms of the rate of loss of organic material from the *Donax incarnatus* population to the higher members of the food chain (predators) came to 916 mg dry tissue/day for the two year-groups.

Thus the net change in the population is indicated by the difference between production ( $P$ ) through accumulation of organic material by the somatic and gonadal growth and elimination by the loss of organic material through death in the population. For the 1967 settlement during 1968, elimination exceeded production, while for the 1968 settlement, production exceeded elimination until the period 13 September to 29 October. Thereafter, production failed to keep pace with elimination and the biomass declined. For the total population, there was a net loss of material throughout the year.

Normally, production and elimination would balance over the year. In this study of *Donax incarnatus*, the 1967 settlement had been apparently greater than the 1968 settlement. This resulted in higher elimination, since



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the 1967 settlement obviously died during 1968, while the recruitment of a new population was not sufficient in 1968 to maintain the balance of production and elimination. This can be taken only as a peculiarity of the year.

Looking at the relationship between production ( $P$ ), elimination ( $E$ ) and biomass ( $B$ ) and calculating the ratios  $P/B$  and  $E/B$ , the above model is confirmed, since production thus calculated is 6.2 g dry wt tissue/g biomass and elimination is 7.5 g dry wt tissue/g biomass. But in years when more abundant settlement occurs, the ratio  $P/B$  would be greater than  $E/B$ .

The values of the ratios  $P/B$  and  $E/B$  show two important aspects of the trophic ecology of the beach - one being an indication of the food requirement of the macrobenthos population and the second an indication of the contribution by the macrobenthos to the next trophic level, assuming that the bivalve population contributes mainly to the macrofauna. Taking the annual production as 6.5 times the biomass, the total production is 227.5 g/m transect/year (average biomass is approximately 35 g dry tissue/m transect for the year). Assuming that 50% of the organic material is carbon, the production will be equivalent to 114 g C/m transect/yr. With an ecological efficiency of 10%, the annual requirement by the population would be 1140 g C/m transect, and the quantity of food available to the predators seems to be of the order of 228 g/m transect/yr.

#### **Summary**

Primary production of six different environments from the Indian region, namely: coastal waters, backwaters and estuaries; coral reefs and atolls, mangrove swamps, seagrass beds, and sandy beaches, has been described. Along both the coasts of India, the rate of production near the shores is greater than in regions away from the coast. High instantaneous rates of production are generally recorded in upwelling areas during the monsoon period.

The backwater system of Kerala is a relatively well studied estuarine system. Primary production in this turbid and polluted environment is high, and is largely contributed by nannoplankton. Three main ecological factors seem to govern the rate of primary production in the backwater. These are salinity, light and nutrients. The influence of each of these factors was studied experimentally on several unialgal cultures. Maximum photosynthesis in all the organisms was recorded at low salinities. Such a dependence of algae on low salinity seems to be an adaptation to utilize the enrichment of water, associated with large dilutions in the estuary during the monsoon months, to a maximum degree. The saturation points ( $I_k$ ) of several algae were determined by exposing them to varying light intensities. When the organisms were exposed to different wavelengths of light,

no wavelength dependence of photosynthesis in saturation light was observed.

The capacity of two organisms to utilize phosphate and nitrate either singly or in combination was determined from the values of the half-saturation constant ( $K_s$ ). High concentrations of nutrients seem to favour the abundance of diatoms in the backwaters, while at low concentrations of nutrients dinoflagellates become predominant. The annual cycle of phytoplankton production and succession was found to be related to the increased flushing of the estuary caused by the monsoon.

The other important food constituent in the backwater is organic detritus, which leads to several pathways in the food chain. The energy budget of a penaeid prawn *Metapenaeus monoceros* was worked out by feeding it on estuarine detritus.

On the west coast of India, the other estuarine system on which some information has been gathered is the Mandovi-Zuari complex of Goa. These estuaries are also greatly influenced by the monsoon cycle. The Zuari estuary gets more marine influence than the other. Primary production in these estuaries is lower than that of the backwater at Cochin. Similarly, the average primary production of the Bombay harbour bay has also been found to be low.

On the east coast of India, the Vellar-Coleroon estuarine system has been studied fairly well, and from the available data on primary production, largely based on oxygen technique, it seems that the system is very productive. The nutrient and chlorophyll concentrations in this estuary remain high practically throughout the year.

The coral reefs studied are of two types, the fringing reefs and the atoll reefs. Both these types of reefs have been found to be highly productive communities. Primary production in all the reefs, except the Andaman reef, has been found to be much greater than their respiration. The water surrounding Kavaratti Atoll (Laccadives) is low in phytoplankton content but the particulate organic carbon in the vicinity of the atoll is high, indicating that the reef produces large quantities of organic matter which appear in the form of microscopic particles.

Observations on the mangrove swamps of the Mandovi-Zuari estuaries indicate that the mangrove trees along the waterfront appear in succession. The swamps undergo marked seasonal changes induced by the monsoon and are generally characterized by a low phytoplankton production.

The two seagrass beds studied form highly productive systems. Both the beds are luxuriant communities. One grows on an atoll in oceanic conditions and the other in association with a fringing reef in coastal waters.

Primary production in the sandy beaches of the south-west coast of India has been found to be extremely low. Marked changes in the profile of the

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beaches occur during the monsoon, resulting in active erosion followed by accretion during the post-monsoon period and stable conditions during the pre-monsoon period. The biomass of several animals inhabiting the beaches was determined and a quantitative trophic relationship of the beach fauna has been attempted. From the relationship between production and biomass and from the estimate of total carbon, it became possible to determine the total food requirement of the beach macrofauna during the year.

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### References

- Ansell, A. D., Sivadas, P., Narayanan, B., Sankaranarayanan, V. N. & Trevallion, A. (1972a). The ecology of two sandy beaches in southwest India. I. Seasonal changes in physical and chemical factors, and in the macrofauna. *Marine Biology*, **17**, 38-62.
- Ansell, A. D., Sivadas, P., Narayanan, B. & Trevallion, A. (1972b). The ecology of two sandy beaches in southwest India. II. Notes on *Emerita holthuisi*. *Marine Biology*, **17**, 311-17.
- Ansell, A. D., Sivadas, P., Narayanan, B. & Trevallion, A. (1972c). The ecology of two sandy beaches in southwest India. III. Observations on the population of *Donax incarnatus* and *D. spiculum*. *Marine Biology*, **17**, 318-32.
- Aruga, Y. (1973). Primary production in the Indian Ocean. II. In *The Biology of the Indian Ocean, ecological studies 3*, ed. B. Zeitzschel, pp. 117-30. Berlin: Springer-Verlag.
- Balasubramanian, T. & Wafar, M. V. M. (1974). Primary productivity of some fringing reefs of south-east India. *Mahasagar-Bulletin of the National Institute of Oceanography*, **7**, 157-64.
- Balasubramanian, T. & Wafar, M. V. M. (1975). Primary productivity of some seagrass beds in the Gulf of Mannar. *Mahasagar-Bulletin of the National Institute of Oceanography*, **8**, 87-91.
- Bhatnagar, G. P. (1971). Primary organic production and chlorophyll in Kille backwaters, Porto Nova (S. India). In *Proceedings of the symposium on tropical ecology with an emphasis on organic productivity*, ed. P. M. Golley & F. B. Golley, pp. 351-62. New Delhi. (Mimeo.)
- Bhattathiri, P. M. A., Devassy, V. P. & Bhargava, R. M. S. (1976). Production at different trophic levels in the estuarine system of Goa. *Indian Journal of Marine Sciences*, **5**, 83-6.
- Das, R. K., Murty, C. S. & Varadachari, V. V. R. (1972). Flow characteristics of Cumbarjua canal connecting Mandovi and Zuari estuaries. *Indian Journal of Marine Sciences*, **1**, 95-102.
- Dehadrai, P. V. (1970a). Observations on certain environmental features at the Dona Paula point in Marmugao Bay, Goa. *Proceedings of the Indian Academy of Sciences*, **B72**, 56-67.
- Dehadrai, P. V. (1970b). Changes in the environmental features of the Zuari and Mandovi estuaries in relation to tides. *Proceedings of the Indian Academy of Sciences*, **B72**, 68-80.

*S. Z. Qasim*

- Dehadrai, P. V. & Bhargava, R. M. S. (1972a). Distribution of chlorophyll, carotenoids and phytoplankton in relation to certain environmental factors along the central west coast of India. *Marine Biology*, **17**, 30-7.
- Dehadrai, P. V. & Bhargava, R. M. S. (1972b). Seasonal organic production in relation to environmental features in Mandovi & Zuari estuaries, Goa. *Indian Journal of Marine Sciences*, **1**, 52-6.
- Derbyshire, M. (1967). The surface waters off the coast of Kerala, south-west India. *Deep-Sea Research*, **14**, 295-320.
- Devassy, V. P. & Bhattathuri, P. M. A. (1974). Phytoplankton ecology of the Cochin backwater. *Indian Journal of Marine Sciences*, **3**, 46-50.
- Gopinathan, C. K. & Qasim, S. Z. (1971). Silting in navigational channels of the Cochin harbour area. *Journal of the Marine Biological Association of India*, **13**, 14-26.
- Humphrey, G. F. (1972). The biology of the Indian Ocean. In *Braun memorial lectures*, Technical Series 10, pp. 7-22. Intergovernmental Oceanographic Commission, UNESCO, Paris.
- Jegatheesan, G. & Venugopalan, V. K. (1973). Trace elements in the particulate matter of Porto Novo waters (11° 29' N-79° 49' E). *Indian Journal of Marine Sciences*, **2**, 1-5.
- Kabanova, J. G. (1968). Primary production of the northern part of the Indian Ocean. *Oceanology*, **8**, 244-25.
- Kohn, A. J. & Helfrich, P. (1957). Primary organic productivity of a Hawaiian coral reef. *Limnology and Oceanography*, **2**, 342-51.
- Krey, J. (1973). Primary production in the Indian Ocean. 1. In *The Biology of the Indian Ocean, Ecological Studies* **3**, ed. B. Zeitzschel, pp. 115-26. Berlin: Springer-Verlag.
- Krishnamoorthy, T. M. & Viswanathan, R. (1968). Primary productivity studies in Bombay harbour bay using <sup>14</sup>C. *Indian Journal of Experimental Biology*, **6**, 115-16.
- Krishnamurthy, K. (1971). Phytoplankton pigments in Porto Novo waters (India). *Internationale Revue der gesamten Hydrobiologie*, **56**, 273-82.
- Krishnamurthy, K. & Sundararaj, V. (1973). A survey of environmental features in a section of the Vellar-Coleroon estuarine system, South India. *Marine Biology*, **23**, 229-37.
- McIntyre, A. D. (1968). The microfauna and macrofauna of some tropical beaches. *Journal of Zoology*, **156**, 377-92.
- Margalef, R. (1967). Laboratory analogues of estuarine plankton systems. In *Estuaries*, ed. G. H. Lauff, pp. 515-21. Publication No. 83. Published by the American Association for the Advancement of Science, Washington DC.
- Murty, C. S. & Das, P. K. (1972). Premonsoon tidal flow characteristics of Mandovi estuary, Goa. *Indian Journal of Marine Sciences*, **1**, 148-51.
- Muscantine, L., Pool, R. R. & Cernichiaro, F. (1972). Some factors influencing selective release of soluble organic material by zooxanthellae from reef corals. *Marine Biology*, **13**, 298-308.
- Nair, P. V. R. (1970). Primary productivity in the Indian Seas. In *Bulletin of the Central Marine Fisheries Research Institute, No. 22*, Mandapam Camp, India. (Mimeo.), 56 pp.
- Nair, P. V. R. & Pillai, C. S. G. (1972). Primary productivity of some coral reefs in the Indian seas. In *Proceedings of the symposium on corals and coral reefs, 1969*, ed. C. Mukundan & C. S. G. Pillai, pp. 33-42. Cochin: Marine Biological Association of India.

### Production in some tropical environments

- Nair, P. V. R., Samuel, S., Joseph, K. J. & Balachandran, V. K. (1973). Primary production and potential fishery resources in the seas around India. In *Proceedings of the symposium on living resources of the seas around India*, 1968, pp. 184-198. Special publication. Cochin: Central Marine Fisheries Research Institute.
- Pillai, C. S. G. (1972). Stony corals of the seas around India. In *Proceedings of the symposium on corals and coral reefs*, 1969, ed. C. Mukundan & C. S. G. Pillai, pp. 191-216. Cochin: Marine Biological Association of India.
- Pillai, P. P. (1971). Studies on the estuarine copepods of India. *Journal of the Marine Biological Association of India*, 13, 167-72.
- Pillai, P. P., Qasim, S. Z. & Nair, A. K. K. (1973). Copepod component of zooplankton in a tropical estuary. *Indian Journal of Marine Sciences*, 2, 38-46.
- Prasad, R. R. & Nair, P. V. R. (1963). Studies on organic production. I. Gulf of Mannar. *Journal of the Marine Biological Association of India*, 5, 1-26.
- Purushothaman, A. & Venugopalan, V. K. (1972). Distribution of dissolved silicon in the Vellar estuary. *Indian Journal of Marine Sciences*, 1, 103-5.
- Qasim, S. Z. (1970a). Some problems related to the food chain in a tropical estuary. In *Marine food chains*, ed. J. H. Steele, pp. 45-51. Edinburgh: Oliver & Boyd.
- Qasim, S. Z. (1970b). Some characteristics of a *Trichodesmium* bloom in the Laccadives. *Deep-Sea Research*, 7, 655-60.
- Qasim, S. Z. (1972a). The dynamics of food and feeding habits of some marine fishes. *Indian Journal of Fisheries*, 19, 11-28.
- Qasim, S. Z. (1972b). Some observations on *Trichodesmium* blooms. In *Taxonomy and biology of blue-green algae*, pp. 443-8. Madras: University of Madras.
- Qasim, S. Z. (1973). Productivity of backwaters and estuaries. In *The biology of the Indian Ocean, ecological studies 3*, ed. B. Zeitzschel, pp. 143-54. Berlin: Springer-Verlag.
- Qasim, S. Z. (1977). Biological productivity of the Indian Ocean. *Indian Journal of Marine Sciences*, 6, 122-37.
- Qasim, S. Z. & Bhattathiri, P. M. A. (1971). Primary production of a seagrass bed on Kavaratti Atoll (Laccadives). *Hydrobiologia*, 38, 29-38.
- Qasim, S. Z., Bhattathiri, P. M. A. & Abidi, S. A. H. (1968). Solar radiation and its penetration in a tropical estuary. *Journal of Experimental Marine Biology and Ecology*, 2, 87-103.
- Qasim, S. Z., Bhattathiri, P. M. A. & Devassy, V. P. (1972a). The influence of salinity on the rate of photosynthesis and abundance of some tropical phytoplankton. *Marine Biology*, 12, 300-6.
- Qasim, S. Z., Bhattathiri, P. M. A. & Devassy, V. P. (1972b). The effect of intensity and quality of illumination on the photosynthesis of some tropical phytoplankton. *Marine Biology*, 16, 22-7.
- Qasim, S. Z., Bhattathiri, P. M. A. & Devassy, V. P. (1973). Growth kinetics and nutrient requirements of two tropical marine phytoplankters. *Marine Biology*, 21, 299-304.
- Qasim, S. Z., Bhattathiri, P. M. A. & Reddy, C. V. G. (1972). Primary production of an atoll in the Laccadives. *Internationale Revue der gesamten Hydrobiologie*, 57, 207-25.
- Qasim, S. Z. & Easterson, D. C. V. (1974). Energy conversion in the shrimp, *Metapenaeus monoceros* (Fabricius), fed on detritus. *Indian Journal of Marine Sciences*, 3, 131-4.

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- Qasim, S. Z. & Gopinathan, C. K. (1969). Tidal cycle and the environmental features of Cochin Backwater (a tropical estuary). *Proceedings of the Indian Academy of Sciences*, **B69**, 336-48.
- Qasim, S. Z. & Sankaranarayanan, V. N. (1970). Production of particulate organic matter by the reef on Kavaratti Atoll (Laccadives). *Limnology and Oceanography*, **15**, 574-78.
- Qasim, S. Z. & Sankaranarayanan, V. N. (1972). Organic detritus of a tropical estuary. *Marine Biology*, **15**, 193-99.
- Qasim, S. Z., Vijayaraghavan, S., Joseph, K. J. & Balachandran, V. K. (1974). Contribution of microplankton and nanoplankton in the waters of tropical estuary. *Indian Journal of Marine Sciences*, **3**, 146-9.
- Qasim, S. Z., Wellershaus, S., Bhattathiri, P. M. A. & Abidi, S. A. H. (1969). Organic production in a tropical estuary. *Proceedings of the Indian Academy of Sciences*, **B69**, 51-94.
- Radhakrishna, K. (1969). Primary productivity studies in the shelf waters off Alleppey, south-west India, during the post-monsoon, 1967. *Marine Biology*, **4**, 174-81.
- Rao, M. U. (1972). Coral reef flora of the Gulf of Mannar and Palk Bay. In *Proceedings of the symposium on 'corals and coral reefs'*, 1969, ed. C. Mukundan & C. S. G. Pillai, pp. 217-30. Cochin: Marine Biological Association of India.
- Rao, M. U. (1973). The seaweed potential of the seas around India. In *Proceedings of the symposium on 'living resources of the seas around India'*, 1968, pp. 687-92. Special publication. Cochin: Central Marine Fisheries Research Institute.
- Ryther, J. H., Hall, J. R., Pease, A. K., Bakun, A. & Jones, M. M. (1966). Primary organic production in relation to the chemistry and hydrography of the western Indian Ocean. *Limnology and Oceanography*, **11**, 371-80.
- Samuel, C. T., Shah, N. M. & Fogg, G. E. (1971). Liberation of extracellular products of photosynthesis by tropical phytoplankton. *Journal of the Marine Biological Association, UK*, **51**, 793-8.
- Sankaranarayanan, V. N. & Qasim, S. Z. (1969). Nutrients of the Cochin Backwater in relation to environmental characteristics. *Marine Biology*, **2**, 236-47.
- Sargent, M. C. & Austin, T. S. (1949). Organic productivity of an atoll. *Transactions of the American Geophysical Union*, **30**, 245-9.
- Sargent, M. C. & Austin, T. S. (1954). Biologic economy of coral reefs, Bikini and nearby atolls. II. Oceanography (biologic). *Professional Papers of the United States Geological Survey*, **260-E**, 293-300.
- Steele, J. H. & Baird, I. E. (1968). Production ecology of a sandy beach. *Limnology and Oceanography*, **13**, 14-25.
- Steeemann Nielsen, E. & Jensen, E. A. (1957). Primary organic production - the autotrophic production of organic matter in the oceans. *Galathea Reports*, **1**, 49-136.
- Stoddari, D. R. (1972). Regional variation in Indian Ocean coral reefs. In *Proceedings of the symposium on 'corals and coral reefs'*, 1969, ed. C. Mukundan & C. S. G. Pillai, pp. 155-74. Cochin: Marine Biological Association of India.
- Stoddari, D. R. & Pillai, C. S. G. (1972). Raised reefs of Ramanathapuram, south India. *Transactions, Institute of British Geographers*, Publ. No. **56**, 111-25.
- Subba Rao, D. V. (1973). Effects of environmental perturbations on short-term phytoplankton production off Lawson's Bay, a tropical coastal embayment. *Hydrobiologia*, **43**, 77-91.

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- Tranter, D. J. & Abraham, S. (1971). Coexistence of species of *Acartiidae* (Copepoda) in the Cochin Backwater, a monsoonal estuarine lagoon. *Marine Biology*, **11**, 222-41.
- Tranter, D. J. & George, J. (1972). Zooplankton abundance at Kavaratti and Kalpeni Atolls. In *Proceedings of the symposium on 'corals and coral reefs'*, 1969, ed. C. Mukundan & C. S. G. Pillai, pp. 239-56. Cochin: Marine Biological Association of India.
- Trevallion, A., Ansell, A. D., Sivadas, P. & Narayanan, B. (1970). A preliminary account of two sandy beaches in southwest India. *Marine Biology*, **6**, 268-79.
- Untawale, A. G., Dwivedi, S. N. & Singhal, S. Y. S. (1973). Ecology of mangroves in Mandovi and Zuari estuaries and the interconnecting Cumbarjua canal, Goa. *Indian Journal of Marine Sciences*, **2**, 47-53.
- Untawale, A. G. & Parulekar, A. H. (1976). Some observations on the ecology of an estuarine mangrove of Goa. *Mahasagar-Bulletin of the National Institute of Oceanography*, **9**, 57-62.
- Venugopalan, V. K. (1969). Primary production in the estuarine and inshore waters of Porto Novo (11° 29' N-79° 49' E). *Bulletin of the National Institute of Science, India*, **38**, Part II, 743-6.
- Vijayaraghavan, S., Joseph, K. J. & Balachandran, V. K. (1974). Preliminary studies on nanoplankton productivity. *Mahasagar - Bulletin of the National Institute of Oceanography*, **7**, 125-9.
- Wyatt, T. & Qasim, S. Z. (1973). Application of a model to an estuarine ecosystem. *Limnology and Oceanography*, **18**, 301-6.