

PRIMARY PRODUCTION IN THE BAY OF BENGAL DURING SOUTHWEST MONSOON OF 1978

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ABSTRACT

Measurements of primary production, chlorophyll *a* and particulate organic carbon were made at 33, 43 and 44 stations respectively during August-September of 1978. The average surface production, chlorophyll *a* and particulate organic carbon values were 69.4 mg C/m³/day, 0.23 mg/m³ and 472 mg/m³. Average column primary production, chlorophyll *a* and particulate organic carbon values of the euphotic zone were 0.98 g C/m²/day, 9.81 mg/m² and 19.7 g/m². The integral mean concentrations of inorganic phosphate phosphorus and nitrate nitrogen ($\mu\text{g-at/l}$) from the euphotic zone were 1.21 ± 0.55 and 2.80 ± 2.46 . Nitrite nitrogen was below the detectable level in almost all the stations. The thickness of the surface layer ranged from 5 to 75 m. Surface salinity was less than 30‰ at the head of the Bay and about 18‰ at the river mouths. Surface current in the northwestern Bay was found to vary from southwesterly to southerly. Along the coast, alternating features of convergences and divergences have been found. A comparison of primary production value obtained during similar seasons of the previous two years and also with those of the Arabian Sea indicated that the average production value obtained during 1978 was the highest of all the values.

INTRODUCTION

Measurements of primary production in the Bay of Bengal were made for the first time during Galathea expedition (Steemann Nielsen and Jensen, 1957). Later during the International Indian Ocean Expedition (IIOE), similar measurements were made from many parts of the Bay of Bengal (Woods Hole Oceanographic Institution, 1964; Kabanova, 1964; Krey, 1973; Prasad, Banerji and Nair, 1970). Recently, Qasim (1977 and 1978) has reviewed the data on primary production and phytoplankton pigments of the Indian Ocean based mostly on the data collected during IIOE. Besides, the authors have made measurements of primary production during the southwest monsoon period of 1976 and 1977 (Radhakrishna, Bhattathiri and Devassy, 1978; Devassy, Bhattathiri and Radhakrishna, in press). This communication deals with primary production and other related parameters measured during August-September of 1978 (37th to 40th cruises of R. V. *Gaveshani*, 13th August to 9th September, 1978). The values have been compared with earlier observations.

MATERIALS AND METHODS

Station positions are shown in Fig. 1. Measurements of primary production, chlorophyll *a* (Chl *a*) and particulate organic carbon (POC) were carried out from 33, 43

and 44 stations. Samplings were done from surface and four other depths (60, 30, 16 and 1% light depths). Primary production was measured by simulated *in situ* incubation of samples for 24 hours, after addition of ($4 \mu\text{Ci}$) ^{14}C . Dark bottles were filtered immediately after addition of radioactive carbon. Samples were filtered on to Sartorius Membrane filters ($0.45 \mu\text{m}$ porosity). Photosynthetic uptake of radioactive carbon was estimated by counting the filter in a liquid scintillation system with 15 ml of NE 220 scintillation

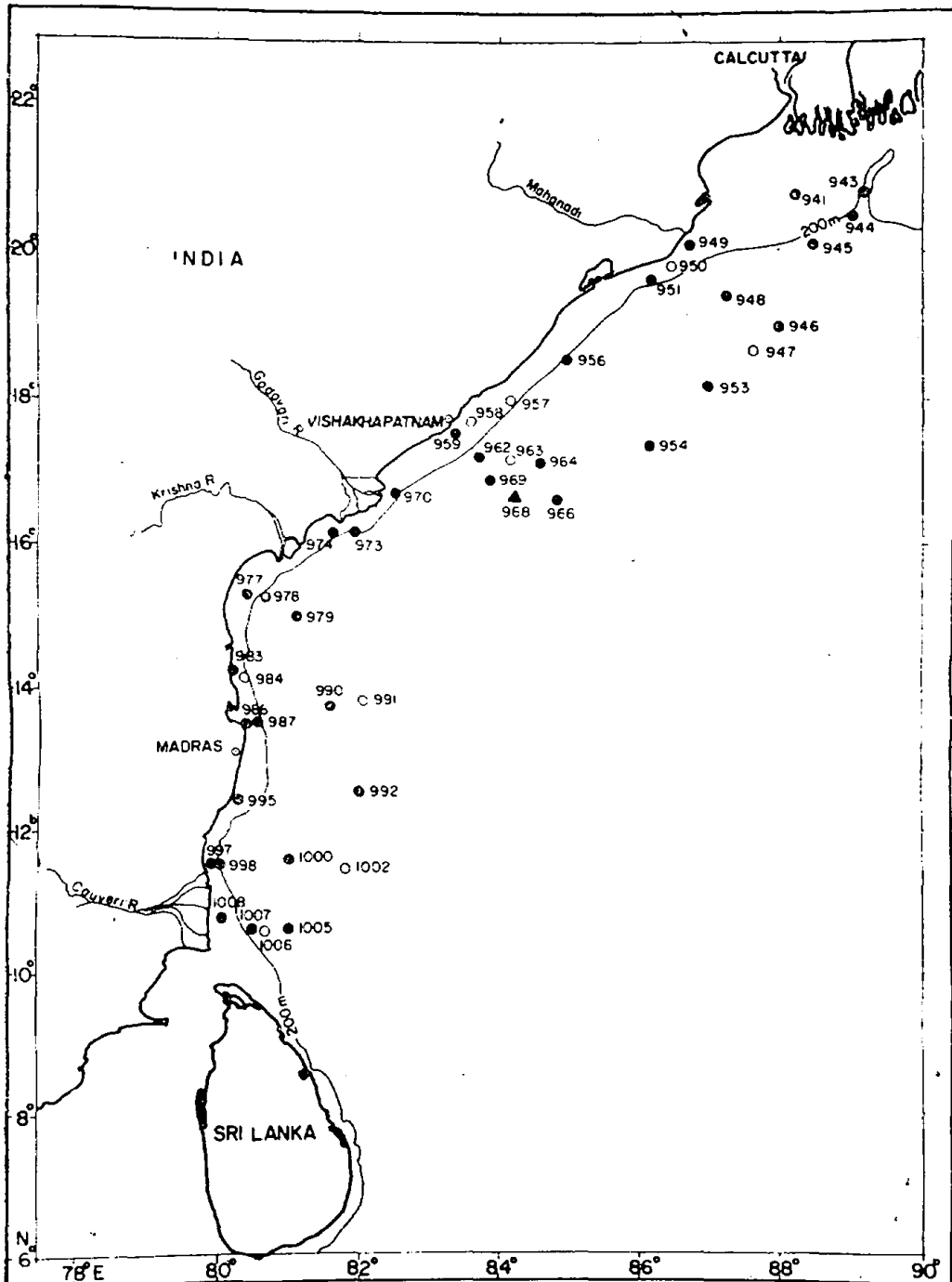


Fig. 1. Station positions

cocktail. Chl *a* was measured by extraction of pigment in 90% acetone and by fluorometry (Strickland and Parsons, 1968). POC was determined by wet acid digestion and colorimetry (Strickland and Parsons, 1968).

RESULTS AND DISCUSSION

Primary production at the surface varied considerably from station to station. Of the 33 stations, 15 were from inshore areas (depth ≤ 200 m) and the rest from offshore areas. Production at the inshore and offshore regions varied from 2.6 to 403.1 and 2.0 to 143.1 mgC/m³/day (Table I). Ratio between the highest and the lowest values of production at both areas were 155 and 72 respectively. The average production values for the inshore, offshore and entire region were 113.2, 32.9 and 69.4 mgC/m³/day. At many inshore stations, the surface production was high (Table I).

Chl *a* at surface varied from 0.02 to 0.93 mg/m³ (average 0.34) at inshore stations (Table I). Many stations where chl *a* was found to be high had higher production as well. The lowest and highest values of chl *a* observed at offshore region were 0.01 and 1.01 mg/m³ respectively. Average values of chl *a* at the offshore and for the entire region were 0.15 and 0.24 mg/m³. Phaeophytin varied from 0 to 0.20 (average 0.07) at the inshore areas and from 0.01 to 0.11 mg/m³ at the offshore areas (average 0.03).

Particulate organic carbon at the surface was found to vary from 88 to 704 and 220 to 924 mg/m³ at the nearshore and the offshore areas (Table I). The respective averages were 523 and 433 mg/m³. The average for all the stations together was 472 mg/m³.

The column primary production varied much from station to station. The ranges in the production values at the inshore and offshore region were from 0.12 to 3.41 and 0.18 to 2.20 gC/m²/day (Table I). The average values of production for the inshore, the offshore and the entire region were 1.28, 0.74 and 0.98 gC/m²/day respectively. Production at stations 987 and 998 were slightly more than 3 gC/m²/day.

The values of column chl *a* for the entire area varied from 1.11 to 50.55 mg/m² (Table I). The variation in chl *a* values from the offshore region was much less (1.28 to 33.72 mg/m²). Average values at the inshore, the offshore and entire area were 11.78, 8.25 and 9.81 mg/m². Phaeophytin concentration varied from 0.46 to 9.43 mg/m² (average 2.76) at different stations. The average values at the inshore and offshore areas were 2.38 and 3.05 mg/m².

POC concentration was found to vary from 2.04 to 46.1 g/m² in the euphotic column (Table I). A direct comparison of POC values from inshore and offshore regions may give misleading information since the values have been integrated over greater depths at offshore stations. Hence integral mean concentration (IMC) over the euphotic zone have been used for comparing the inshore and offshore values which was from 209 to 631 (average 479) and 254 to 610 mg/m³ (average 404). Thus, IMC values from the inshore areas were more than that at the offshore area.

The concentrations of nutrients from the euphotic zone only have been considered here. In the inshore regions, the IMC values of nutrients have been calculated for 50 m column while that for offshore for 100 m column. However, when the actual depth was

Table I. Primary production, chlorophyll *a*, phaeophytin and POC of the Bay of Bengal during August-September, 1978.

St. No.	SURFACE				COLUMN				
	Primary production mgC/m ³ day	Chl <i>a</i> mg/m ³	Phaeophytin mg/m ³	POC mg/m ³	Primary production gC/m ² /day	Chl <i>a</i> mg/m ²	Phaeophytin mg/m ²	POC g/m ²	POC (IMC) mg/m ³
941	42.8	0.09	0.04	445	0.42	4.07	1.93	10.32	344
943	2.7	0.06	0.01	264	0.25	2.98	1.41	19.97	399
944	20.7	0.18	0.02	528	0.82	4.74	2.44	21.78	435
945	8.9	0.10	0.02	286	0.42	3.62	0.96	12.71	254
946	4.5	0.08	0.01	924	0.48	10.62	6.96	46.10	610
947	—	0.07	0.02	594	—	5.89	8.34	24.32	324
948	83.3	0.05	0.02	572	2.20	9.31	5.40	36.61	438
949	33.7	0.44	0.16	484	0.12	1.85	0.46	2.59	431
950	—	0.20	—	440	—	23.81	0.88	14.93	597
951	403.1	0.68	0.14	704	1.08	6.32	1.37	5.04	630
953	55.8	0.25	0.08	396	0.75	12.48	3.36	22.83	507
954	5.5	0.05	0.03	286	0.30	3.52	1.44	24.25	539
956	50.5	1.01	0.11	406	0.50	11.21	2.51	9.22	307
957	—	0.47	0.04	572	—	10.72	2.56	18.15	454
958	—	0.13	0.03	506	—	9.50	2.00	23.65	591
959	174.4	0.27	0.02	418	1.78	2.39	2.03	6.27	209
962	77.0	0.16	0.02	682	1.36	10.21	1.31	21.07	527
963	—	0.17	0.04	396	—	5.09	3.35	17.82	356
964	17.7	0.06	0.01	330	0.55	8.49	4.76	20.27	405
966	13.7	0.06	0.03	308	0.31	6.38	2.96	16.54	331
968	—	—	—	418	—	—	—	21.40	428
969	22.2	0.04	0.02	264	0.76	1.67	1.70	16.78	336
970	83.7	0.16	0.01	440	0.99	5.63	1.39	13.06	435
973	50.3	0.33	—	374	0.24	2.34	0.77	3.71	371
974	107.1	0.21	0.14	484	0.20	12.05	0.49	2.04	407
977	227.9	0.93	0.20	88	1.75	18.39	1.47	3.45	230
978	—	0.24	0.04	418	—	18.60	1.13	27.83	557
979	60.5	0.22	0.01	484	0.90	10.44	0.93	5.83	291
983	23.0	0.08	0.06	594	0.78	9.40	1.28	18.61	465
984	—	0.16	0.01	572	—	15.17	1.09	13.57	631
986	210.6	0.88	0.10	616	1.83	17.47	1.64	7.96	531
987	73.5	0.50	0.14	860	3.41	50.55	9.37	23.88	477
990	2.0	0.03	0.01	550	0.18	1.50	0.67	23.56	507
991	—	0.02	0.03	308	—	1.28	0.74	13.65	273
992	4.0	0.01	0.02	220	0.28	3.85	1.34	26.18	349
995	2.6	0.05	0.02	792	0.22	1.11	0.46	18.94	473
997	74.0	0.34	0.05	440	0.96	6.84	1.47	7.77	388
998	175.9	0.52	0.09	506	3.23	13.66	5.20	21.50	430
1000	10.2	0.06	0.03	382	0.68	5.60	1.57	39.37	525
1002	—	0.09	0.01	792	—	10.83	2.55	45.50	607
1005	9.6	0.05	0.02	308	0.69	4.30	3.13	39.71	529
1006	—	0.01	0.02	264	—	11.57	4.82	15.84	316
1007	143.1	0.50	0.03	440	1.85	33.72	9.42	17.54	438
1008	16.7	0.02	0.06	594	2.17	22.56	9.43	14.52	484

less than 50 m, the entire column has been considered to calculate IMC. Table II gives the surface and IMC values of nutrients and the corresponding standard deviations for August-September periods of 1978, 1977 and 1976. During 1978, IMC values of PO₄-P ranged

from 0.14 to 2.36 $\mu\text{g-at/l}$ (average 1.21 ± 0.55) while that of $\text{NO}_3\text{-N}$ from 0.35 to 11.95 (average 2.80 ± 2.46). Nitrite nitrogen was below detectable level in almost all the stations. The wide fluctuation in the values is evident from the high standard deviation. Concentration of $\text{PO}_4\text{-P}$ and $\text{NO}_3\text{-N}$ near surface (10m) ranged from 0.06 to 2.38 and 0.13 to 5.10 $\mu\text{g-at/l}$. The respective averages were $0.83 (\pm 0.64)$ and $1.04 (\pm 1.17) \mu\text{g-at/l}$.

Surface salinity was $< 30\text{‰}$ at the head of Bay. At river mouths it was about 18‰ . In general, the surface salinity increased southwards. At most of the stations σ_t at the surface was found to vary between 18 and 21 except at locations near the mouths of the rivers. At the offshore stations σ_t ranged from 20 to 25 in the upper 100 m.

The thickness of the surface layer ranged from 5 to 50 m in the inshore region and from 20 to 75 m in the offshore areas. Wyrski (1971) reported that the thickness of the surface layer was about 60 m in most of the areas of the Bay. However, in the northern Bay, it was less than 40 m.

Based on the sea surface temperature data, it was found that the surface currents varied from southwesterly to southerly in the northwestern Bay. A clockwise gyre was present in the north Central Bay. Off the river Godavari, the flow is northwards. South of Godavari, the flow was complicated with several eddies and the circulation was clockwise. These eddies in turn lead to convergences and divergences (*i.e.* sinking and upwelling). Along the coast, these alternating features have been found. This feature in turn results in alternating situation of lower and higher production. Because of the lower salinity at the top layer, the subsurface water perhaps may not reach the surface. However, another factor which helps the subsurface nutrient rich water to get mixed up with the surface layer is the intense cyclonic activity during the post southwest monsoon.

Based on the data collected during IIOE, it was found that during southwest monsoon, a huge clockwise cell exist at the central Bay of Bengal (Wyrski, 1971). According to Varadachari, Murty and Das (1968), "the circulation is characterised by two anti-cyclonic cells centred at 11°N , 83°E and 16°N , 85°E with a zone of strong cyclonic shear between them extending towards the southeast from the regions of Godavari and Krishna river mouths to about 87°E longitude". The surface waters move across the Bay to the eastern and northeastern, which pile up in the coastal regions. This causes cyclonic circulation at the head of the Bay till September. West of Andaman Islands, however, the circulation is anticlockwise. Surface water moves southwards during northeast monsoon. The anticlockwise gyre, formed at the head of the Bay during this season, persists till April (Wyrski, 1971).

It has been reported earlier that upwelling occurs at some places off the east coast of India during premonsoon and southwest monsoon seasons (Lafond, 1954; Anand, Murty, Jayaraman and Aggarwal, 1968; Murty and Varadachari, 1968). The wind distribution is conducive to generate upwelling on the east coast since winds blow parallel to the coast during southwest monsoon. Anand, Murty, Jayaraman and Aggarwal (1968) reported intense subsurface upwelling off the mouths of the rivers Godavari and Krishna during southwest monsoon periods. It is not manifested at the surface due to the river and coastal run off. The features mentioned above have been found during August–September of 1978 as well.

Table II. Average inorganic phosphate and nitrate concentrations ($\mu\text{g-at/l}$) at the surface and column during August-September of 1978, 1977 and 1976. Column values are the integral mean concentration from the euphotic zone. Standard deviation is given in paranthesis.

Zone	Period	SURFACE			COLUMN		
		$\text{P}_4\text{-P}$	$\text{NO}_3\text{-N}$	$\text{PO}_4\text{-P}$	$\text{NO}_3\text{-N}$	$\text{PO}_4\text{-P}$	$\text{NO}_3\text{-N}$
Inshore	1978	0.99 (0.75)	1.72 (1.49)	1.02 (0.47)	1.63 (0.96)		
	1977	0.50 (0.70)	3.63 (5.13)	0.46 (0.52)	3.06 (4.32)		
	1976	0.69 (0.37)	0.38 (0.73)	0.72 (0.37)	1.07 (1.41)		
Offshore	1978	0.75 (0.59)	0.50 (0.29)	1.30 (0.57)	2.84 (3.13)		
	1977	0.32 (0.17)	0.02 (0.07)	0.43 (0.14)	2.13 (2.27)		
	1976	0.73 (0.49)	0.09 (0.35)	0.76 (0.30)	0.95 (1.00)		
Entire	1978	0.83 (0.64)	1.04 (1.17)	1.21 (0.55)	2.30 (2.46)		
	1977	0.35 (0.26)	0.58 (2.01)	0.43 (0.20)	2.27 (2.44)		
	1976	0.72 (0.44)	0.21 (0.55)	0.75 (0.32)	1.00 (1.16)		

Table III. Primary production, chlorophyll *a*, phaeophytin and particulate organic carbon in Bay of Bengal during the period of August-September of 1978, 1977 and 1976.

Season	Primary production			Chlorophyll <i>a</i>			Phaeophytin			Particulate organic carbon					
	Inshore	Offshore	Entire	Inshore	Offshore	Entire	Inshore	Offshore	Entire	Inshore	Offshore	Entire			
1978 (Aug-Sept)	mg C/m ³ /day	32.9	69.4	0.34	0.15	0.24	0.07	0.03	0.05	523	433	472			
													113.2	34.5	51.2
													18.7	25.6	40.5
1977 ^a (Aug)	mg C/m ³ /day	32.9	40.5	1.04	0.50	0.73	0.16	0.19	0.18	381	412	400			
													11.8	12.9	13.7
													0.93	0.64	0.28
1976 ^b (Aug-Sept)	g C/m ² /day	0.27	0.28	13.7	17.3	15.2	5.0	8.0	6.7	10.2	13.1	12.0			
													1.28	0.74	0.93
													0.98	0.57	0.64
1978	mg/m ²	8.3	9.8	2.4	3.1	2.8	14.2	22.7	10.7	14.2	22.7	10.7			
													8.3	9.8	2.4
													3.4	3.5	3.5
1977 ^a (Aug)	mg/m ²	17.3	15.2	5.0	8.0	6.7	10.2	13.1	12.0	10.2	13.1	12.0			
													17.3	15.2	5.0
													17.3	15.2	5.0
1976 ^b (Aug-Sept)	g C/m ² /day	0.27	0.28	13.7	17.3	15.2	5.0	8.0	6.7	10.2	13.1	12.0			
													17.3	15.2	5.0
													17.3	15.2	5.0

(a) Devassy, Bhattathiri and Radhakrishna (in Press).

(b) Radhakrishna, Bhattathiri and Devassy, 1978.

Primary production along the coast shows alternating high and low values. This is perhaps due to the convergences and divergences occurring near mouths because of eddies. The results obtained during August–September 1978 indicated that average surface production of inshore waters was 3.5 times higher than that of offshore waters. Similarly, chl. *a* and POC were also found to be higher at the inshore stations as compared to offshore stations. The average phosphate–phosphorus concentration did not differ much in the two zones although nitrate–nitrogen was higher in the nearshore regions.

Column production during 1978 was highest at the inshore waters despite a lower euphotic depth. Table III gives the value of primary production, chl *a*, phaeopigments and POC at the inshore, offshore and entire areas for the periods of August–September 1978, 1977 and 1976. A comparison will show that the production was highest during 1978 although chl *a* was not so. Production was lowest during 1976. POC was, however, highest during 1978. The respective average values of production during 1978, 1977 and 1976 were 0.98, 0.64 and 0.28 gC/m²/day. Surface values of production and POC were also higher during 1978. Chl *a* did not show the above trend. A comparison of the inshore and offshore values of production and chl *a* showed that they were higher at the inshore areas (Table III).

The data available on the primary production of Bay of Bengal have been compiled in Table IV. Thus, during April–May 1957, April–May 1963 and March–April 1975, the average production in the Bay of Bengal was 0.60, 0.82 and 0.18 in the inshore areas, 0.21, 0.14 and 0.17 in the offshore areas and 0.28, 0.18 and 0.17 gC/m²/day for the entire area. Compared to the above values and those reported by the authors for August–September 1976, the values obtained during 1978 and 1977 were much higher. It is difficult to pinpoint the reasons for such higher production.

The average primary production of Bay of Bengal during August–September 1978 was found to be higher than that (0.13 to 0.70 gC/m²/day) of many areas of the Arabian Sea such as northern Arabian Sea, northeastern Arabian Sea and Laccadive Sea (Radhakrishna, Devassy, Bhargava and Bhattathiri, 1978; Radhakrishna, Devassy, Bhattathiri and Bhargava, 1978; Bhattathiri and Devassy, 1979). It was about 3.8 times the average value of 0.26 gC/m²/day computed for the entire Indian Ocean (Qasim, 1977). It is more

Table IV. Primary production in the Bay of Bengal. The unit of production is gC/m²/day.

Area	Galathea (a) Expedition April–May 1951	Anton Bruun (b) April–May 1963	INS Darshak (c) March–April 1975	R. V. Gaveshani (d) Aug–Sept. 1976	R. V. Gaveshani (e) August 1977	R. V. Gaveshani Aug–Sept. 78 Present Paper
Inshore	0.60	0.82	0.18	0.295	0.98	1.28
Offshore	0.21	0.14	0.17	0.265	0.57	0.74
Entire	0.28	0.18	0.17	0.275	0.64	0.98

(a) Steemann Nielsen and Jensen, 1957; (b) Woods Hole Oceanographic Institution, 1964, (c) Radhakrishna, 1978; (d) Radhakrishna, Bhattathiri and Devassy, 1978; (e) Devassy; Bhattathiri and Radhakrishna (in press).

than the production value of 0.27 gC/m²/day found during February 1979 (Bhattathiri and Devassy, 1980) in the Andaman Sea.

The account given above indicates that the primary production of Bay of Bengal is not less than that reported for the Arabian Sea.

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