

Productivity Studies in the Southeastern Arabian Sea

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Primary productivity, chlorophyll *a*, pheophytin, particulate organic carbon (POC), inorganic phosphate, ammonia, nitrate and zooplankton from 14 stations in October 1976 and 14 stations in December 1976 in the southeastern Arabian Sea were estimated. In the euphotic zone, daily primary productivity averaged 134 mgC/m²/day in October and 357.9 mgC/m²/day in December and chl. *a* averaged 6.44 mg/m³ and 10.6 mg/m³ respectively. Concentration of nutrients, likewise, were higher in December than in October, but POC was higher in October. Highly significant correlations between primary productivity and chl. *a* and between chl. *a* and nitrate and chl. *a* and ammonia were observed.

STUDIES on primary production and phytoplankton in Indian seas were relatively meagre compared to those on zooplankton. During the International Indian Ocean Expedition also, primary productivity studies did not receive adequate attention in the Indian waters. In the southeastern Arabian Sea, Anton Brunn¹ occupied 5 stations in her II cruise and Meteor² another 5 stations. Radhakrishna³ investigated productivity and related factors at 13 stations on the southwest coast of India.

Nair⁴ tabulated data on column productivity from 31 stations in this area. However, seasonal coverage of this area was still meagre. Besides, the factors affecting primary production were also not well covered. Hence, primary production together with related parameters like chlorophyll *a*, pheophytin, particulate organic carbon (POC), macronutrients and zooplankton were studied during the 10th and 13th cruises of *RV Gaveshani* and these results are reported here.

Materials and Methods

Samples were collected from 5 light penetration depths (100, 60, 30, 16 and 1%) at 14 stations during October 1976 and 14 stations during December 1976. Of these, only 3 stations occupied during the latter period were located in the continental shelf. The area covered was between 7° 15'N and 15°30'N and 71°E and the west coast (Fig. 1). Light penetration depths were determined by a 'Kahlsico' submarine photometer and by Secchi disc when the photometer could not be operated. Primary productivity was measured by ¹⁴C method; samples were incubated for 24 hr under simulated *in situ* conditions employing appropriate neutral density filters. Dark assimilation was corrected for Chlorophyll *a* (chl. *a*) and pheophytin were estimated by fluorometry and POC by wet oxidation and spectrophotometry. Inorganic phosphate, ammonia, nitrite and nitrate were estimated by standard methods⁵. Zooplankton samples were collected with IOS net from 150 m depth to surface

and from near the bottom at shallow stations; biomass was determined by displacement method.

Results and Discussion

Studies were conducted at 28 stations and the results are given here separately for the shelf

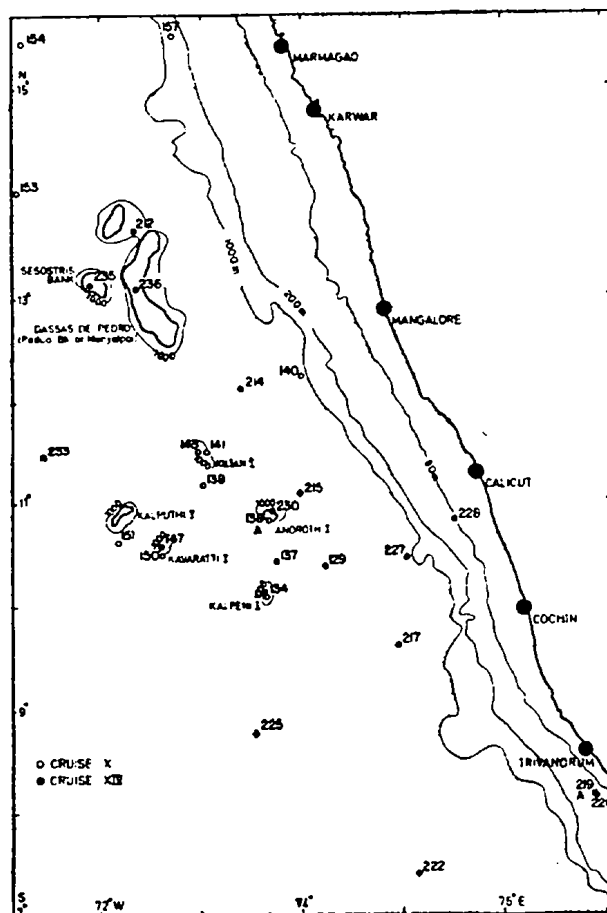


Fig. 1 — Station locations

region and beyond. Stations in the shelf region were highly productive. Thus at station 228 south of Calicut, primary productivity was quite high: 42.23 mgC/m³/day at the surface and 1166.65 mgC/m³/day in the column. Chl. *a* also was high. At the other 2 shelf stations (219A and 220 — south of Trivandrum), the average productivity and chl. *a* were high in the column: 607.12 mgC/m³/day and 15.39 mg/m² respectively.

At 25 stations situated beyond the continental shelf daily productivity at the surface varied from 0.33-28.32 mgC/m³/day (av. 5.37) and in the column from 21.8-676.07 mgC/m³/day (av. 180.3). In comparison with the north Arabian Sea^{6,7}, the ranges encountered were less. Chl. *a* values were less variable: surface — 0.023 to 0.165 mg/m³ (av. 0.09); column — 0.89 to 16.90 mg/m² (av. 7.69). Values of pheophytin, POC, PO₄-P, NO₃-N, NH₄-N and zooplankton are given in Table 1.

In the Laccadive sea region (71°30'-74°30'E and 10°15'-11°30'N) the average column productivity (at 10 stations) in October was 143.4 mgC/m³/day while in December it was slightly higher (179 mgC/m³/day from 4 stations). At station 222 the surface and column productivity were high during December (28.32 mgC/m³/day and 676.07 mgC/m³/day) as also the chl. *a* (0.165 mg/m³ and 16.90 mg/m²) and the nutrient concentrations. High productivity could probably be attributed to a dense patch of phytoplankton there, as corroborated by the high chl. *a* concentration at 16% and 1% light penetration depths.

It would be worthwhile here to summarize the work done so far in this region and compare with

the present results. Average productivity values in the offshore waters of S.E. Arabian Sea are as follows:

Period	Av. productivity mgC/m ² /day	Period	Av. productivity mgC/m ² /day
May (5 stations) ¹	76.0	Oct. (5 stations) ⁴	182.6
Feb. (5 stations) ²	171.6	Oct. (14 stations)*	134.0
Aug.-Dec. (17 stations) ³	806.6	Dec. (14 stations)*	357.9
Eight months (31 stations) ⁴	210.6		

*Present work.

From the hydrographic point of view the month of October when upwelling ceases could be expected to be relatively infertile. During this period, the Arabian Sea upper subsurface water mass (up to 100 m) occupies the surface waters especially on the continental shelf⁸. In the present studies, σ_t ranged from 23 to 24 in the upper layers and the oxygen concentration dropped suddenly to approximately 0.5 ml/litre below 75 m. In conformity with above the productivity was low as also the concentration of chl. *a*, pheopigments and nutrients. On the other hand, during December σ_t was low (≈ 22) and the low oxygen layer shifted further downwards with the average oxygen concentration of >1ml/litre at 100 m. The nutrient concentration was also comparatively high. This is due to the fact that the surface water mass (up to 100 m) originates in the Bay of Bengal and flows southward along the east coast of India, rounds Ceylon

TABLE 1 — VARIATIONS IN PRIMARY PRODUCTIVITY AND RELATED PARAMETERS AT ALL STATIONS

(Averages in parentheses)

Month	Primary productivity	Chlorophyll <i>a</i>	Pheophytin	POC	PO ₄ -P	NO ₃ -N	NH ₄ -N		
	mgC/m ³ /day	mg/m ³	mg/m ³	g/m ³	µg-at/litre	µg-at/litre	µg-at/litre		
SURFACE									
October	0.33-14.67 (5.43)	0.023-0.156 (0.082)	0.029-0.053 (0.043)	0.079-0.709 (0.222)	0.04-1.04 (0.49)	0.08-2.65 (0.9)	0.78-3.34 (2.18)		
December	0.67-42.23 (10.07)	0.043-0.578 (0.166)	0.007-0.32 (0.075)	0.05-2.46 (0.111)	0.0-88 (0.42)	0.09-10.34 (3.31)	1.53-9.18 (5.63)		
Pooled av.	7.75	0.121	0.059	0.164	0.45	2.15	3.97		
COLUMN									
	mgC/m ³ /day	mg/m ²	mg/m ²	g/m ²	IMC	IMC	IMC	Zooplankton biomass ml/m ³	
October	22-350 (134)	0.89-12.09 (6.44)	0.26-10.89 (4.63)	2.05-35.8 (18.26)	0.04-1.13 (0.68)	0.38-7.89 (2.82)	1.85-4.51 (2.74)	0.01-0.19 (0.048)	
December	45-1167 (357.9)	3.84-18.86 (10.6)	1.35-11.49 (7.36)	1.97-14.75 (7.2)	0.25-1.57 (0.83)	0.52-8.05 (3.27)	3.09-10.31 (5.44)	0.034-0.453 (0.174)	
Pooled av.	225	8.52	6.06	12.53	0.76	3.04	4.09	0.119	

IMC = Integral mean concentration.

and then moves northward along the west coast of India and also enters the Laccadive region⁹. The nutrient concentration in this water mass is high due to the heavy river discharge and the NE monsoon in the Bay of Bengal resulting in the high production.

To find out the interrelationship between primary productivity and other parameters and among the various parameters themselves, multilinear regression analyses were carried out. Data for all the stations were pooled. The correlation coefficients thus derived are given in the form of a matrix with corresponding levels of significance (Table 2).

Correlation between primary productivity and chl. *a* was highly significant (0.1% level) both at the surface and in the column. To test whether such a correlation was present at different light penetration depths, further analyses were carried out. Light penetration depths and the corresponding correlation coefficients (*r*) with their levels of significance within parentheses are as follows:

60% : *r* = 0.79 (0.1%)
 30% : *r* = 0.39 (2%)
 16% : *r* = 0.75 (0.1%)
 1% : *r* = 0.59 (1%)

When the data of light penetration depths were pooled the correlation was highly significant (at 0.01% level), the *r* value being 0.59 for *n* 131. In the present study the production was maximum at the surface. However, Radhakrishna³ reported maximum production at subsurface levels in the SW Arabian Sea during August-December. In the northern Arabian Sea also maximum production during January-May was at subsurface⁷. When the average values of productivity for all stations at the 5 different light penetration depths are considered together with chl. *a* (Fig. 2), it is seen that productivity gradually decreased from surface to the 30% depth while chl. *a* remained constant. At the lower limits of the euphotic zone, viz. 16% and 1% light penetration depths, productivity showed an increase over that of 30% depth, notwithstanding the limiting light factor. This is obviously due to chl. *a* maxima observed at these depths (Fig. 2). Saijo¹⁰ also observed chl. *a*

maxima and concomitant high rate of photosynthesis at subsurface levels nearer to the lower limit of the euphotic zone and attributed them to the "growth of shade-adapted phytoplankton in the deeper layer and the deterioration of pigments by light in the upper layer".

Distribution of pheophytin closely followed that of chl. *a* (Table 2). Average pheophytin concentration (mg/m³) increased with depth: surface, 0.048; 60%, 0.048; 30%, 0.067; 16%, 0.109; and 1%, 0.148. Distribution and concentration of pheophytin will give an idea of the amount of pigment which is not photosynthetically active. Its amount can vary depending on the grazing pressure of zooplankton. Variation in the column pheophytin during October and December was not much although the minimal value in October was much less as compared to that in December.

Concentration of POC varied widely at the surface and in the column (Table 1). It was minimum at the surface and showed an increasing trend

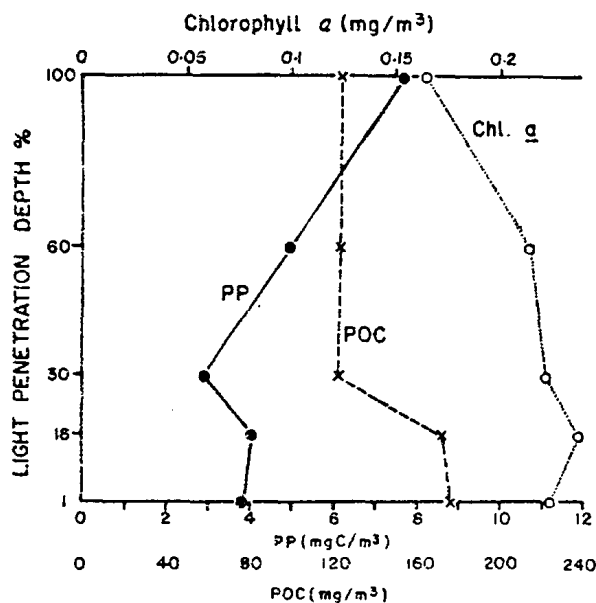


Fig. 2 — Distribution of primary productivity (PP), Particulate organic carbon (POC) and chl. *a* (Chl. *a*) at the 5 light penetration depths

TABLE 2 — CORRELATION MATRICES FOR PRIMARY PRODUCTIVITY AND RELATED PARAMETERS AT SURFACE AND IN COLUMN

	SURFACE					COLUMN						
	Primary productivity	Chlorophyll <i>a</i>	Pheophytin	POC	Phosphate	Nitrate	Primary productivity	Chlorophyll <i>a</i>	Pheophytin	POC	Phosphate	Nitrate
Chlorophyll <i>a</i>	0.79a						0.65a					
Pheophytin	0.31d	0.43b					0.44b	0.46b				
POC	0.02	0.046	-0.17				-0.16	0.014	-0.043			
Phosphate	0.004	0.068	0.36c	0.07			0.25	0.46b	0.31	0.094		
Nitrate	0.59a	0.62a	0.058	-0.17	-0.28		0.12	0.36c	-0.29	0.35c	0.69a	
Ammonia	0.21	0.38c	0.048	-0.02	-0.07	0.31d	0.074	0.38c	-0.40c	-0.31d	0.098	0.20

Level of significance (%): a, 0.1; b, 2; c, 5 and d, 10.

through the lower light penetration depths (Fig. 2). It did not exhibit any positive relationship either with primary productivity or chl. *a* or pheophytin (Table 2). The studies of the column chlorophyll and POC values revealed that the living phytoplankton constituted a lower percentage of particulate carbon in October as compared to that in December assuming that carbon to chlorophyll ratio is the same in both periods. Ryther and Menzel¹¹ mention that living matter constitutes 10-20% of total particulate matter in the western Arabian Sea. Most of the particulate matter is refractory and hence may have little role in the biochemical cycle of organic matter¹². In the present case it was found that during October though productivity was lower than that of December, POC within euphotic zone was twice as high as in December. The differences in the concentration are probably due to the different water masses existing at that time.

Variations and average values of macronutrients, viz. PO₄-P, NO₃-N and NH₄-N, at the surface and in the column are given in Table 1. Nitrite was below the level of detection at most of the stations in the euphotic column. The interrelationships of productivity and chl. *a* with these nutrients in the form of matrix of correlation coefficients are given in Table 2. At the surface PO₄-P did not show significant correlation with productivity or chl. *a*. In the column it showed no correlation with productivity but with chl. *a*, correlation significant at 1% level is seen. Nitrate showed highly significant correlation (at 0.1% level) at the surface with both productivity and chl. *a* while in the column, showed only with chl. *a* (at 5% level). Ammonia had no correlation with productivity either at the surface or in the column, while with chl. *a* the correlation was significant (at 5% level) both at surface and column.

Distribution of zooplankton biomass was similar to that of primary productivity. During October the average zooplankton biomass was 0.048 ml/m³

while during December it was 0.174 ml/m³. For both the months put together the average was 0.119 ml/m³. There was positive correlation between these 2 variables, significant at 0.001 level ($r = 0.62$, $n = 25$).

Productivity studies through the year with wider coverage is needed to obtain information on the general level of productivity and their seasonal variations in the offshore region of the southeastern Arabian Sea.

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