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Chlorophyll profile of the euphotic zone in the Lakshadweep Sea during the southwest monsoon season

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ABSTRACT

The distribution of chlorophyll *a*, *b* and *c*, the inorganic phosphate and nitrite of the euphotic zone at 56 locations in the Lakshadweep Sea was studied during the southwest monsoon period of 1990. The average chlorophyll *a* concentration varied from 4.62 mg/m^3 at the surface to 2.23 mg/m^3 at 50 m depth with a column mean of 161 mg/m^2 in the euphotic zone. The chlorophyll *b* averaged to 2.28 mg/m^3 at 10 m to 2.79 mg/m^3 at 50 m depths and 115 mg/m^2 in the column. The chlorophyll *c* varied from 4.03 mg/m^3 at the surface to 4.97 mg/m^3 at the 20 m depth and showed an average value of 202 mg/m^2 for the column. The chlorophyll *c* was the dominant pigment in the water column throughout the period of study. The average ratios of chlorophyll *c/a* and *b/a* fell in the range of 1.3 – 2.4 and 0.80 – 1.3 respectively and were positively correlated with depths in the euphotic zone. The inorganic phosphate values fluctuated from 0.65 µg at/l at surface to 1.36 µg at/l at 50 m depth with a mean of 49 mg at/m^2 in the water column. The nitrite concentration varied widely, very often below the level of detection.

Introduction

It is well known that compared to other seasons, the southwest monsoon is highly productive in the Arabian Sea. This is attributed to the phenomenon of upwelling together with the large influx of nutrient-rich river water into the sea. If other factors like, temperature and cloud cover are not limiting, the abundance of phytoplankton increases the basic productivity. The spawning season of many of the commercially important finfishes and shellfishes in these waters also coincide with the same period. Hence the study pertaining to the availability of photosynthetic pigments, the basic components of standing crop of phytoplankton in the food chain, during the monsoon season in these waters is of great ecological importance.

While considerable information is available on the physico-chemical and biological characteristics of the Arabian Sea, (Ramamirtham and Jayaraman, 1960; Jayaraman *et al.*,1960;

Patil *et al.*, 1963, 1964; Sharma, 1966; Radhakrishna, 1969; Qasim, 1977, 1978, 1982; Qasim *et al.*, 1972; Bhattathiri and Devassy, 1979; Pant, 1979, 1992) information on the primary productivity during the southwest monsoon period from these waters is very limited. Subrahmanyan (1959) has reported on the seasonal variation of surface phytoplankton and chlorophyll from the coastal waters of Calicut. Some information on nutrients and chlorophyll *a* during the southwest monsoon period in the shelf waters of the Arabian Sea have been given by Banse (1968). Krey (1976) has given a general picture of chlorophyll distribution in this area, and Sumitra Vijayaraghavan and Krishnakumari (1989) have reported on the distribution of chlorophyll *a* from the southeastern Arabian Sea during June-July 1987. Balachandran *et al*, (1989) have studied the surface chlorophyll *a* and pheophytin in the inshore waters off Cochin during 1987-'88. The present account deals with a detailed study on the chlorophylls in relation to nutrients such as inorganic phosphate and nitrite along with a comparative study of relevant hydrographic features in the euphotic zone for July and August during the southwest monsoon season of 1990.

Material and methods

The data presented in this paper was collected during the cruises of FORV *Sagar Sampada* (Nos. 74, 76 & 77) from 56 stations spread over the area 08° 30' N to 12° 30' N and 74° 25' E to 76° 55' E in the Lakshadweep Sea during July-August 1990 (Fig. 1). The number of observations were 15 and 41 respectively for July and August. The water samples were collected from surface, 10, 20, and 30 m depths for

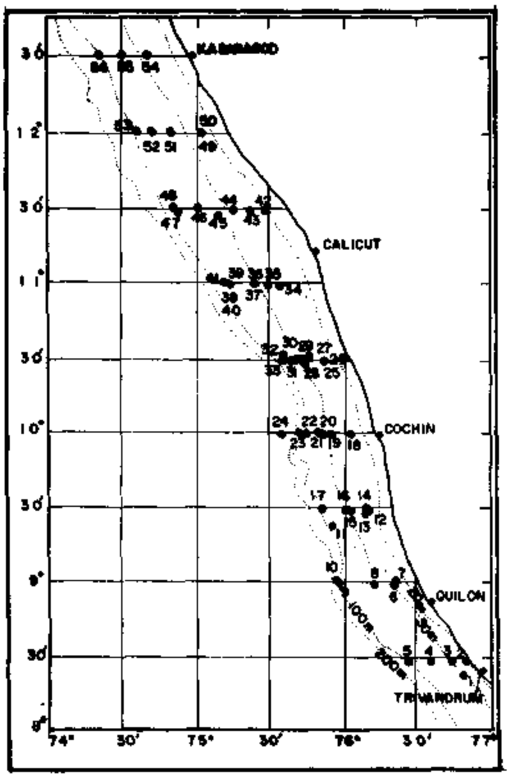

Fig. 1. Sampling stations.

inshore stations and from surface, 10, 20, 30 and 50 m depths for offshore stations with Nishkin bottles and the averages and column values were assessed accordingly for each station.

Earlier investigations (Nair *et al.*, 1973) conducted in this area using a Tinsley's irradience meter with a deck cell and sea cell connected through a ratio meter and galvanometer indicated that 1% of surface light penetrates between 60 and 50 m over the continental shelf region on a normally bright day. In the clear blue waters of the open ocean it may even extend upto 90 m. Towards the coast where there is turbidity it shrinks to about 30 m on cloudy days. So the compensation depth for the shelf waters for most part of the year has been assumed to be 50 m. So the term 'euphotic zone' has been used for the productive zone over the shelf. In the text Zs = denotes sampling depth in the euphotic zone.

The method of Parsons *et al.* (1984) was followed for the extraction and estimation of chlorophyll. Five hundred ml of the sample was filtered through 47 mm HA Millipore membrane filters of 0.45 μ pore size. Ten ml of 90% acetone was used for extraction. Extinction values were measured at the wavelengths of 630, 647, 664 and 750 nm using a digital UV/VIS spectrophotometer (Spectronic 1001) and the chlorophyll *a*, *b* and *c* were calculated using the formulae given by Parsons *et al.* (1984). The column chlorophylls were assessed using the formula of Dyson *et al.* (1965). Dissolved oxygen was determined by winkler method and salinity by titrimetric method as mentioned in Strickland and Parsons (1968). The methods given by Murphy and Riley (1962) and Bendschneider and Robinson (1952) were followed for the determination of inorganic phosphate and nitrite respectively by colorimetric method using the spectrophotometer (Spectronic 1001, Milton Roy).

Results

The results presented in this paper are based on the pooled data for July and August unless otherwise stated. The observed values are given in Table 1.

Chlorophyll a

The general distribution pattern of chlorophyll *a* from surface down to Zs = 50 m in the study area is given in Fig. 2a - 2e. Distribution of surface chlorophyll *a* from south to north in the Lakshadweep Sea showed (Fig. 2a)

TABLE 1. *The variations, average, ratio and the column values of chlorophyll a, b and c and phosphate in different depths of euphotic zone (0-50 m) in the Lakshadweep Sea during southwest monsoon season of 1990. (Average values are given in brackets)*

Parameters	Surface		10m		20m		30m		50m		Column values mg/m^2	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Chl. *a* (mg/m^3)	0.80	19.40	0.67	17.32	0.86	22.41	0.76	22.23	0.41	4.37	45	906
	(4.62)		(3.43)		(3.98)		(2.76)		(2.23)		(161)	
Chl. *b* (mg/m^3)	0.81	11.06	0.06	5.05	0.57	9.55	0.32	7.26	0.52	7.27	36	258
	(2.59)		(2.28)		(2.70)		(2.60)		(2.71)		(115)	
Chl. *c* (mg/m^3)	0.73	15.0	1.23	12.66	1.39	16.22	0.90	12.60	0.62	11.63	71	447
	(4.03)		(4.30)		(4.97)		(4.67)		(4.79)		(202)	
Ratios:												
Chl. *c*/*a*	0.18	3.84	0.30	3.59	0.20	3.49	0.26	5.44	0.86	3.43	-	-
	(1.29)		(1.60)		(1.75)		(2.01)		(2.39)			
Chl. *b*/*a*	0.07	1.94	0.03	1.69	0.07	2.06	0.04	2.33	0.42	2.31	-	-
	(0.82)		(0.87)		(0.97)		(1.18)		(1.28)			
											mg at/m^2	
Phosphate (μg at P/l)	0.15	1.51	0.15	2.25	0.42	2.51	0.21	2.46	0.57	2.46	18	86
	(0.65)		(0.83)		(1.17)		(1.25)		(1.36)		(49)	

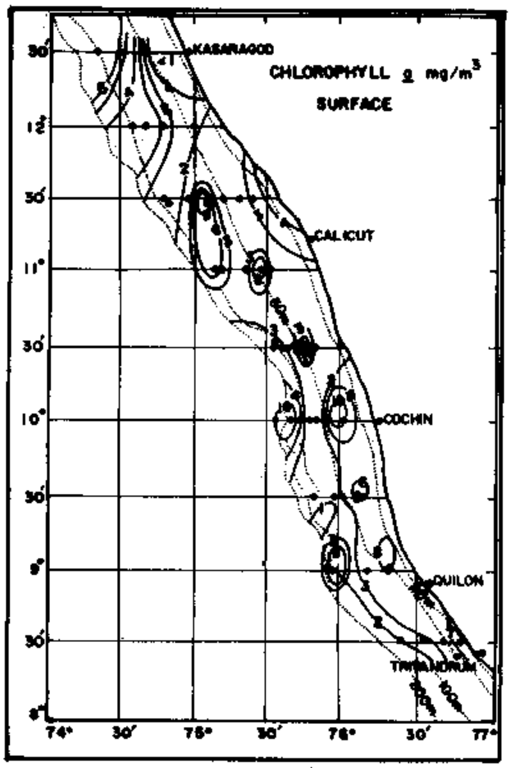

Fig. 2 a. Distribution of chlorophyll *a* at surface (July-August).

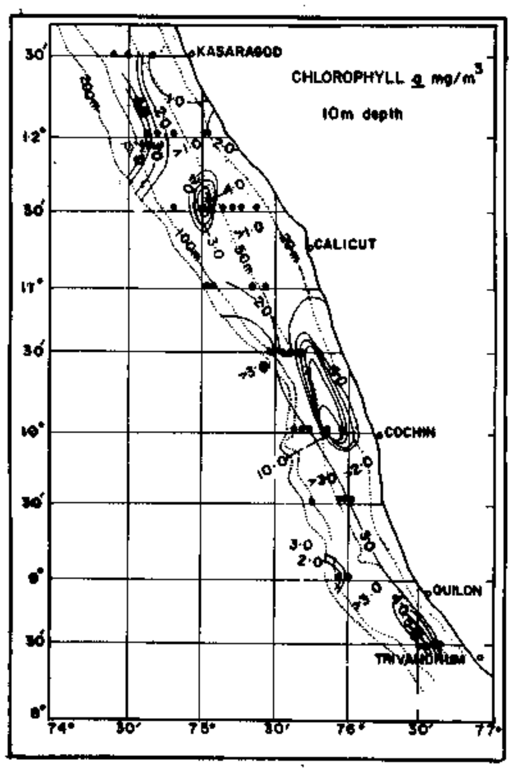

Fig. 2 b. Distribution of chlorophyll *a* at 10 m photic depth (July-August).

pockets of rich phytoplankton biomass with varying intensity at different locations such as north of Trivandrum where the depth to bottom was within 40 m, north of Quilon (40 and 100 m depth zone), off Cochin (50 and 200 m depth zone) and off Calicut (150 and 200 m depth zone). South of Kasaragod, it was found progressively increasing towards stations in deeper zones. More or less similar trend was observed with lesser magnitudes at the subsequent lower depths in the euphotic zone. It was also observed that most of the high values of column chlorophyll *a* (Fig. 3) occurred between 50 and 100 m depth contour except a maximum value of 900 mg/m² at a station of 110 m depth (St. 10) within the continental shelf, north of Quilon.

The chlorophyll *a* vaired from 0.41 mg/m³ at Zs = 50 m in St. 1 to 22.4 mg/m³ at Zs = 20 m in St. 10 in the euphotic zone. Though the maximum chlorophyll *a* recorded was at Zs = 20 m, moderately high values of surface chlorophyll *a* (19.4, 16.1, 14.5 and 13.9 mg/m³) were noticed in stations 10, 19, 24 and 38 respectively. The maximum average chlorophyll *a* (4.62 mg/m³) was at surface and the minimum (2.23 mg/m³) at Zs = 50 m. The column chlorophyll *a* fluctuated from 45 mg/m² in St. 43 to 906 mg/m² in St. 10 with a mean of 161 mg/m² (Table 1). All the higher values were recorded during August.

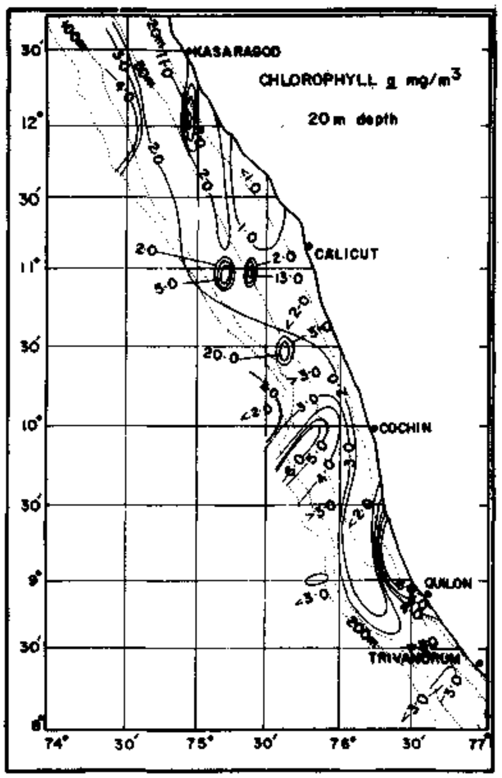

Fig. 2 c. Distribution of chlorophyll *a* at 20 m photic depth (July-August).

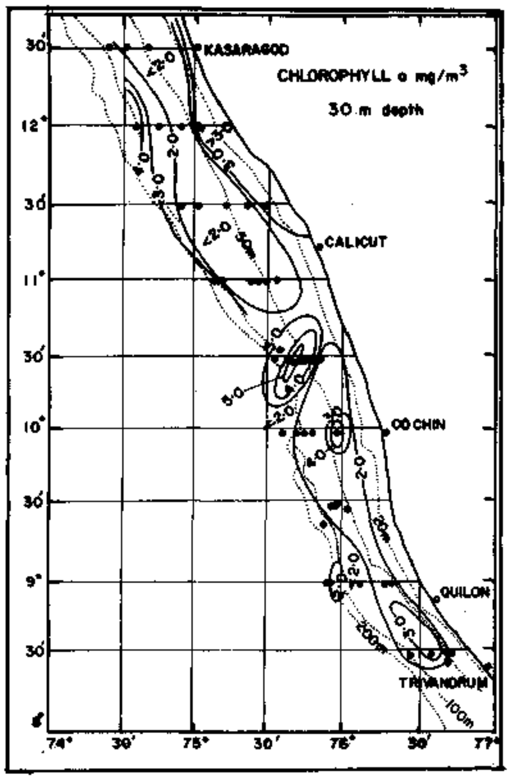

Fig. 2 d. Distribution of chlorophyll *a* at 30 m photic depth (July-August).

Chlorophyll b

The maximum concentration of chlorophyll *b* (11.1 mg/m³) was at the surface in St. 3 and the minimum (0.06 mg/m³) was at Zs = 10 m in St. 53, both in August. At Zs = 20 and 30 m in stations 46 and 48 and at Zs = 50 m in stations 5 and 6 the chlorophyll *b* was absent during August. The average value fluctuated between 2.3 mg/m³ at Zs = 10 m and 2.71 mg/m³ at Zs = 50 m in the euphotic zone. The column chlorophyll *b* varied from 36 mg/m² (St. 43) to 258 mg/m² (St. 17) with an average of 115 mg/m² (Table 1).

Chlorophyll c

The chlorophyll *c* at surface, fluctuated from 0.73 to 15.0 mg/m³ and at Zs = 50 m it was from 0.62 to 11.63 mg/m³. The high concentration of 16.22 mg/m³ was at Zs = 20 m in St. 49. The average value at surface (4.03 mg/m³) was lower than other sampling depths. The depth profile of chlorophyll *c* showed an increasing trend towards deeper layers with a slightly higher value at Zs = 20 m in the euphotic zone (Fig. 4). The column chlorophyll *c* was found to vary from 71.0 mg/m² (St. 1) in July to 447 mg/m² (St. 31) in August with 202 mg/m² on an average, which was higher than the other pigments (Table 1).

Chlorophyll ratios

The ratios of different components of

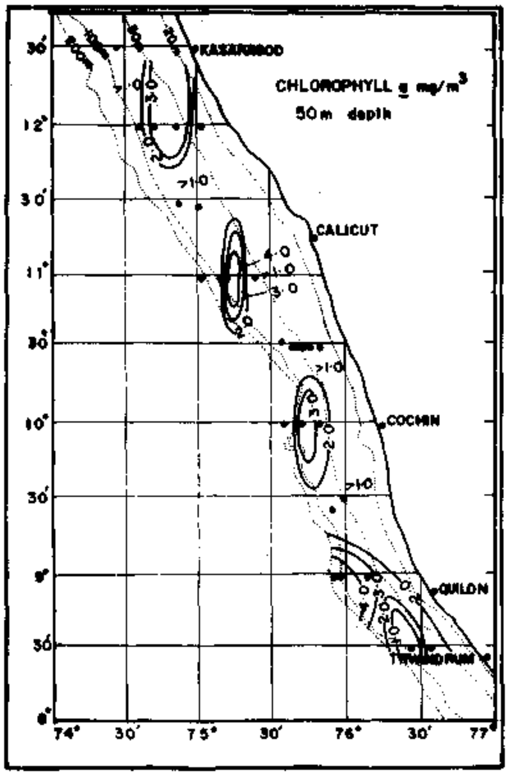

Fig. 2 e. Distribution of chlorophyll *a* at 50 m photic depth (July-August).

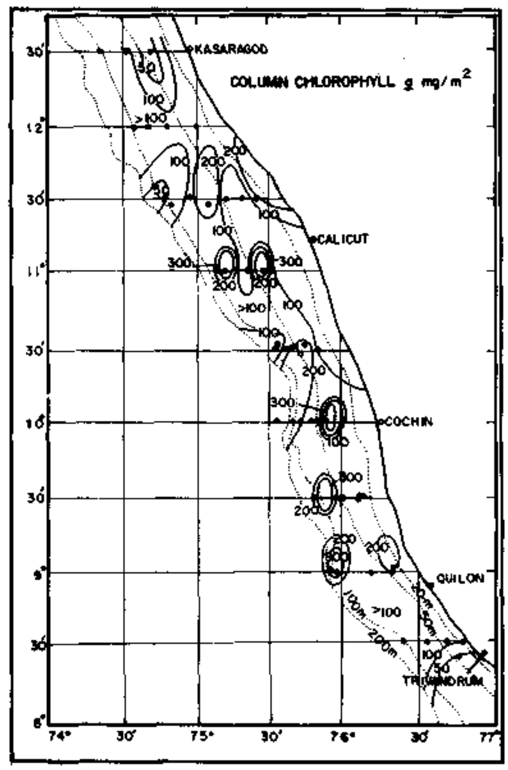

Fig. 3. Distribution of column chlorophyll *a* (July-August).

chlorophyll may give an insight into the taxonomic composition, photo-adaptability, physiology and degradation state of the communities.

The chlorophyll *c*/*a* ratio varied from 0.18 – 3.84 at surface to 0.86 – 3.43 at Zs = 50 m with a lower average at surface and Zs = 10 m. The chlorophyll *b*/*a* ratios ranged from 0.07 - 1.94 at surface to 0.42 – 2.31 at Zs = 50 m (Table 1).

Inorganic phosphate

The general phosphate distribution from surface to Zs=50 m in the study area is shown in Figs. 5 a to 5 e and the column concentration in Fig. 6. Fig. 5 a shows that the surface concentration of

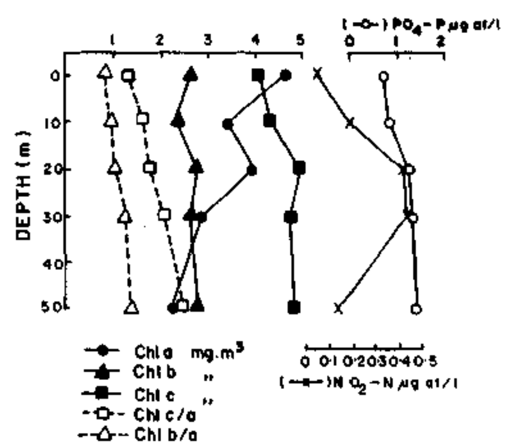

Fig. 4. Vertical profiles of chlorophylls *a*, *b*, *c*, *c*/*a*, *b*/*a*, PO_4-P and NO_2-N (averages for July-August).

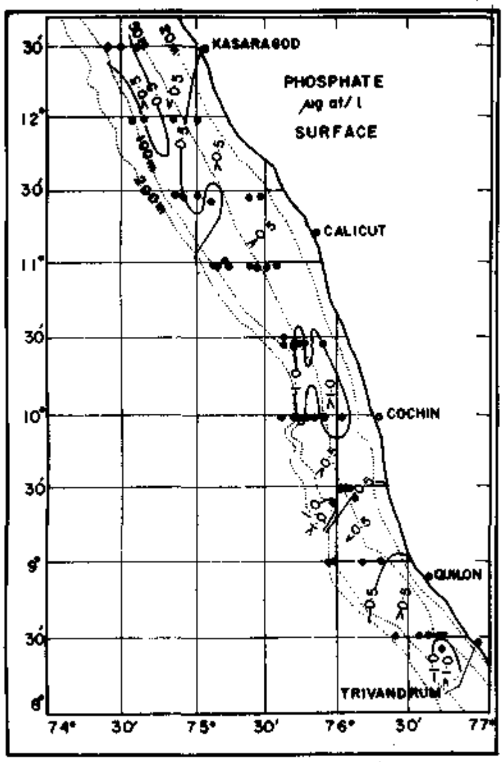

Fig. 5 a. Distribution of PO_4-P at surface (July-August).

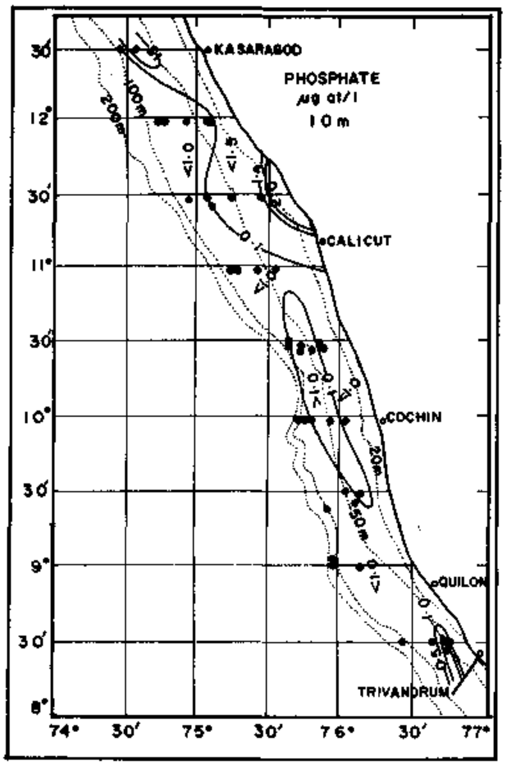

Fig. 5 b. Distribution of PO_4-P at 10 m photic depth (July-August).

1.0 to 1.5 µg at/l was recorded in the area off Trivandrum between depth zone 50 and 200 m, off Alleppey beyond depth zone 100 m and north of Cochin between depth zone 30 and 100 m. In other regions, the surface phosphate values were less than 1.0 µg at/l. At Zs = 10 m (Fig. 5 b) a high concentration of 2.0 to 2.5 µg at/l in the shallow coastal region north of Calicut (St. 42) and between 50 and 75 m depth zone off Kasaragod a concentration between 1.5 and 2.0 µg at/l was observed in August. At Zs = 20 m (Fig. 5 c) north of Trivandrum around 50 m depth the phosphate concentration was more than 2.0 µg at/l. North of Quilon at depth between 50 and 100 m and north of Calicut between 50 and 200 m 1.5 to 2.0 µg at /l were found. In other areas in the Zs = 20 m depths, the concentration of phosphate remained less than 1.0 µg at/l. At Zs = 30 m (Fig. 5 d) 2 µg at/l were observed north of Calicut at 35 m, south of Cochin around 30 m, south of Calicut at 50 m and off Cochin between 50 and 100 m depth zones. More than 1.5 µg at/l but less than 2 µg at/l was recorded in the coastal stations south of Kasaragod, off Calicut, south of Calicut and north of Trivandrum. Other areas contained less than 1.5 µg at/l in Zs = 30 m (Fig. 5d). The maximum phosphate concentration was recorded at Zs = 50 m depths. The highest value of 2.5 µg at/l observed was at 80 m depth

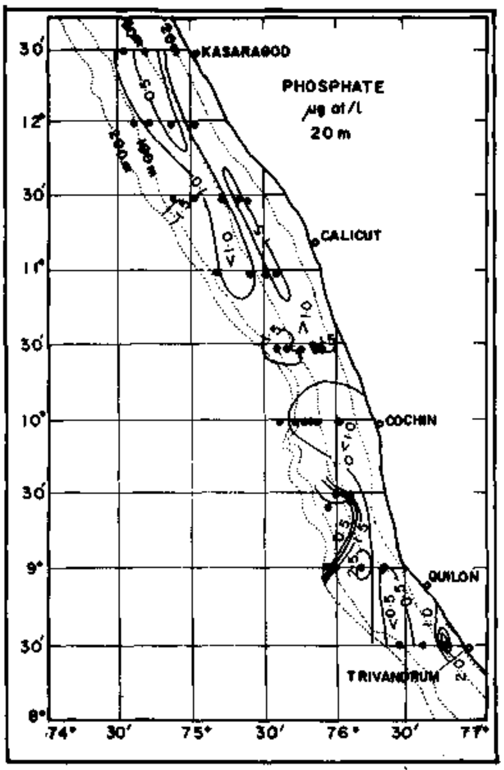

Fig. 5 c. Distribution of PO_4-P at 20 m photic depth (July-August).

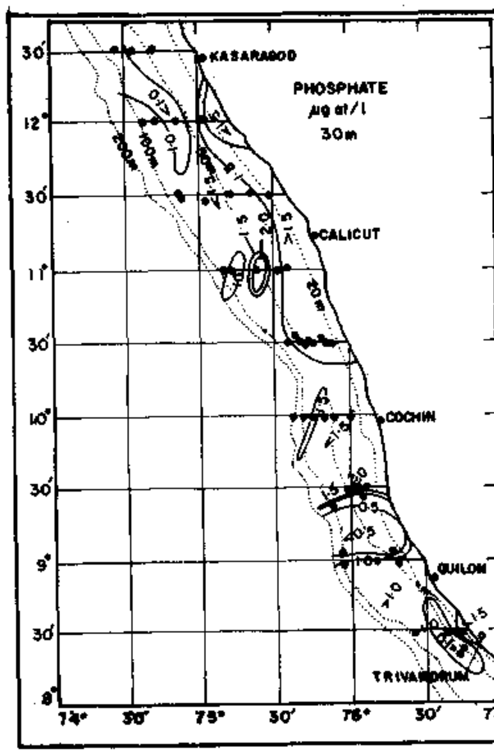

Fig. 5 d. Distribution of PO_4-P at 30 m photic depth (July-August).

zone off Cochin, while in the other regions, the concentrations at Zs = 50 m were below 2.0 µg at/l (Fig. 5e). The column phosphate in the euphotic zone ranged from 18.0 (St. 10) to 86.0 mg at/m^2 (St. 29), both in August with an average column value of 49 mg at/m^2 (Table 1).

Inorganic nitrite

In most of the samples collected from the euphotic zone (Zs = 0-50 m), the nitrite concentration was negligible and was present at an average level of 0.07, 0.20, 0.30, 0.44 and 0.14 µg at/l at Zs = surface, 10, 20, 30 and 50 m respectively.

Variation during July and August

The data were processed monthwise and the results are depicted in figs. 7 and 8 in order to understand the changes occurring in the ecosystem of the Lakshadweep Sea during July and August 1990. The vertical profiles (Zs= 0-50 m) presented in Figs. 7 and 8 are the averages of each parameter from the respective sampling depths of the stations representing July and August respectively.

During July (Fig. 7) the average photosynthetic pigments of chlorophyll *a*, *b* and *c* were at their maximum at Zs = 20 m where light is optimum in the

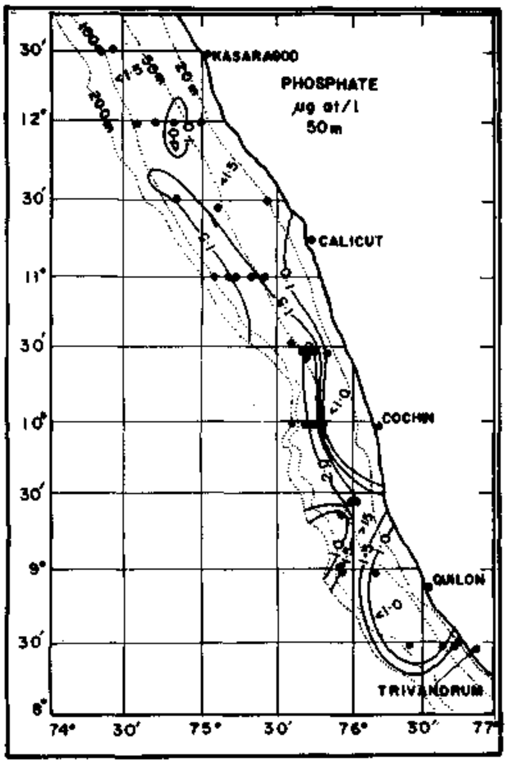

Fig. 5 e. Distribution of PO_4 at 50 m photic depth (July-August).

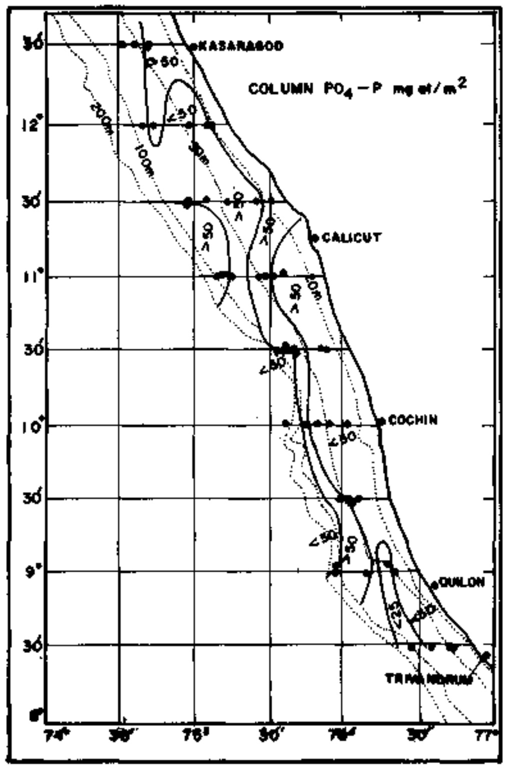

Fig. 6. Distribution of column phosphate (July-August).

euphotic zone and is being indicated as the depth of maximum rate of photosynthesis. At this depth, a maximum of 4.31 mg/m³ of chlorophyll *a* was recorded while it was 1.48 mg/m³ at surface and the least of 1.29 mg/m³ at Zs = 50 m depth. A value of 105 mg/m² was computed as the column chlorophyll *a* in the euphotic zone. The concentrations of chlorophyll *b* were lower at surface and Zs = 10 m depths than those in other depths with a maximum value of 2.38 mg/m³ at Zs = 20 m. The column chlorophyll *b* was 83 mg/m². The column chlorophyll *c* was higher (139 mg/m²) than the other pigments. The *c* / *a* ratio was more or less homogenous from surface to Zs = 30 m depths with a maximum value of 2.3 at Zs = 50 m and more or less same trend with varying intensity was noticed in the case of b/a and $(b + c)/a$ ratios. The vertical temperature profile has shown an increase of about 2°C from Zs = 50 to 20 m and 1.6°C from Zs = 20 m to surface ranging from 22.36 - 26.28°C showing the presence of warmer water in the upper 20 m depth column. The dissolved oxygen profile showed a variation of about 3 ml/l from Zs = 0 - 50 m (3.92 - 0.99 ml/l). The salinity values fluctuated between 33.57 ppt (surface) and 34.96 ppt (Zs = 50). The phosphate concentration varied from 0.66 µg at/l

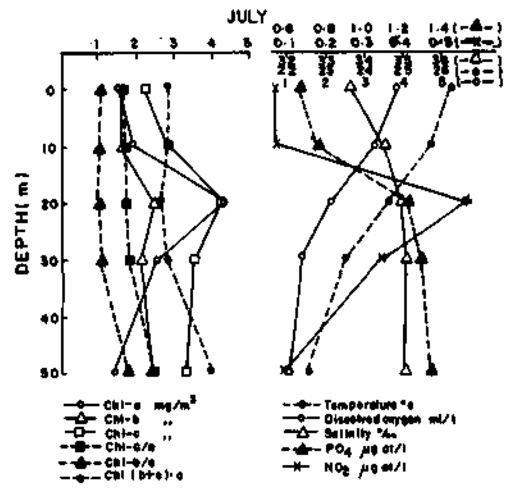

Fig. 7. Vertical profiles of chlorophylls *a*, *b*, *c*, their ratios, temperature, dissolved oxygen, phosphate and nitrite (average values) for July.

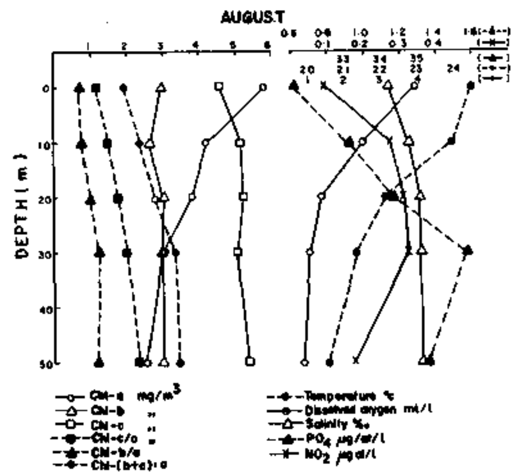

Fig. 8. Profiles of chlorophylls a, b, c, their ratios, temperature, dissolved oxygen, phosphate and nitrite (average values) for August.

at surface to 1.32 µg at/l at Zs = 50 m with a column value of 47 mg at/m². Comparatively low values of phosphate were observed at above Zs = 20 m. The nitrite maximum (0.56 µg at/l) was at Zs = 20 m followed by 0.34 µg at/l at Zs = 30 m and the other sampling depths recorded less than 0.06 µg at/l.

It is evident that the environmental features of the study area has changed due to the impact of heavy monsoon during August (Fig. 8). The temperature noticed at Zs = 0 and 50 m were 24.46°C and 20.54°C respectively. Regarding dissolved oxygen a maximum of 3.93 ml/l at surface and a minimum of 0.83 ml/l at Zs = 50 were recorded, while the respective values for salinity were 34.16 and 34.07 ppt. The phosphate and nitrite showed an increasing trend from Zs = 0 - 30 m, the former varying from 0.63 µg at/l at surface to 1.56 µg at/l at Zs = 30 m with an average column value of 46 mg at/m² in the euphotic zone. The nitrite concentration ranged from 0.1 µg at/l at surface to 0.33 µg at/l at Zs = 30 m with maximas at Zs = 20 and 30 m (0.31 & 0.33 respectively). The chlorophyll *a* concentration varied from a maximum of 5.76 mg/m³ at surface to a minimum of 2.5 mg/m³ at Zs = 50 m depth showing decrease to increasing depths in the euphotic zone. The column chlorphyll *a* value was 183 mg/m². The chlorophyll *b* was more or less steady with a column production of 130 mg/m². The chlorophyll *c* values have been almost uniformly distributed with a minimum value of 4.6 mg/m³ at surface and maximum of 5.4 mg/m³ at Zs = 50 m the column value being 238 mg/m² which was higher than in July. A direct relationship among chlorophyll *a*, temperature and dissolved oxygen has been noticed in the vertical profiles for August.

Discussion

It is well known that areas where upwelling is intense, the phytoplankton production is high and it is apparent in the case of Lakshadweep waters also. From Fig. 4, it can be seen that during the present study the average chlorophyll *a* was at its maximum at surface and this is in agreement with the observations reported by many earlier workers (Banse, 1959; Subrahmanyan, 1959, Subrahmanyan and Sarma, 1965; Ramamurthy and Dhawan, 1967; Nair *et al.*, 1973). Banse (1968) reported off Cochin, a value of 5 mg/m^3 surface chlorophyll *a* in the middle of the shelf at a depth of 50 - 60 m during August/October 1958-'59. Sumitra Vijayaraghavan and Krishnakumari (1989) in their investigation on primary production in the southeastern Arabian Sea during the southwest monsoon (June-July 1987) have reported very low mean values of chlorophyll *a* (0.11 mg/m^3) for surface and column (3.43 mg/m^2). Qasim *et al.* (1978) in their studies of the coastal waters of India from Dhabol to Tuticorin have given an average value of 0.655 mg/m^3 chlorophyll *a* for the premonsoon and suggested that the regions off Karwar and Calicut to be more productive followed by Cochin during March-April 1977. In a study off Cochin under Joint Remote Sensing Programme (Narain, 1983) higher chlorophyll *a* value of 6.4 mg/m^3 was observed in October, followed by a sharp fall during November (1.7 mg/m^3) and December (1.4 mg/m^3) in the Cochin waters of the Arabian Sea.

In the present investigation, most of the high pockets of chlorophyll *a* have been found to occur between 50-100 m depth contour all along the Lakshadweep waters from Trivandrum to Kasaragod which coincide with the low concentrations of phosphate, thus establishing a negative correlation with chlorophyll *a* (Figs. 3 & 6). The surface as well as the column distribution of chlorophyll *a* during the period revealed an increasing trend towards areas of deeper zones which may be due to the movements of enriched upwelled waters away from the coast (Laevatsu and Hela, 1970). The column concentration of chlorophyll *a* in this study is highly variable (45-906 mg/m^2). Yentsch (1965) in his extensive studies in the Indian Ocean region has pointed out that the absolute amount of chlorophyll is highly variable between 25 and 150 mg/m^2 throughout the upper 50 m, while Krey and Babernad (1976) have reported still lower range of 15-20 mg/m^2 chlorophyll in the water column from surface to 50 m depths in the northern and western Arabian Sea and southeastern and southwestern coasts of India. Very low chlorophyll *a* values ranging from 0.89 to 18.86 mg/m^2 for postmonsoon of 1976 and 1.4 to 15.4 mg/m^2 for premonsoon of 1978 periods have been reported from the waters of Lakshadweep Sea (Bhattathiri *et al.*, 1978).

During the study period, the most dominant pigment in the water column was chlorophyll *c*, and the chlorophyll *b* was lesser than the chlorophyll *a*. A similar condition has been pointed out by Qasim and Reddy (1967) in the Cochin backwater during monsoon months. Humphrey (1963 a) has noticed that there was always less chlorophyll *b* than chlorophyll *a* and usually more chlorophyll *c* than chlorophyll *a* in the waters off Sydney. In 1969, in an investigation in the Indian Ocean along 110°E on chlorophyll *a* and *c* the same author has also pointed out that in the water column down to 150 m, the amount of chlorophyll *a* was between 10 and 30 mg/m^2 and the amount of chlorophyll *c* was between 15 and 40 mg/m^2 the higher quantities being in June-August.

In the present study, the average *c* : *a* ratios obtained were less than 2 for the first 3 depths from Zs = surface to 20 m, and from Zs = 30 to 50 m they were more than 2, but less than 2.5 (Table 1) which indicate the abundance of detritus in the water column due to monsoon. However, it could also be a photo-adaptation to low light conditions and or a change in species composition of phytoplankton. The *b* : *a* ratios showed the same pattern of distribution with lesser magnitude. Qasim and Reddy (1967) have also mentioned that the *c*/*a* ratios are generally higher than 1 and nearer to 2 and often 3 in the Cochin Backwater during monsoon. Loftus and Carpenter (1971) have observed the ranges for *c* : *a* ratio as 0.4 - 0.52 and for b/a ratio as 0.21 - 0.35 in the culture extracts of *Gymnodinium splendens* and *Dunaliella tertiolecta* respectively. A value of 1 – 3.3 *c* / *a* ratio has been reported by Burkholder and Borkholder (1960) for natural populations of phytoplankton from Coral and Tasmanian Sea. Humphrey (1969) in his survey of the southeast Indian Ocean has shown that the winter values of chlorophyll *a* and *c* were higher than summer values and both chlorophyll *a* and *c* varied significantly with depths and also suggested that there were organisms which could contain much more chlorophyll c than chlorophyll *a* (Humphrey, 1963 b).

Though chlorophyll *b* and *c* indicate steady increase with depth except at Zs = 10 m, it appears that they are almost stable in the euphotic zone in the monsoon season (Fig. 4). Jacques and Gerald (1986) using Spectrofluorometry illustrated the constant presence of chlorophyll *b* in the waters of the western Indian Ocean from July to August 1979 and suggested that green algae contributed significantly to primary production in that area. Lorensen (1981) found chlorophyll *b* to be 5 to 15% of chlorophyll *a* in the North Pacific Ocean. According to Jeffrey (1974) and Hallegraff (1981), the chlorophyll *b* and *c* are more stable in the euphotic zone than chlorophyll *a*.

Among the nutrients examined *viz.* inorganic phosphate and nitrite, only phosphate seems to be significant to chlorophylls. An inverse relationship of phosphate to chlorophyll *a* can be observed from this study between 50-100 m depth contour indicating that phytoplankton is able to meet its requirements for growth through inorganic phosphate sources. A positive correlation between chlorophyll *a* and phosphate has been reported by Balachandran *et al.* (1989) from the surface inshore waters off Cochin. In this study also the high values of phosphate have been noticed especially in coastal stations off Cochin where chlorophyll production is moderately high. High value of 1.68 µg at/l phosphate at surface and 2.11 µg at/l at the bottom have been reported by Subrahmanyan (1959) in August 1957 from Calicut waters.

A distinct variation among the parameters studied in July and August was apparent (Figs. 7 and 8) and this may be due to the variations in the intensity of monsoon during July and August as mentioned earlier. During July, the chlorophyll *a* maximum is at

Zs = 20 m while in August it is at surface. Temperature and dissloved oxygen showed a decrease by an average value of 2.07°C and 0.38 ml/l respectively while salinity and inorganic phosphate increased in the order of 0.13 ppt and 0.07 µg at/1 from July to August. All these variations indicate that the process of upwelling is prominent during August than July. Murty (1987) has stated that the upwelling attains its maximum by August/September from Quilon to Kasaragod and by September/October off Karwar in the west coast of India. Banse (1968) has also remarked that because of low oxygen content of water entering the entire shelf of the west coast of India during the southwest monsoon, the nutrient content is high and the effect of phytoplankton development is marked in the euphotic zone.

From the foregoing account, it can be inferred that majority of the integrated values for column concentration of chlorophyll *a* are localised in pockets between 50 and 100 m depth contour at latitudes 09°00', 09°30', 10°00', 10°30', 11°00' and 11°30'N. It is also observed that at the edge of continental shelf there is a zone of high chlorophyll concentration (09° 04' N) exceeding 900 mg/m^2 which could probably be due to localised phytoplankton blooming, a common phenomenon during monsoon in this area. Enrichment of phosphate in the surface waters could also be a causative factor in triggering the bloom of phytoplankton.

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