

## Primary Productivity of the Bay of Bengal During August-September 1976

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Primary productivity was measured at 29 stations in the Bay of Bengal during the southwest monsoon of 1976 together with related parameters like phytoplankton counts, chlorophyll *a*, pheophytin, particulate organic carbon, inorganic phosphate and nitrate. Primary productivity in the offshore area (219.79 mg C/m<sup>2</sup>/day) was relatively less than in the shelf (294.8 mg C/m<sup>2</sup>/day) and slope (315.43 mg C/m<sup>2</sup>/day) areas. At all the stations (except No. 115) the productivity at the surface was maximum relative to the subsurface layers. The season under study was more productive compared to the premonsoon season. Concentration and distribution of pheophytin (6.45 mg/m<sup>2</sup>) and particulate organic carbon (11967 mg/m<sup>2</sup>) from the Bay of Bengal were reported for the first time. Phytoplankton analysis showed that diatoms contributed 70%, flagellates 23% and dinoflagellates 7% to the biomass at the surface.

AS a part of the NIO institutional project on marine food chains and survey of living resources in the Indian seas, primary productivity and related parameters, viz. phytoplankton, chlorophyll *a*, pheophytin, particulate organic carbon, inorganic phosphates and nitrates, have been investigated in the Bay of Bengal during the southwest monsoon of 1976. The results are discussed in the present paper.

### Materials and Methods

Data were collected from 29 stations in the area between 80°02' and 92°21'E and 09°58' and 20°38'N in the Bay of Bengal (Fig. 1). At each station samplings for all parameters were done from 5 predetermined light penetration (optical depth; 100, 60, 30, 16 and 1%).

Primary productivity was measured by <sup>14</sup>C method; samples were incubated under simulated *in situ* conditions for 24 hr. Chlorophyll *a* and pheophytin were estimated on board by fluorimetry. Chlorophyll *a* values were corrected for pheophytin. Particulate organic carbon (POC) was determined by wet oxidation and titrimetry. GF/C filters were used for filtration of samples for estimation of both chlorophyll *a* and POC.

### Results

Based on the bottom topographic conditions the region studied was divided into 3 areas, viz. shelf (12 stations), slope (8 stations) and offshore (9 stations).

The average values and the corresponding variations of primary productivity for the 3 areas are given in Table 1. In Fig. 2 are depicted the magnitude of column productivity and the station locations. The slope area is found to be relatively more productive than the shelf.

Surface productivity in the offshore areas was low, while the column productivity was comparable to the nearshore areas, as the column value is an integer of a wider depth column (62 m, on the average). At all the stations, except No. 115, productivity at the surface was maximum relative to the subsurface levels. As stated by Radhakrishna<sup>1</sup> this is probably due to the low incident radiation reaching the sea surface in the Bay of Bengal.

Distribution of chlorophyll *a* at the surface showed a clear decreasing trend from the shelf to offshore while an increasing trend was seen in the column from the shelf to offshore (Table 2). Pheophytin values from the Bay of Bengal are being reported for the first time here. At the surface, the average concentration of pheophytin was minimum in the shelf and maximum in the slope area. In the column, however, there was a clear increase in the pheophytin concentration from the shelf to offshore areas (Table 2). The distribution of POC at the surface followed the same trend as pheophytin, being low in the shelf and high in the slope (Table 2). The column values again increased offshore.

Concentration of the inorganic phosphate in the euphotic zone is given in Table 3. The values at the surface in the 3 areas were generally high, the highest being in the slope. The integral mean concentration (IMC) for the euphotic zone was also highest in the slope.

Inorganic nitrate was not detectable at the surface at 25 out of the 29 stations studied; it was detectable at 16 stations at the 10% optical depth and at 23 stations at the lower limit of the euphotic zone. As this nutrient was not detectable in the upper layers for the majority of stations, column values were not calculated. Under these circumstances, the role of nitrate in productivity could not

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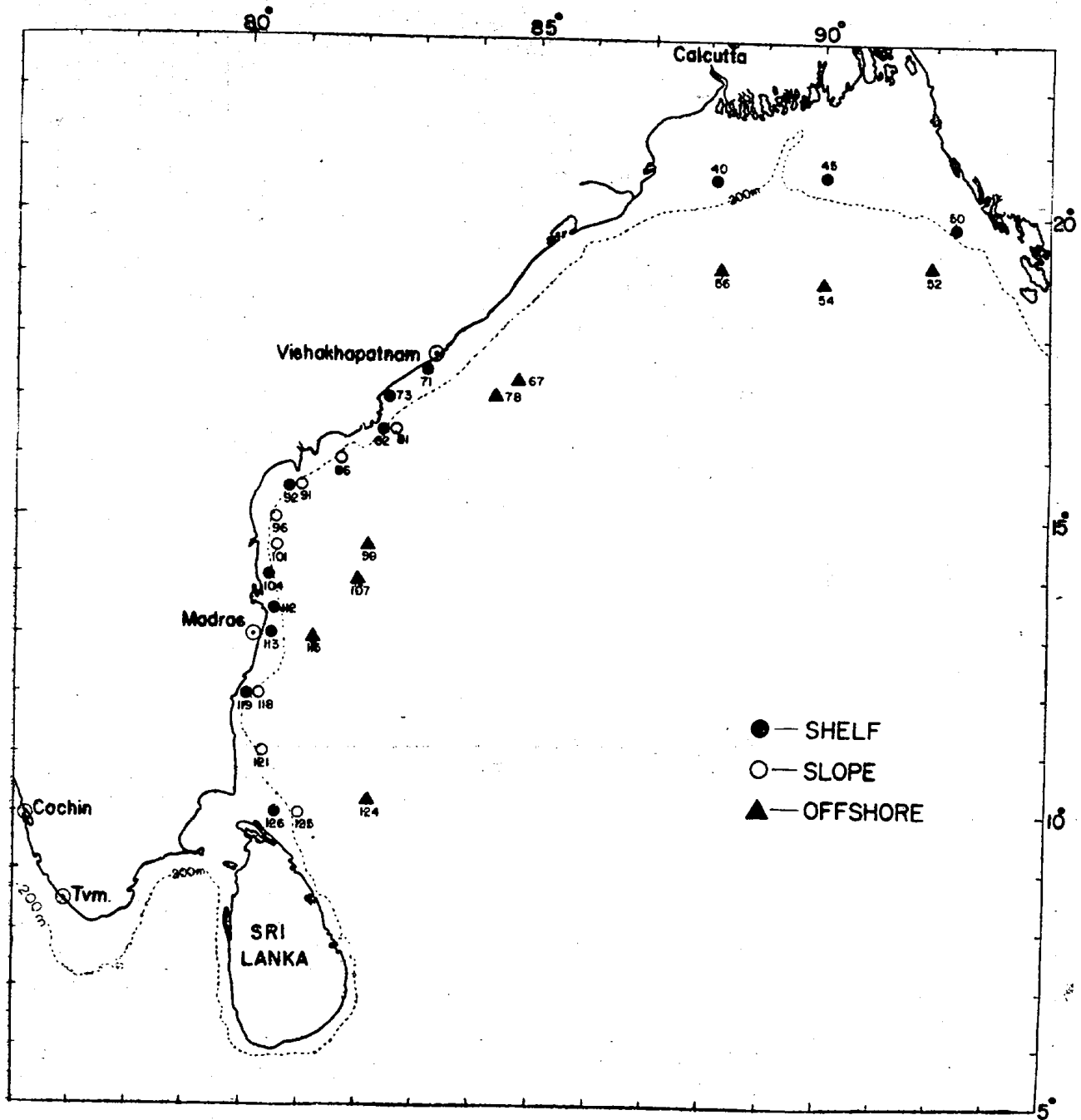


Fig. 1 — Location of stations

TABLE 1 — PRIMARY PRODUCTIVITY IN THE BAY OF BENGAL (AUG.-SEPT. 1976)

(Values represent average with range in parentheses)

Area	Surface (mg C/m <sup>2</sup> /day)	Column (mg C/m <sup>2</sup> /day)
Shelf	51.22 (7.99-222.93)	294.8 (49.03-559.91)
Slope	57.9 (4.07-279.31)	315.43 (49.66-606.37)
Offshore	10.69 (2.71-39.48)	219.79 (129.99-329.45)
Entire region	40.55	275.13

be studied. Nitrite or ammonia values were not available.

Although phytoplankton samples were collected from each light penetration depth, surface values only are presented here. The cell counts were maximum in the shelf area averaging  $35.5 \times 10^6/m^3$  (range 5 to  $175 \times 10^6/m^3$ ). The offshore crop was quite low, and averaged  $8 \times 10^6/m^3$  (range, 5 to  $45 \times 10^6/m^3$ ). The slope value was comparable to the shelf value (av.  $32.4 \times 10^6/m^3$ ; range 11.5 to  $112.5 \times 10^6/m^3$ ).

Diatoms dominated in all the surface samples accounting for 70% of the total phytoplankton standing crop. Among the diatoms, the genus

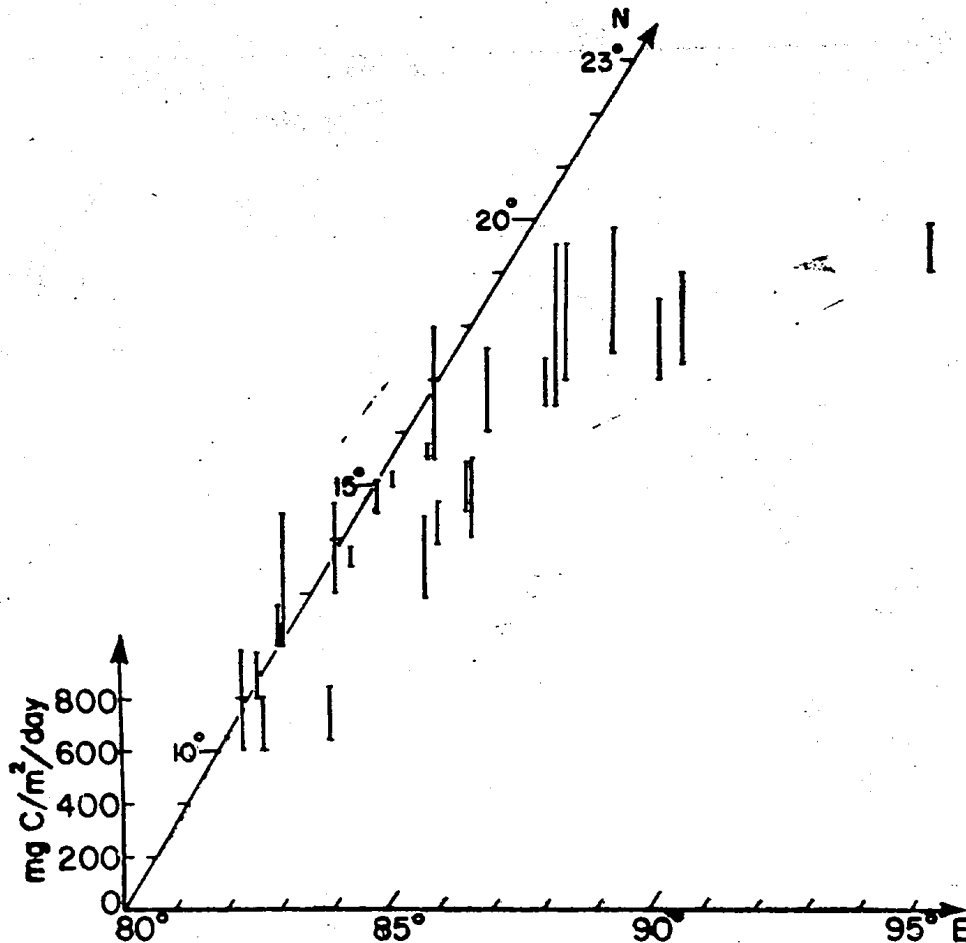


Fig. 2 — Magnitude of column productivity and location of stations [X axis longitude, Z axis latitude, Y axis column productivity]

*Navicula* was present in all the stations, followed by *Rhizosolenia*, *Coscinodiscus*, *Nitzschia*, *Bacteriastrum*, *Chaetoceros* and *Thalassiothrix* in that order of frequency. However, in terms of quantitative abundance, *Rhizosolenia* topped the list followed by *Navicula*, *Nitzschia*, *Thalassiothrix*, *Chaetoceros*, *Bacteriastrum*, *Coscinodiscus*, *Biddulphia*, *Asterionella* and *Denticula*. *Bellerochea*, *Climacodium* and *Ditylum* were encountered at several stations while *Stephanopyxis*, *Pleurosigma*, *Eucampia*, *Cyclotella*, *Thalassiosira*, *Mastogloia* and *Skeletonema* were present at 1 station each in insignificant numbers.

Next to diatoms, flagellates were present in considerable numerical abundance (23%). *Tetraselmis* was the most frequent flagellate encountered.

Dinoflagellates which ranked 3rd in abundance were relatively few accounting for only 7% of the total crop. Of them, *Peridinium* was encountered at 24 of the total 29 stations, followed by *Prorocentrum* at 5 stations, *Ceratium* and *Ceratocorys* at 2 stations each and *Dinophysis* at 1 station.

Blue-green algae and silicoflagellates were encountered rarely and in insignificant numbers.

### Discussion

To understand the relationship between primary productivity and related factors like phytoplankton

standing crop, concentration of chlorophyll *a*, pheophytin, particulate organic carbon and inorganic phosphate, both at the surface and through the euphotic column, correlation coefficients were calculated. These are presented in the form of a matrix in Table 4.

At the surface, the most significant correlation (at 0.1% level) was observed between primary productivity and chlorophyll *a* [regression equation is: primary productivity = 5.437 + 48.31 chlorophyll *a*; scatter = 38.27]. Between surface productivity and phytoplankton and between phytoplankton and POC the correlations were less, being significant at 5% level. There was no correlation at all, even at 10% level, among the other parameters.

In the column also, the correlation among the various parameters was very poor (Table 4). The coefficient values were not significant even at 10% level, except between primary productivity and POC, which was significant at 5% level. The values indicate that within the small number of observations made, variations in each parameter were very large rendering the correlations statistically insignificant.

A further attempt was made to find out if any correlation existed among these parameters at

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TABLE 2 — DISTRIBUTION OF CHLOROPHYLL *a*, PHEOPHYTIN AND PARTICULATE ORGANIC CARBON IN BAY OF BENGAL (AUG.-SEPT. 1976)

(Values represent average with range in parentheses)

Area	Surface (mg/m <sup>3</sup> )	Column (mg/m <sup>2</sup> )
CHLOROPHYLL <i>a</i>		
Shelf	1.039 (0.116-5.717)	13.66 (6.037-32.252)
Slope	0.684 (0.104-2.195)	16.01 (9.008-23.509)
Offshore	0.343 (0.084-1.675)	18.6 (8.630-28.448)
Entire region	0.725	15.2
PHEOPHYTIN		
Shelf	0.159 (0.0.444)	5.04 (0.194-10.964)
Slope	0.214 (0.0.598)	6.23 (2.32-9.51)
Offshore	0.177 (0.021-0.848)	9.6 (0.45-18.54)
Entire region	0.186	6.45
PARTICULATE ORGANIC CARBON		
Shelf	283 (63-817)	10202 (1233-33534)
Slope	429 (63-1071)	11131 (6827-20650)
Offshore	366 (158-536)	14866 (4057-25505)
Entire region	400	11967

each optical depth. Once again the scatter was wide and no significant correlation emerged.

Owing to the limitations in the coverage of stations conclusions could not be drawn on the general level of productivity or on the geographical delineation into areas of low or high production. However, by comparing the data collected earlier (Table 5), it is possible to state that the off-shore areas are relatively less productive. The shelf and slope areas are, more or less, equally productive; in fact, in the present study the slope was more productive than the shelf area. In this connection, it may be mentioned that in the Bay of Bengal the shelf is rather narrow (30 km up to 200 m) and the slope is also abrupt (11 km wide, 200-1000 m), and the two together form a narrow band, especially between 10° and 20°N in the east-west direction. Lower productivity in the shelf, as reported in the present study, could be attributed to the high content of inorganic and organic material carried by the large number of major rivers, especially in the monsoon season, notwithstanding the high levels of nutrients, as evidenced by the inorganic phosphate concentration. This river discharge rendered the waters less transparent, thus limiting photosynthesis. Radhakrishna<sup>1</sup> attributed the low productivity in shelf stations to turbidity. The high levels of productivity at the shelf observed during *Galathea* expedition<sup>2</sup> and *Anton Bruun*<sup>3</sup> cruises could be due to the upwelling that preceded the periods of those observations and also to the dry season when the effect of river discharge is much

TABLE 3 — INORGANIC PHOSPHATE IN THE BAY OF BENGAL (AUG.-SEPT. 1976)

(Values, µg at/litre, are average with range in parentheses)

Area	Surface	Column IMC
Shelf	0.689 (0.13-1.19)	0.74 (0.24-1.37)
Slope	0.888 (0.2-2.25)	0.80 (0.55-1.21)
Offshore	0.597 (0.2-1.39)	0.71 (0.43-1.36)
Entire region	0.71	0.74

TABLE 5 — PRIMARY PRODUCTIVITY MEASUREMENTS IN THE BAY OF BENGAL (g C/m<sup>2</sup>/day)

(Number of stations are given in parentheses)

Area	<i>Galathea</i> <sup>2</sup> expedition (April-May 1951)	<i>Anton Bruun</i> <sup>3</sup> (April-May 1963)	Radha- krishna <sup>1</sup> (March-April 1975)	Present study (Aug.-Sept. 1976)
Shelf	0.6 (1)	0.82 (3)	0.18 (2)	0.29 (12)
Slope	0.31 (1)	0.13 (1)	0.24 (1)	0.32 (8)
Offshore	0.19 (4)	0.14 (46)	0.16 (8)	0.22 (9)

TABLE 4 — CORRELATION MATRICES FOR VARIOUS PARAMETERS AT SURFACE AND IN THE COLUMN

	Surface					Column				
	Primary producti- vity	Phyto- plankton	Chloro- phyll <i>a</i>	Pheo- phytin	POC	Primary producti- vity	Chloro- phyll <i>a</i>	Pheo- phytin	POC	
Phytoplankton	0.440*									
Chlorophyll <i>a</i>	0.828†	0.061				0.173				
Pheophytin	0.200	0.046	0.252			0.027	0.259			
POC	0.231	0.358*	-0.129	0.002		0.431*	-0.124	0.361		
Phosphate (P/PO <sub>4</sub> )	0.074	0.127	0.053	0.012	-0.158	-0.002	0.093	0.098	0.164	

Level of significance: \*5%; †0.1%; all other values are not significant.  
POC = particulate organic carbon.

less. The productivity values from the various sources are given in Table 5.

Productivity in the slope and offshore waters was higher in the south-west monsoon season than the premonsoon season, suggesting that the monsoon season is more productive than the premonsoon season, notwithstanding the fact that the shelf values in the monsoon season were low, for reasons discussed earlier.

Chlorophyll *a* did not show any correlation with primary production in the column. At the surface, the shelf average was relatively higher than the slope average and the latter was double the offshore value. Incidentally, the phytoplankton standing crop in the offshore area was also very low. When the column averages were considered, the value increased towards offshore areas. This anomaly could be due to integration of values over the euphotic depth column. The offshore values were naturally high, as greater depth columns (c. 62 m) were considered while the average depth for the shelf area was 20 m and the slope was 31 m. The *Anton Bruun*<sup>3</sup> values of 0.25 and 0.11 mg/m<sup>3</sup> for the shelf and offshore areas respectively were much lower than the present values of 1.04 and 0.34 mg/m<sup>3</sup>. Besides, *Anton Bruun*<sup>3</sup> values were not corrected for pheophytin and if the pheophytin correction were applied, the *Anton Bruun* chlorophyll *a* values would be still lower.

At the surface, the relation between POC and primary productivity or between POC and chlorophyll *a*, which is an (indirect) index of the photosynthetically active living matter, was nonlinear and highly scattered. However, there was a significant correlation at 5% level between POC and phytoplankton. Ryther and Menzel<sup>4</sup> found a similar situation in the Arabian Sea and suggested the possibility of large and variable quantities of detrital carbon in the particulate matter.

In the euphotic zone, the scatter between primary productivity and POC was much less and the correlation coefficient was significant at 5% level. But the living carbon values (chlorophyll *a*) showed no linear relationship to productivity.

In this study, POC at the surface averaged 400 mg/m<sup>3</sup> ranging from 283 mg/m<sup>3</sup> on the shelf to 429 mg/m<sup>3</sup> on the slope with the intermediate value of 366 mg/m<sup>3</sup> in the offshore area. The present authors recalculated the *Anton Bruun*<sup>3</sup> and *Meteor*<sup>5</sup> raw data of the IIOE for the Arabian Sea and the averages obtained were 600 and 899 mg/m<sup>3</sup> respec-

tively. Bhattathiri and Devassy<sup>6</sup> reported an average POC concentration of 251 mg/m<sup>3</sup> ranging from 85 to 372 mg/m<sup>3</sup> for the shelf stations off Bombay. These values are much greater than the ranges in the surface POC values (12-32 mg/m<sup>3</sup>) of south-east Indian Ocean<sup>7</sup> and the overall average of 54 µg/litre (=54 mg/m<sup>3</sup>) and 30 µg/litre (=30 mg/m<sup>3</sup>) reported for the surface waters of South Atlantic and Pacific Oceans<sup>8</sup>. POC values of the Bay of Bengal and the Arabian Sea, both of which are semi-enclosed seas, are naturally higher than the typical oceanic values cited above. Parsons<sup>9</sup> while reviewing the POC in the sea stated that the concentration of POC in coastal waters is generally 1 or 2 orders of magnitudes higher than the oceanic waters.

This study was undertaken in a limited area, just for one time of the year. As far as surface values are concerned, large seasonal and regional variations in POC can be expected, since living phytoplankton are included in the measurement for these layers<sup>10</sup>. To obtain a clear picture of the concentration and distribution of POC and its role in the food chain in the Bay of Bengal, much more intensive effort covering different seasons, greater depths and wider areas is necessary.

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