Bull. Cent. Mar. Fish. Res. Inst., 1992, **45** : 9 - 37 **3**

PRODUCTIVITY OF THE ARABIAN SEA ALONG THE SOUTHWEST COAST OF INDIA

M. S. Rajagopalan, P. A. Thomas, K. J. Mathew, G. S. Daniel Selvaraj, Rani Mary George, C. V. Mathew, T. S. Naomi, P. Kaladharan, V. K. Balachandran and Geetha Antony

Central Marine Fisheries Research Institute, Cochin - 31

Abstract

Monsoon plays a critical role in triggering environmental features such as seawater temperature, salinity, dissolved oxygen content and nutrient generation which in turn become responsible for production of phytoplankton and zooplankton. Along the southwest coast of India the intensity of southwest monsoon as evidenced by annual rainfall showed a declining trend during the years 1983 to 1988. An attempt is made here to correlate certain environmental features with the abundance and fluctuations in phytoplankton and zooplankton in the inshore waters off Cochin, Vizhinjam and Minicoy.

At Cochin, the annual total rainfall for the years 1986 to 1988 were respectively 2495, 2410 and 2895 mm as against expected rainfall of around 323 cm per annum. During the monsoon months the rainfall was 1295, 1490 and 1665 mm respectively. Generally, June received the maximum rainfall. At Vizhinjam the rainfall did not show any definite pattern. During 1984-85 the premonsoon period and during 1987-88 the postmonsoon period recorded more rainfall of about 490 mm.

At Cochin, the levels of gross primary production showed increase from 0.830 to 1.624 g C/m^3/day corresponding with increasing rainfall during April to June 1986. Again in 1987 similar increase of production from 0.597 to 0.975 g C/m^3/day was observed to coincide with increasing monthly rainfall from May to June and in August.

However, Chlorophyll *a* concentration in surface waters showed a decreasing trend during premonsoon, monsoon and postmonsoon months. This has been attributed to physiological state and productive potential of phytoplankters during the sampling period. The studies also revealed that productivity of 10 m station was around 50% of the productivity in the 20 m depth zone. Gross primary production also showed positive correlation with abundance of nutrients such as phosphates and nitrates in inshore waters which in turn is attributed to coastal upwelling.

The annual net primary production in the euphotic waters off Cochin was estimated as 731.43 tonnes Carbon/km^2 indicating high productivity.

Zooplankton biomass indicated higher volumes during monsoon months as also most of the constituent groups. Peaks of secondary production were observed in September of 1984 and 1986. While primary peaks of biomass abundance coincided with copepod maximum in July '85, '86 and August '88, the abundance of other groups contributed to the peak in July '84 and August '87 including blooms of *Fragilaria oceanica* or swarms of cladocerans or salps. The fluctuation in the abundance of various groups are discussed in detail. In terms of Carbon, the mean production in the area was worked out as 6.652 t C/km^2/year.

The average displacement volumes at Vizhinjam recorded higher values during postmonsoon season and low values during premonsoon period. High salinity was observed to be a characteristic of premonsoon period. Within the overall range in salinity values, peaks of different plankton groups coincided with higher values of salinity. It was observed that landings of pelagic fishes were maximum during monsoon months, followed by postmonsoon months.

In the Lakshadweep, zooplankton was observed to be maximum during premonsoon period and lower in other months. Zooplankton volumes were higher in the open sea than in the lagoons.

Introduction

It is well known that the production of phyto and zooplankton in the sea has a great bearing on the fish yield. Environmental features such as monsoon, upwelling, temperature, salinity and dissolved oxygen and nutrients play vital role in this production, initially at the primary and subsequently at the secondary and tertiary levels. Among these, southwest monsoon in India is of critical importance in the production of phyto and zooplankton especially in the inshore upwelling areas. It has been known that an intense monsoon triggers of strong upwelling along the southwest coast of India. The studies carried out by Subrahmanyan (1959), Qasim and Reddy (1967), Nair *et al.* (1968), Radhakrishna (1969), Subrahmanyan *et al.* (1975) have revealed that the phytoplankton production is at its peak during the southwest monsoon (June-September) all along the west coast. According to Silas (1972), the peak in the zooplankton production in the shelf area of the west coast of India occurs during June-October period. The later studies (Anon., 1976; Devidas Menon and George, 1977) have confirmed these findings. Mathew *et al.* (1989) have extended the period of high abundance for zooplankton in the the shelf waters upto December.

Since 1983, the southwest monsoon has been a failure along the west coast. The year 1987-88 was specially considered as a period of weak monsoon. Consequently there has been marked decrease in the catch of pelagic fish especially the oilsardine. In this situation, an understanding of the effect of monsoon on the fish production along the west coast has become an essential prerequisite. For this purpose a comparative study of the various environmental and productivity parameters in the inshore areas at selected centres *viz.* Cochin, Vizhinjam and Lakshadweep has been made and the present paper embodies the results of these studies.

Data Base

The area of study at Cochin, extends between Chellanam and Munambam, covering a coastline of 47 km and a shelf area of 1,175 km^2.

R. V. Cadalmin I & IX were engaged in the fortnightly collection of data from 10 m, 20 m and 30 m depth stations. The data included in the present paper pertain to chlorophyll *a* from the postmonsoon of 1986 to monsoon season of 1988 and gross and net primary productivity and rainfall for 1986-'88. Seasonwise nutrient data on dissolved phosphates, nitrates and silicates from the three stations for 1987 only have been used. The data obtained were pooled to get the monthly and seasonal averages.

The period of investigation was divided into three seasons *viz.*, premonsoon (February-May), monsoon (June-August) and postmonsoon (September-January). Chlorophyll *a* concentration was determined by Lorenzen's method (1967) using Spectrophotometer (ECIL: G. S. 8650); primary productivity experiments were conducted under simulated *in situ* condition for three hours by light and dark bottle - oxygen method and the values obtained were extrapolated for the day hours in which photosynthetic quotient was taken as 1.25 (Nair, 1970); primary production for the water column was estimated by the formula given by Steemann Nielsen and Aabye Jensen (1957). Monthly rainfall data for Cochin region were obtained from the 'Daily Weather Chart' of IMD; dissolved phosphate-P, nitrate-N and silicate-Si were estimated adopting the methods given by Strickland and Parsons (1968). The mean surface and column production values for 1986-88 were used to assess the productive potential of the region.

Zooplankton samples were collected at fortnightly intervals from two depth zones *viz.*, 15 m and 30 m in the fishing grounds off Cochin during July 1984 to August 1988. The net used for the collection of samples was a Bongo-20 net having a ring diameter of 20 cm each and fitted with a calibrated flowmeter. The twin cones of the net were made of nylon material of 0.5 mm square mesh. The sampling was made by oblique hauls from bottom to surface at an average speed of 2 knots. The samples were preserved in 5% formalin.

Biomass was determined as the mean wet displacement volume of the samples from the two cones. The plankton biomass in ml per 100 m^3 of water filtered was computed based on flowmeter readings. Similarly the mean number on different groups per 100 m^3 was also computed. Though samples were collected from two different depth zones, for the purpose of this study the region upto the 30 m depth zone off Cochin is treated as one.

Cushing's (1973) method was followed for calculating the biomass of the plankton for the different seasons based on the copepod generation time computed from the seasonal mean temperature and the secondary production was determined by adopting the formula 1 ml = 0.065 gC. The secondary production was thus estimated in terms of tonnes of carbon in an area of 1,175 km^2.

At Vizhinjam the rate of primary production was estimated by the light and dark bottle technique following Strickland and Parsons (1968). Fortnightly observations were made from two

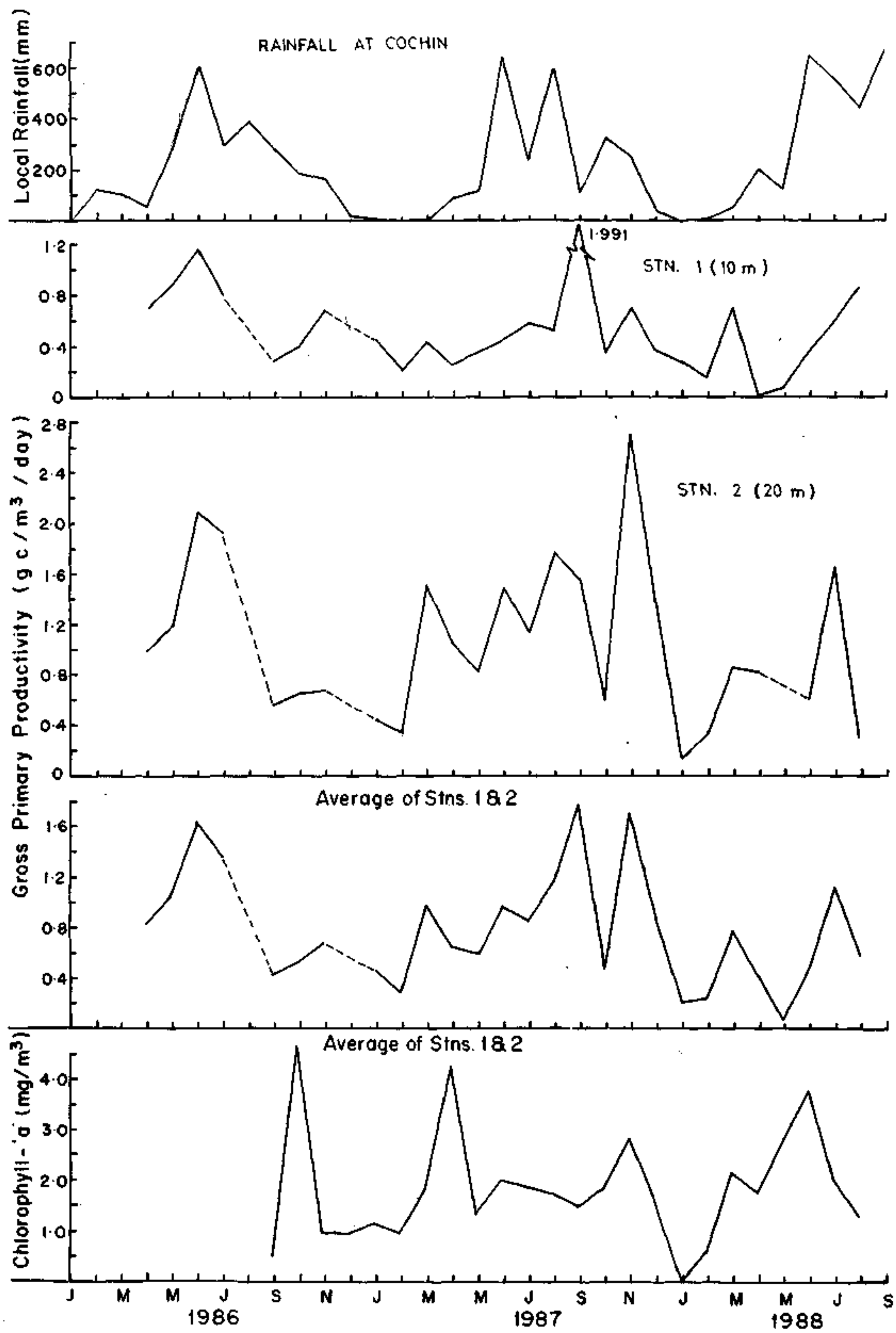

Fig. 1. Monthly trend of rainfall, gross primary productivity and chlorophyll 'a' concentration at Cochin.

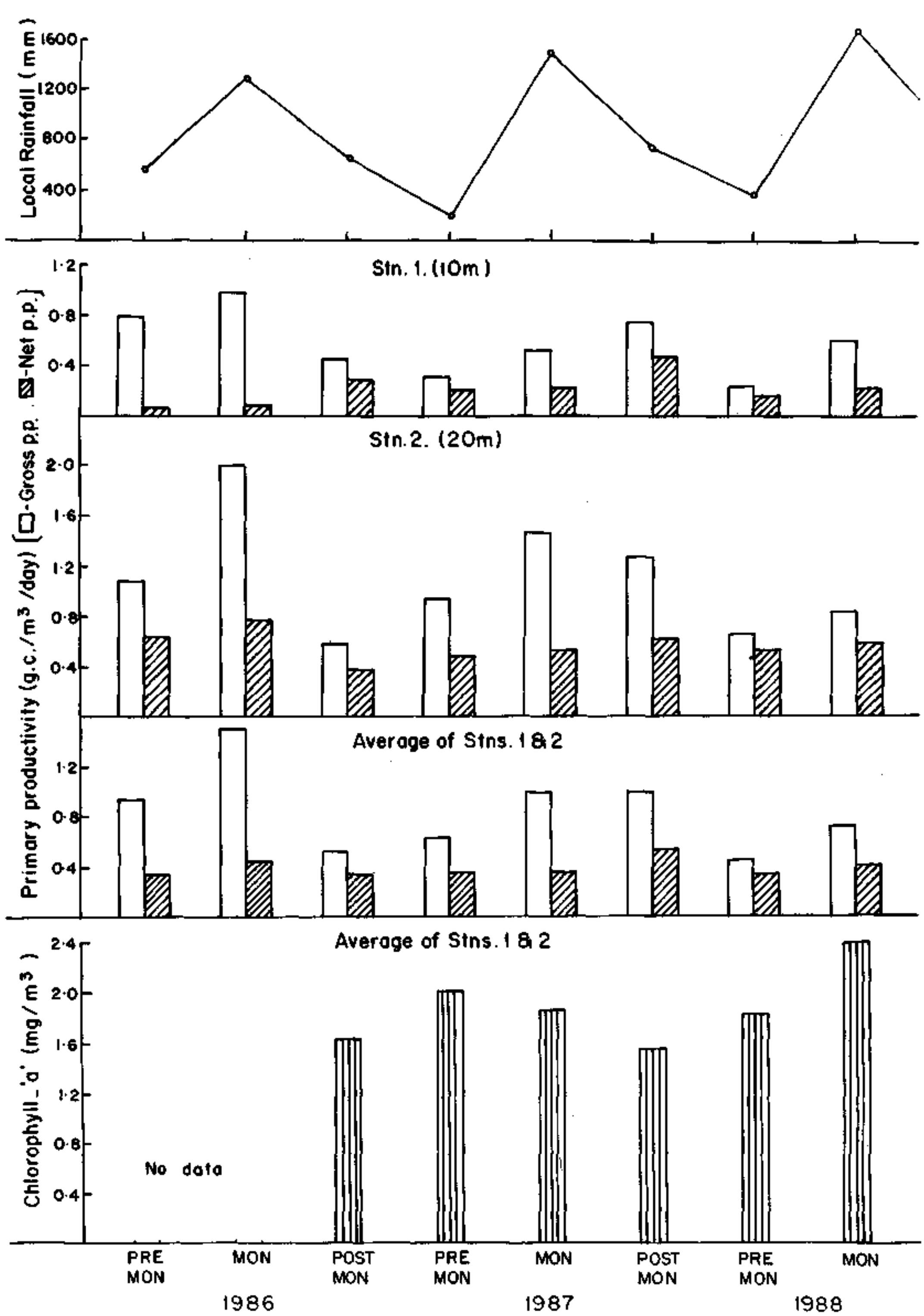

Fig. 2. Seasonal trend of rainfall, gross and net primary productivity and chlorophyll 'a' concentration at Cochin.

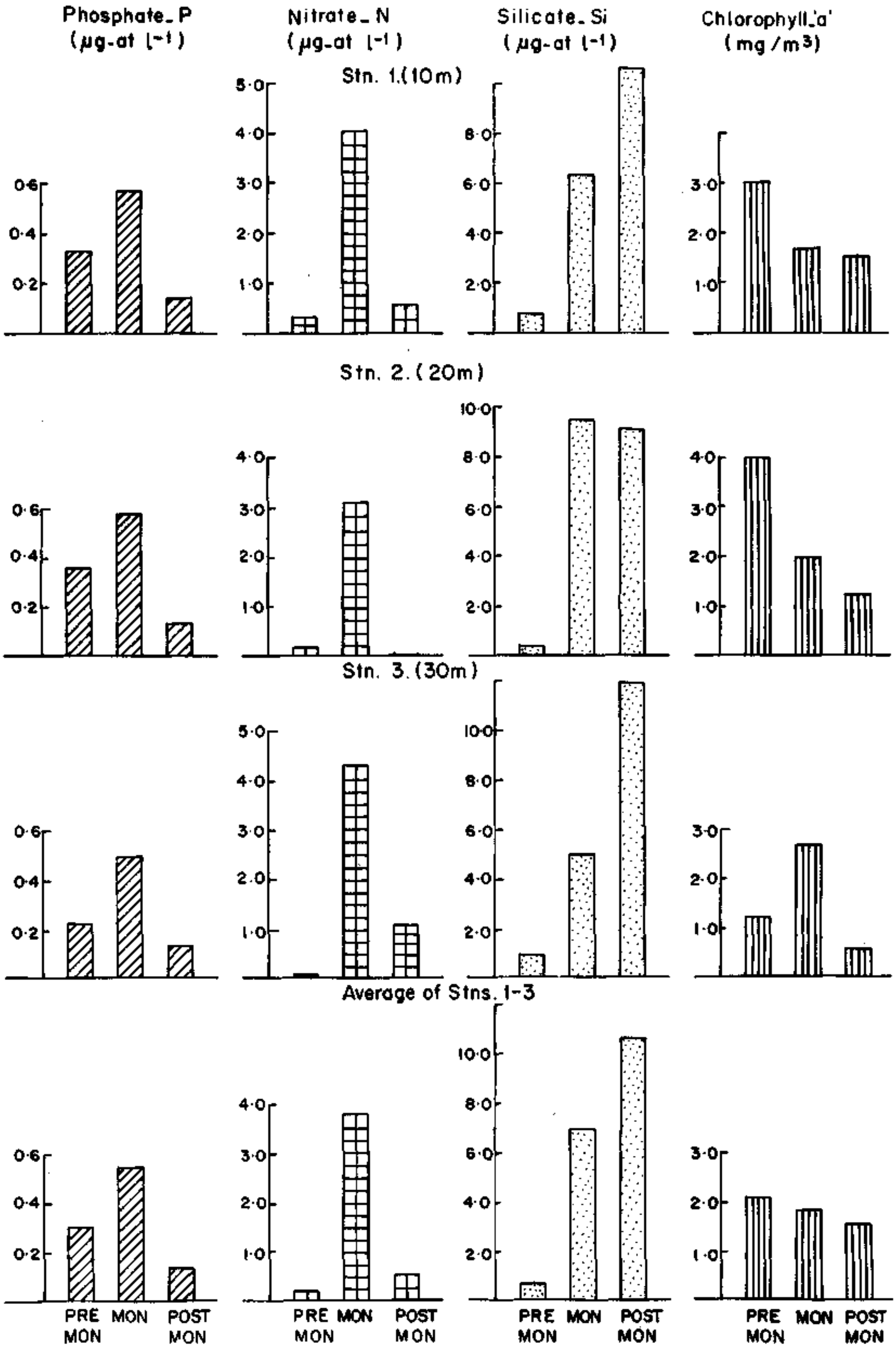

Fig. 3. Seasonwise distribution of phosphates, nitrates, silicates and chlorophyll '*a*' in the surface waters off Cochin during 1987.

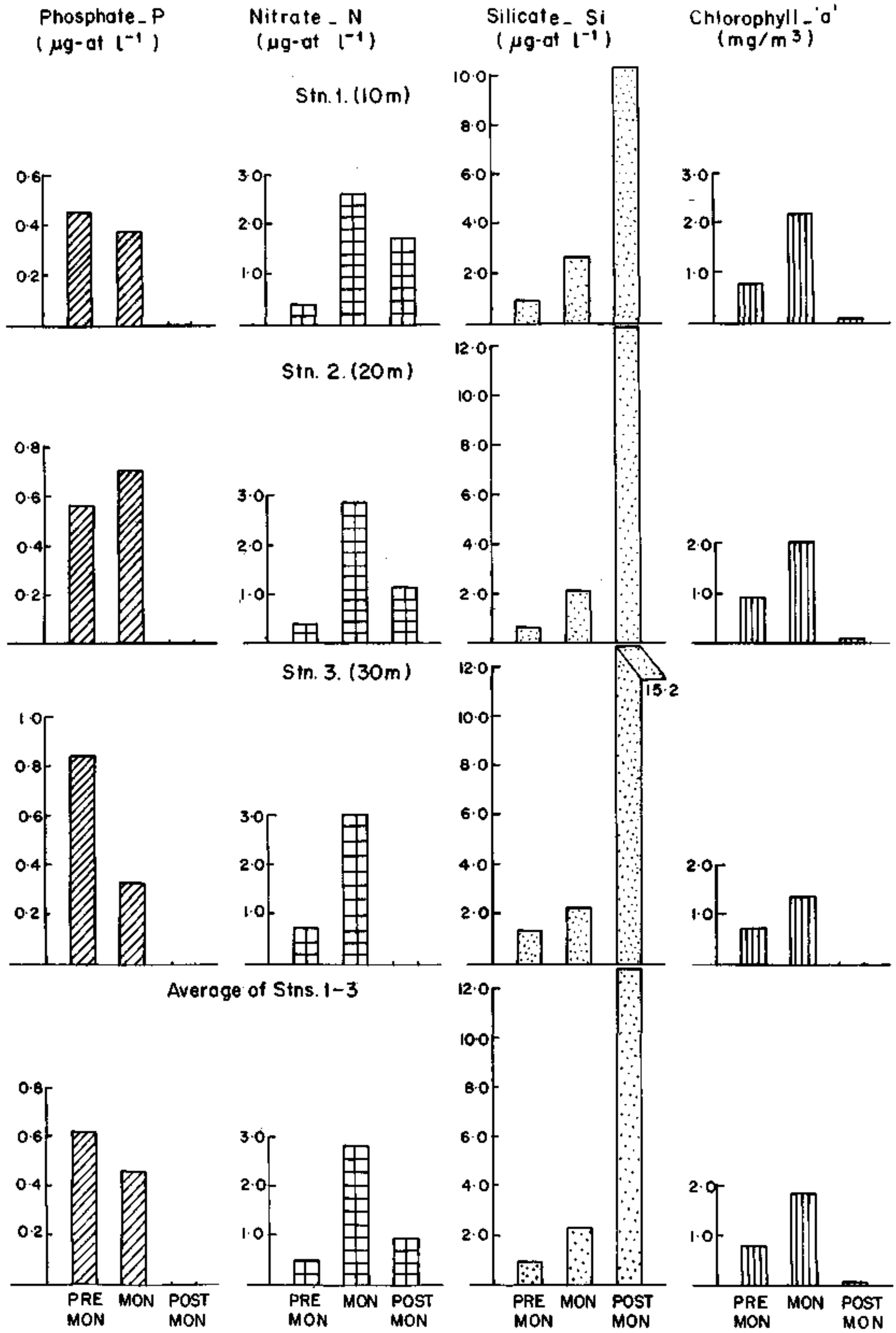

Fig. 4. Seasonwise distribution of phosphates, nitrates, silicates and cholophyll 'a' in the bottom wates off Cochin during 1987.

stations at 15 m and 30 m depth points from February 1984 to January 1986. The values were averaged to represent seasons such as premonsoon, monsoon and postmonsoon. The relevant hydrographic parameters were also studied.

TABLE 1. *Yearwise and seasonwise fluctuations in rainfall (in mm) at Vizhinjam*

Season	1984-85	'85-86	'86-87	'87-88	Average
Premonsoon	729.9 (48.8)*	364.5 (26.0)	366.3 (29.7)	320.6 (16.0)	445.3 (29.0)
Monsoon	352.6 (23.6)	568.6 (40.4)	460.7 (37.3)	578.4 (28.8)	490.0 (31.9)
Postmonsoon	411.5 (27.6)	471.6 (33.6)	407.0 (33.0)	1109.2 (55.2)	599.8 (39.1)

* Percentages are given in parenthese

The zooplankton samples at this centre were collected fortnightly during 1984 to 1988 from one station at 30 m depth using a 50 cm mouth diameter conical net of 0.4 mm mesh size towed from a catamaran. The zooplankton was estimated for 100 m^3 of water. The hydrographic data were obtained by analysis of the water following standard methods.

Fortnightly sampling for zooplankton was carried out at Lakshadweep from two stations in the lagoon from November 1985 to August 1988. At Station 1 the samples were collected from the surface only in all the seasons while at Station 2 the samples were collected from surface and 5 m depth for the premonsoon and postmonsoon only. The zooplankton was collected by surface hauls for a duration of 10 minutes using a half metre mouth diameter conical net of 0.4 mm mesh size. The samples for hydrography were analyzed following standard methods.

RESULTS

The environment

Cochin

Rainfall : During 1986, Cochin had a wide-spread monsoon rainfall from May to September with its peak during June (610 mm) while 1987 data showed peaks in June (650 mm) and August (603 mm) with an intermittent break in July (237 mm). In 1988, monsoon extended upto September with peaks in June (654 mm) and September (674 mm). In general, December-February recorded very low rainfall (35 mm) during 1986-88 (Fig. 1) with an exception in February 1986 (118 mm).

The rainfall data showed a progressive increase from year to year recording 1295, 1490 and 1665 mm during the monsoon season, 633, 725 and 855 mm in the postmonsoon season in 1986, 1987 and 1988 respectively Fig. 2). The rainfall of postmonsoon season constituted about 50% of monsoon rainfall. The rainfall during premonsoon season was maximum in 1986 (567 mm) and minimum in 1987 (195 mm). Overall seasonal average rainfall for premonsoon, monsoon and postmonsoon during 1986-88 were 379, 1483 and 738 mm respectively, constituting an annual average rainfall of 2600 mm, while the annual rainfall values (aggregate of three seasons) for 1986, 1987 and 1988 were 2495, 2410 and 2895 mm respectively.

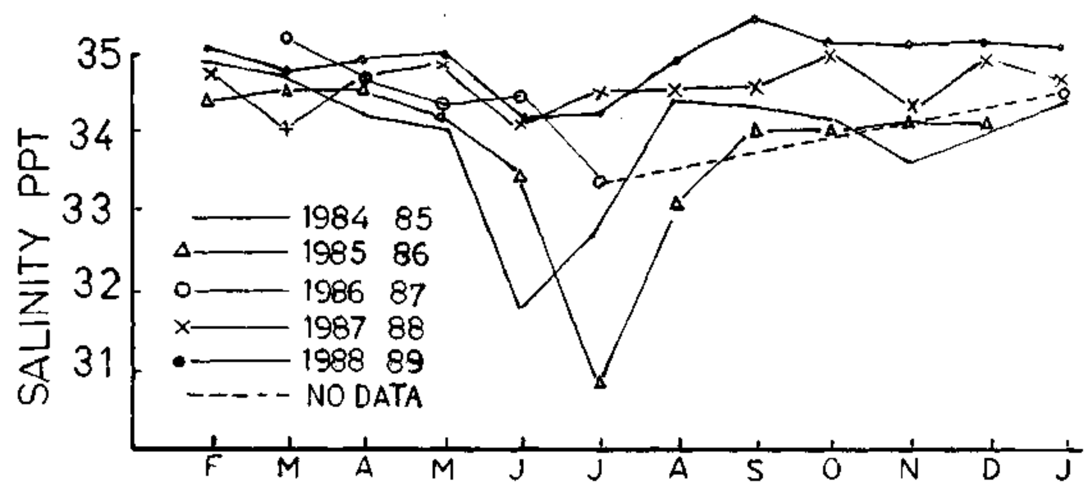

Fig. 5. Montly mean values for salinity during 1984-85 to 1988-89.

Dissolved nutrients : Seasonal averages of phosphate, nitrate and silicate concentrations for the surface and bottom waters at the three depth stations are shown in Fig. 3 & 4. The mean phosphate concentration was maximum in the bottom waters (0.62 µg at/l) during premonsoon and at surface (0.55 µg at/l) during monsoon; while the minimum values were recorded in surface and bottom waters during postmonsoon season.

In the case of nitrates, the mean values were higher in surface during monsoon (3.82 µg at/l) than at the bottom. During pre and postmonsoon seasons the mean values were relatively higher at the bottom. In general, low values were recorded at surface and bottom waters during the premonsoon, high values during the monsoon and medium values during the postmonsoon period.

In the case of silicates, the values were minimum at surface and bottom during premonsoon, medium at monsoon with surface values higher than bottom and higher during postmonsoon season in surface (10.6 µg at/l) and bottom waters (12.8 µg at/l).

Vizhinjam

Rainfall : The data obtained from the Meteorological Station indicate that the rainfall is rather protracted around Trivandrum and is influenced by both southwest (June - Aug.) and northeast (Nov. - Dec.) monsoons. The rainfall recorded during the southwest monsoon is considerably higher than that in the northeast monsoon. An examination of rainfall data for the various seasons (pre, post and monsoon) of 4 years (1984-85; '85- 86; '86-87 and '87-88), reveals that the rainfall never follows any set pattern (Table 1). The monsoon season of 1985-'86 and 1986-87 received maximum rain than in the other years. But in 1984-85 and 1987-88 the highest rainfall was recorded during premonsoon and postmonsoon periods respectively. While comparing the premonsoon period of various years it becomes evident that the rainfall was quite below the average during 1985-86 and 1987- 88. A similar deviation from the average rainfall could be noted during the monsoon period of 1984-85 and 1986-87 also. Postmonsoon figures of rainfall indicate an excess only in 1987-88 period while the same for other years were below average.

Salinity : Monthly mean values of salinity are given in Fig. 5. The monsoon dip in salinity was quite well marked during 1984-85 and 1985-86, while in other years the fluctuations were not so wide. The figures for rainfall during the monsoon period (June-Aug.) were 352.6, 568.6, 460.7 and 578.4 mm respectively (Table 1) for the years 1984-85, '85-86, '86-87 and '87-88, while the pooled average for the monsoon period of the above 4 years was only 490.0 mm. This shows that though the rainfall was less than the average during 1984-85, the salinity values showed a dip in the monsoon season. But the same trend could not be noticed in 1987-88 when the rainfall was higher than the average.

After the southwest monsoon dip, the salinity increases gradually and attains a level quite similar to that of the premonsoon period in some years. But during 1984-85 and '87-88 the salinity values for postmonsoon period were less than those of the premonsoon period and this may be attributed to northeast monsoon which is prevalent during October-November period. Rainfall recorded during these two months, when pooled, was 276.9, 331.1, 310.8 and 613.5 mm respectively for 1984-85, '85-86, '86-87 and '87-88. Here also the salinity fluctuations noted during these months have no correlation with the rainfall because in 1987-88 when rainfall recorded the maximum (1109.2 mm) the salinity value was also the maximum (34.7 ppt).

TABLE 2. *Seasonwise average salinity (ppt) of surface waters at Vizhinjam during 1984-85—1988-89*

Season	1984-85	'85-86	'86-87	'87-88	'88-89	Average
Premonsoon	34.5	34.4	34.6	34.6	34.8	34.6
Monsoon	32.9	32.5	33.9	34.3	34.4	33.6
Postmonsoon	34.1	34.1	34.6	34.7	35.1	34.5

Season wise analysis of salinity for the entire period indicates that the seasonal average for premonsoon period varies from 34.4 to 34.8 ppt, for monsoon period from 32.5 to 34.4 ppt and for postmonsoon period from 34.1 to 35.1 ppt (Table 2). The average salinity values for '84-85 and '85-86 were less than those noted for the subsequent years. The magnitude of differences on a season to season basis, in the average salinity values (Table 3) showed that it was 1.6 ppt between pre and monsoon period of 1984-85, while it was only 1.2 ppt between monsoon and postmonsoon period. These differences gradually narrowed as the years advanced and in 1987-88 these were 0.3 and 0.4 ppt respectively. Although the reason for this narrow differences is not clear, it appears that the rainfall during the various seasons of the same year has no bearing on the fluctuations in salinity.

TABLE 3. *Salinity difference between seasons for the years 1984-'85 to 1988-'89 at Vizhinjam*

Difference in salinity values between	1984-85	'85-86	'86-87	'87-88	'88-98	Average
Premonsoon & Monsoon	1.6	1.9	0.7	0.3	0.4	1.0
Monsoon & Postmonsoon	1.2	1.6	0.7	0.4	0.7	0.9

Temperature: Monthly mean values of temperature for the different seasons of the various years are given in Fig. 6. The dip in temperature during monsoon was quite well pronounced in all the years of observation. In all the years, the temperature was at its highest level (28-30°C) during the premonsoon period, but it started decreasing by June at the onset of southwest monsoon. After southwest monsoon, the temperature again started showing an upward trend; but during the postmonsoon period it never attained a premonsoon level except during 1987-88. The temperature recorded during the premonsoon period was also subject to considerable variation in all the years. During premonsoon of 1987-88 it was constantly at 30°C, while in 1984-85 at 28°C and in other years there were considerable month to month variations. The temperature after the southwest monsoon period, started showing an upward trend by September in all years. The temperature then reached a higher level by October, except during 1984-85 when it was at the lowest level for the year (24.75°C). The peak in temperature for the postmonsoon period was discernible during October in two years (1985-86) and 1988-86) and then declined by the onset of northeast monsoon and finally got established at 28°C (1988-89) or at 27°C (1985-86). There was actually no decrease in temperature during northeast monsoon period of 1987-88 and it was constant at 30°C during October-December period. The postmonsoon temperature of 1984-'85 was quite low (24.75 to 25.2°C).

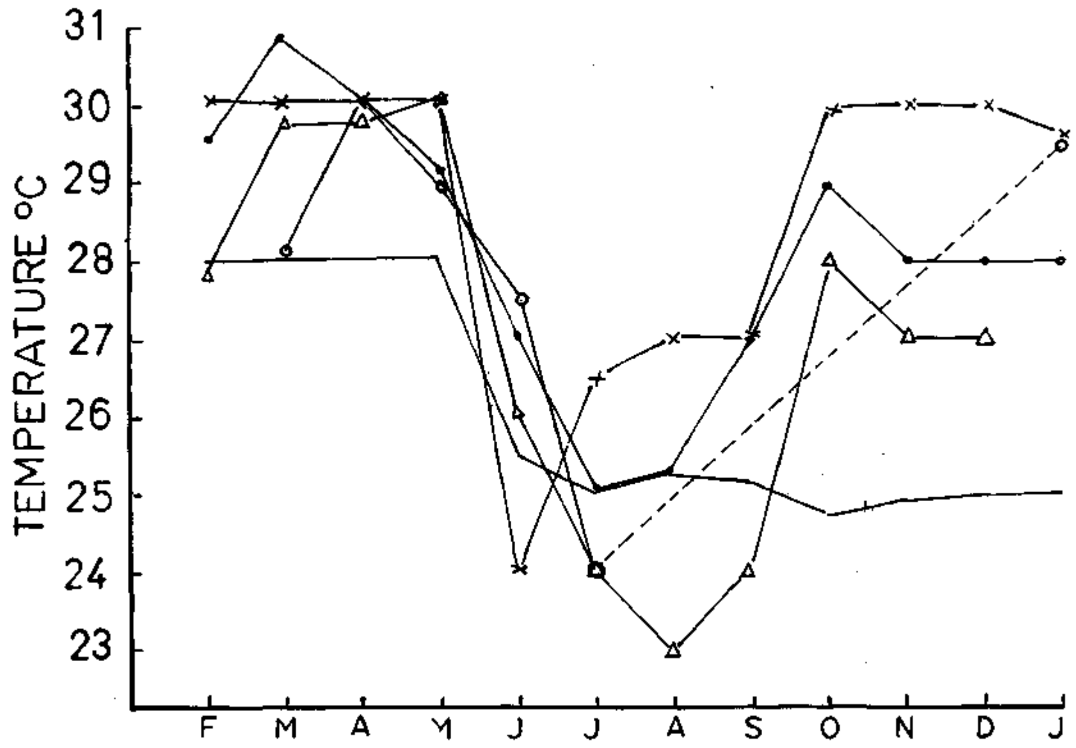

Fig. 6. Montly mean values for temperature during 1984-85 to 1988-89.

The differences in temperature between the seasons showed that during 1984-85 (2.7 and 0.3°C) it was much less than the average (4.0 and 2,2°C) and in 1987-88 they were above averages. Considering the general trend for the entire period it may be seen that the difference in temperature between the seasons increased as the years advanced. It is interesting to note in this context that in the case of salinity a reverse order of fluctuation was evident.

Dissolved oxygen : The monthly mean values for dissolved oxygen are given in Fig. 7. The highest and lowest values for dissolved oxygen vary very little. Highest values were common in premonsoon periods while the lowest, in the postmonsoon periods.The highest value, when considered monthwise, were in March (1984-85, 1986-87); February 1985-86, 1987-88) and in May/August (1988-89), while the lowest values in September (1984- 85, 1988-89); September-October (1985-86) and July (1987-88).

Lowering of dissolved oxygen content was characteristic of monsoon period of 1984-85, 1985-86 and 1987-88, but was equal to those of other seasons in 1986-87. In 1988-89, however, the value recorded was the highest when compared to the other two seasons. The differences in dissolved oxygen content were somewhat well marked as seen for monsoon and premonsoon in some years or not well pronounced as observed for monsoon and postmonsoon periods.

and 4.4/µg at/1 off Vizhinjam and October-November period registered the maximum value.

Lakshadweep

Temperature : Monthly mean values are plotted in Fig. 8 A & B. Lower temperature was recorded in the postmonsoon season and maximum in the premonsoon period. The trend in the variation was almost similar at both stations. Mean temperature varied from 27.3°C in November to 31.3°C in April. In general, high temperature prevailed during March-May.

Salinity : Monthly variations in salinity are presented in Fig. 8 C and D. The values showed fluctuations from 32.26‰ in June to 34.93‰ in March. In general, lower salinity was observed at Station 1. The low value obtained during June in the shallow water (Station 1) may be due to the land run off as a result of monsoon.

Dissolved oxygen : Monthly averages are presented in Fig. 8 E & F. The values ranged from 3.98ml/l in March to 4.66 ml/l in June. The fluctuation was not much at both stations. The values were generally higher in the surface water during monsoon months.

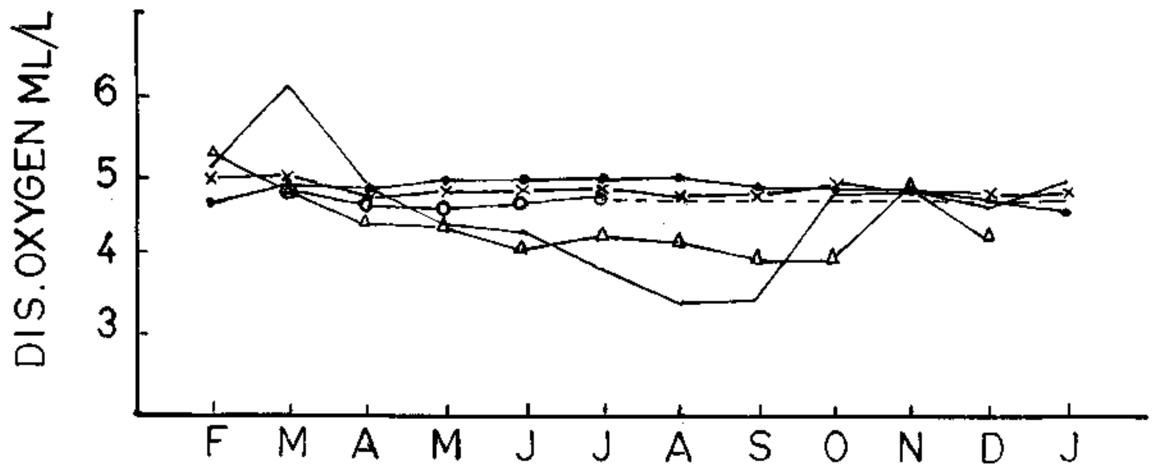

Fig. 7. Montly mean values for dissolved oxygen content for the period 1984-85 to 1988-89.

Phosphates : The earlier report (Rani Mary Jacob and Vasanthakumar, 1987) has given a range from 0.8-4. 08 µg at/1 for this area. A peak in the values for phosphate, according to the above authors, occurs during September-october.

Nitrite : The range of fluctuation in nitrite values recorded off Vizhinjam was quite narrow. The highest values were recorded during July-August (monsoon) period (Rani Mary Jacob and Vasanthakumar, 1987).

Nitrate : The values of nitrate fluctuated between 0.9

Productivity

Cochin

Chlorophyll a : Monthly mean values of chlorophyll *a* are indicated in Fig. 1. Seasonal analysis revealed that the mean chlorophyll *a* concentration was maximum (2.4 mg/m^3) during southwest monsoon of 1988. In 1987, the seasonal mean values in surface waters were 2.093, 1.861 and 1.557 mg/m^3 during premonsoon, monsoon and postmonsoon respectively (Fig. 2 & 3), while the overall seasonal average surface values for 1986-88 were 1.963, 2.129 and 1.589 mg/m^3 during the three seasons respectively indicating highest concentration during monsoon season. The column average (1987 data) also indicated highest concentration during monsoon season.

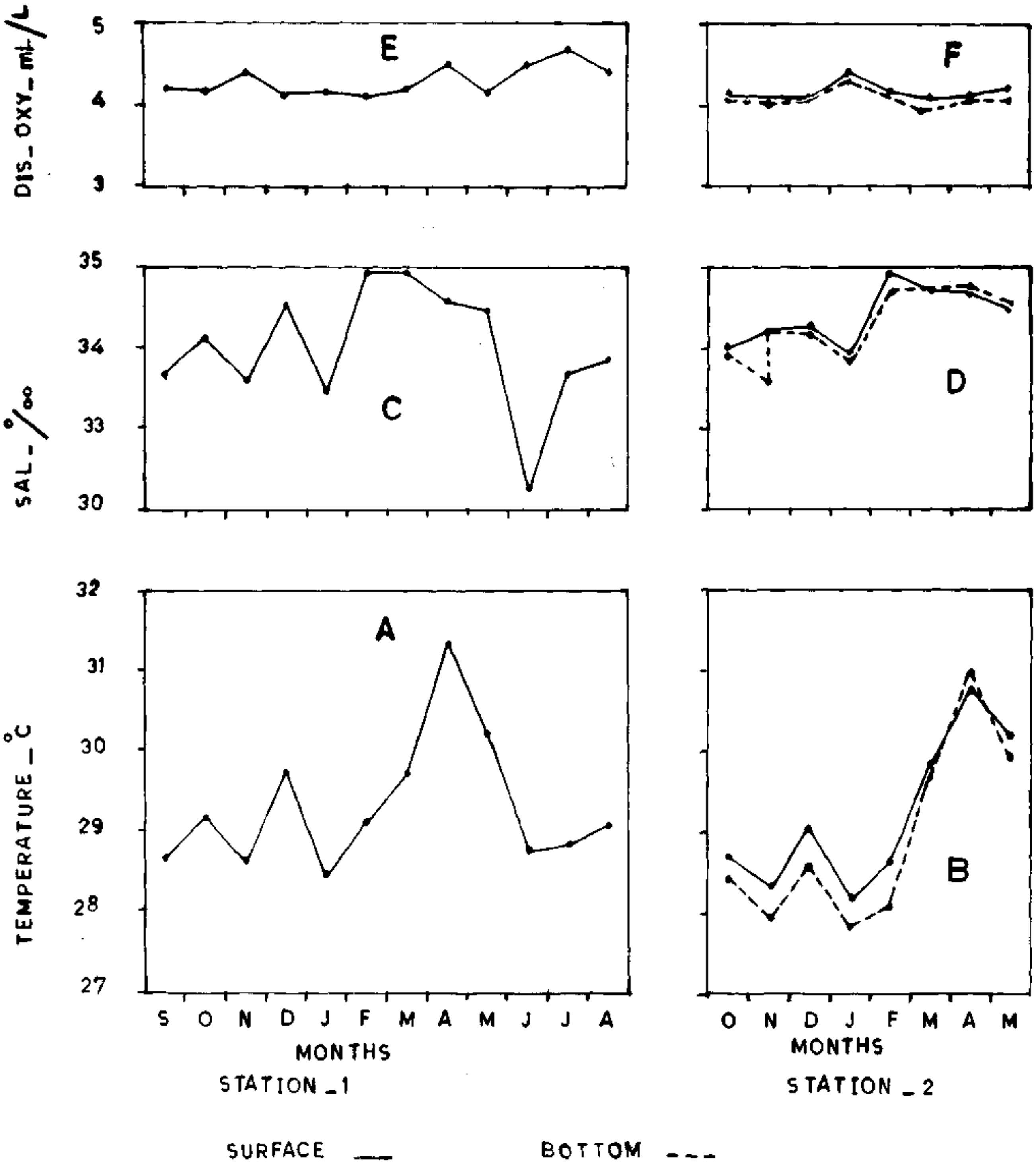

Fig. 8. Variations in temperature (A and B), salinity (C and D) and dissolved oxygen (E and F) at Lakshadweep.

Gross primary productivity : Monthly and seasonal mean values of gross productivity in surface waters upto 1 m depth are illustrated in Fig. 1 & 2 respectively. Maximum production rate of 1.991, 2.700 and 2.400 g C/m^3/day were recorded at 10 m, 20 m and 30 m depth stations during September, November and October 1987 respectively (postmonsoon months); and in general, productivity was higher at 20 m depth station (Fig. 1). Seasonwise pooled data (1986-88) for premonsoon, monsoon and postmonsoon showed mean values of 0.444, 0.706 and 0.596 g C/m^3/day at 10 m depth 0.899, 1.439 and 0.932 g C/m^3/day at 20 m depth and an average 0.672, 1.072 and 0.764 g C/m^3/day respectively in the inshore surface waters indicating peak production rate during the monsoon season (Fig. 2). The average monsoon values of 1986, 1987 and 1988 were 1.493, 0.995 and 0.729 g C/m^3/day respectively indicating a decreasing trend from 1986 to 1988. The mean gross production estimates of the different seasons during 1986-88 per km^2 area off Cochin (K-5 zone) are given for the surface waters in Table 4.

TABLE 4. *Estimated surface primary production off Cochin (in tonnes carbon)*

	Premonsoon (120 days)	Monsoon (92 days)	Postmonsoon (153 days)	Annual (365 days)
Gross production				
Daily average production per Km^2 area	0.672	1.072	0.764	
Seasonal/annual prod. per Km^2	80.640	98.624	116.892	296.156
Seasonal/annual prod. per 1175 Km^2	94,752	1,15,883	1,37,348	3,47,983
Monthly mena per Km^2	20.16	32.875	23.378	
Net production				
Daily production per Km^2 area	0.345	0.405	0.442	
Seasonal/annual prod. per Km^2	41.4	37.26	67.625	146.285
Seasonal/annual prod. per 1175 Km^2	48,645	43,780	79,460	1,71,885
Monthly mean per Km^2	10.35	12.42	13.525	

Net primary productivity : Monthly and seasonal mean values of net productivity in surface waters are presented in Fig. 1 & 2 respectively. In general, higher rate of net production was observed in the 20 m depth station than at 10 and 30 m depth stations (Since regular monsoon data were not available for 30 m depth station, the data for 30 m station were not depicted in Fig. 1 & 2). Seasonwise pooled data for 1986-88 for the three seasons showed mean values of 0.137, 0.179 and 0.379 g C/m^3/day at 10 m depth station; 0.552, 0.631 and 0.505 g C/m^3/day at 20 m depth and on average, 0.345, 0.405 and 0.442 g C/m^3/day respectively in the surface waters off Cochin, indicating highest net productivity during postmonsoon season, while the premonsoon season showed the minimum rate of net production during 1986-88 (Table 4).

The net production estimates in the column waters for the three seasons during 1986-88 per km^2 area are given in Table 5. On average, the net production values were 51.34, 37.78 and 57.85% in gross production during premonsoon, monsoon and postmonsoon respectively in the inshore waters, indicating very low percentage during monsoon season.

The estimated annual net production for the 1175 km^2 area of inshore waters (between Chellanam and Munamban) was 8,59,430 tonnes carbon. It was 2,18,902 tonnes carbon during monsoon season (92 days) constituting 25.47% of annual net production while it was 28.3% during premonsoon (120 days) and 46.23% during postmonsoon season (153 days). The monthly mean net production for the premonsoon, monsoon and postmonsoon seasons were 51.75, 62.10 and 67.63 tonnes Carbon/Km^2 respectively (Table 5).

Vizhinjam

Primary production : In Vizhinjam inshore waters, the average seasonal values of gross and net production showed maximum during monsoon period in both the years of collection. During this season the highest rate of production was in June. The seasonal variations in the gross and net production in the inshore waters off Vizhinjam are given in Table 6.

TABLE 5. *Estimated net primary production off Cochin (Column production in tonnes carbon)*

		Premonsoon (120 days)	Monsoon (92 days)	Postmonsoon (153 days)	Annual (365 days)
Daily average prod. per Km^2 area	: 1986	1.680	2.180	1.700	
	: 1987	1.740	1.865	2.620	
	: 1988	1.755	2.030	2.310	
Daily average per Km^2 (1986-1988)		1.725	2.025	2.210	
% of net production in gross production		51.34%	37.78%	57.85%	
Seasonal/annual prod. per Km^2		207.0	186.3	338.13	731.43
Seasonal/annual prod. per 1175 Km^2		2,43,225	2,18,902	3,97,303	8,59,430
Monthly mean prod. per Km^2		51.75	62.10	67.63	

No primary productivity studies were carried out at Lakshadweep.

Zooplankton productivity

Cochin

Biomass : Fig. 9 A shows that the biomass invariably recorded a primary peak in the southwest monsoon season in July, during 1984 (96 ml), '85 (237 ml) and '86 (541 ml) and in August during '87 (111 ml) and '88 (96 ml). A secondary peak in the postmonsoon season in September was discerned in '84 (51 ml) and '86 (46 ml). Following the occurrence of the primary peak in July '85, the biomass recorded in August was 86 ml, a little less than those of the primary peaks recorded in '84 and '88.

The primary peak recorded in July '86 was constituted by a volume as large as 541 ml, the largest volume observed during the entire period of this study. The biomass observed during the following August was 42 ml, a little less than that of the secondary peak, (46 ml) of September '86. While decrease in the biomass that followed the primary peaks was usually sharp, the decline that succeeded the secondary peaks gradually brought the volume down over a period of 3 or 4 months. The increase in the biomass observed in March 1987 (38 ml) was only one of its kind observed in the premonsoon season during the study.

Zooplankton

Copepods : The numerical abundance of copepods, which was high during July '85 (77,000), '86 (2,58,064) and August '88 (3,19,756) coincided with the primary peaks of plankton biomass, but the copepod peak occurred in September '84 (1,07,614) and during April (1,16,183) and June (1,00,744) in '88 when the plankton biomass was low (Fig. 9 B). It is significant that the copepod component was

TABLE 6. *Average seasonal values of primary productivity (mgC/m³/day), temperature (°C), Salinity (‰), dissolved oxygen (ml/l) and nutrients (µg/at/l) and rainfall (mm) in the premonsoon, monsoon and postmonsoon seasons at Vizhinjam for the period February 1984 to January 1986*

Productivity and environmental parameters	Seasons	1984-85	1985-86
Net production	Pr M	101	229
	M	170	516
	Pt M	106	no data
Gross production	Pr M	217	440
	M	270	711
	Pt M	241	no data
Temperature	Pr M	28.04	29.33
	M	25.28	34.30
	Pt M	25.04	26.50
Salinity	Pr M	34.48	34.44
	M	33.63	32.80
	Pt M	34.14	34.11
Dissolved oxygen	Pr M	5.15	4.75
	M	3.90	4.25
	Pt M	4.50	4.50
Phosphate	Pr M	1.51	0.82
	M	1.26	1.44
	Pt M	1.40	1.97
Nitrite	Pr M	0.48	0.21
	M	0.76	0.25
	Pt M	0.45	0.28
Nitrate	Pr M	1.57	1.08
	M	2.15	1.54
	Pt M	1.78	1.68
Silicate	Pr M	7.23	7.79
	M	13.93	9.65
	Pt M	10.40	11.97

Pr M = Premonsoon, M = Monsoon and Pt M = Postmonsoon very poor in July '84 and August '87 and was comparatively less in July '85 when the biomass recorded the primary peaks for the respective years.

Cladocera : Cladocera occurred in swarms during July '85 (1,18,800), August '85 (1,25,200), '86 (1,61,800) and '88 (4,11,440). The swarm observed in August '88 was more abundant and nearly four times greater than those recorded during the rest of the period (Fig. 9 C). The abundance of cladocera observed in July '86 was nearly twice as much as those recorded in November '84, September '86, October '87 and April '88. It may be seen that between March and June '88 cladocera showed increase in abundance over those recorded in the corresponding period of the previous years.

Lucifer : The increase in the abundance of lucifers was normally observed in the monsoon season as in August '84 (4,600), July '85 (8,770), June '87 (39,330) and August '88 (6,980) except once in the postmonsoon season in December '84 (5,777) and once in the premonsoon season in May '88 (3,375), (Fig. 9 D). The numerical abundance recorded in June '87 remained the highest for the five year period '84-88.

Appendicularia : The peak of abundance observed particularly in July for three consecutive years, '84 (3,500), '85 (3,840) and '86 (48,588) was conspicuous by its absence during the month in '87 and '88 (Fig. 10 A). The mean monthly increase observed in February '86 was slightly more than that recorded in January '87, but almost equalled that abundance recorded in August '88. The Appendicularia showed marginal increase during November '84, June '87, April and June '88.

Siphonophores : Siphonophores were highly abundant in the monsoon in August '85 (5,827), '87 (11,283) and in the early postmonsoon in October '84 (6,086) and in September (17,838) and October (19,086) in '86 (Fig. 10 B). Besides, they tended to increase in abundance towards the end of the postmonsoon in January '88. It may be noted that maximum abundance in '88 was nearly six times greater than the maximum in '85 both occurring in the same monsoon season.

Chaetognatha : Chaetognatha abounded in the monsoon during July - August both in '85 (28,357; 10,181) and '87 (9,424; 10,736) and in the postmonsoon season during September both in '84 (10,440) and '86 (17,762) (Fig. 10 C). The abundance observed in November '84 (8,000) was less than that recorded in January '88 (8,700) by as much as it was more than that occurred in June '88 (7,100).

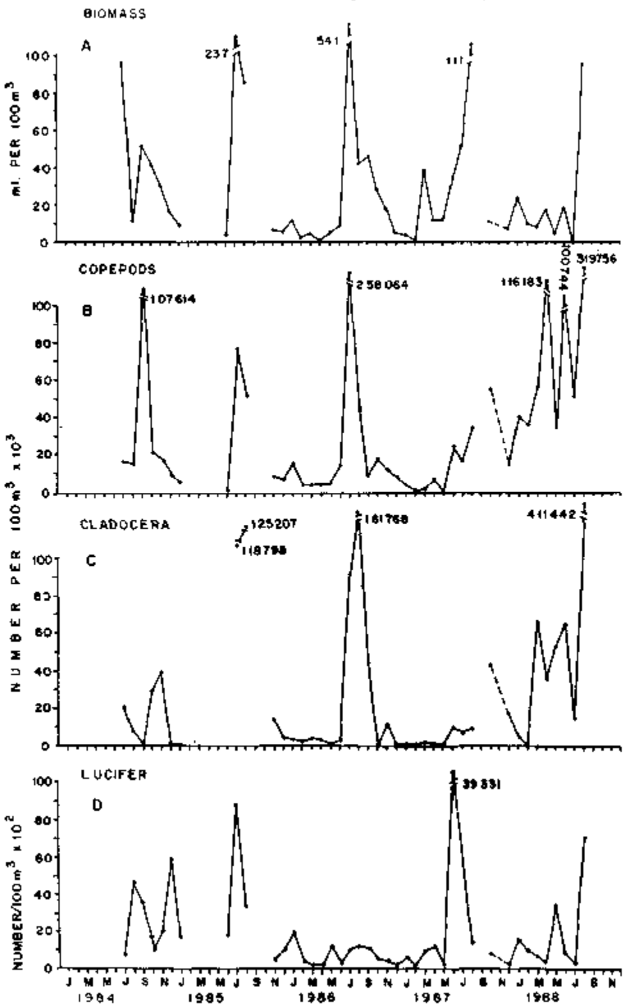

Fig. 9. Seasonal fluctuations in total zooplankton biomass amd abundance of zooplankton groups during 1984-88 at Cochin.

Polychaete larvae : The abundance of larval polychaetes recorded during the different years was 30,999 in July and 4,587 in October (both in '84), 44,384 in July and 47,223 in August (both in '85) and 32,360 in July '86 and 6,025 in August '87 and 4,686 in July '88 (Fig. 10 D).

Fish larvae : The monthly average number of fish larvae was 430 in October '84, 260 in September '86, 240 in August '87 and 945 in January, 310 in February, 270 in March, 260 in April and 320 in August (all in '88) (Fig. 11 A). During the rest of the period the number of fish larvae remained below 240.

Fish eggs : The monthly mean number of fish eggs observed was 920 in August and 560 in November (both in '84), 690 in August '85, 8,584 in August and 810 in September (both in '86) and 1,364 in May and 1,904 in August (both in '88) (Fig. 11 B). Unlike the increased abundance of fish eggs observed at least once during the different years, the maximum of the monthly mean recorded during '87 was as low as 490.

Decapod larvae : The monthly mean of the larval decapods observed during the monsoon in July '85 (6,680) and '86 (4,580), June '87 (53,840), June (13,573) and August (20,399) '88 was high and that recorded in June '87 was the highest for the five year period of this study (Fig. 11 C). In the postmonsoon in December '84, January and November '86, October '87 and January '88, the decapod larvae occurred more in number than during the rest of the months in the same season or the premonsoon season.

Secondary production: Table 7 shows secondary production estimated during the different seasons between 1984 and August 1988. The production in the monsoon season was maximum except in '84 during which year the production in the postmonsoon season (2,864 tonnes C) exceeded that of the monsoon (2,511 tonnes C). A comparison of the estimated values of the secondary production during the monsoon between '84 and '88 showed that there was an increase from 2,511 t of carbon in '84 to 6,352 t of carbon in '85 and further increased to 12,300 t of carbon in '86. But during '87 the monsoon production of 3,074 t of carbon decreased to nearly one fourth of previous monsoon and during '88 it decreased further to 2,379 t of carbon, slightly more than two third of the monsoon production of '87. The seasonal mean of secondary production was the highest in the monsoon at 5,309 tonnes of carbon or 4.52 t of carbon/Km^2 in the postmonsoon season and the premonsoon production was the least at 922 t of carbon or 0.79 t of carbon/Km^2 taking the third and last place. The average monthly zooplankton production for the seasons worked out to be 231 tonnes of carbon in the premonsoon, 1,774 t of carbon for the monsoon and 315 tonnes of carbon for the postmonsoon.

Vizhinjam

Total displacement volume of plankton : The monthwise displacement volume of plankton showed that all maximum were in postmonsoon months, while the minima were in the premonsoon period except during 1985-86 when it was in the postmonsoon period (Sept.). Plankton displacement volume (ml/100 m^3) calculated from pooled monthly data and presented for the entire period (Fig. 12 f) shows that there are actually 3 modes in the production of

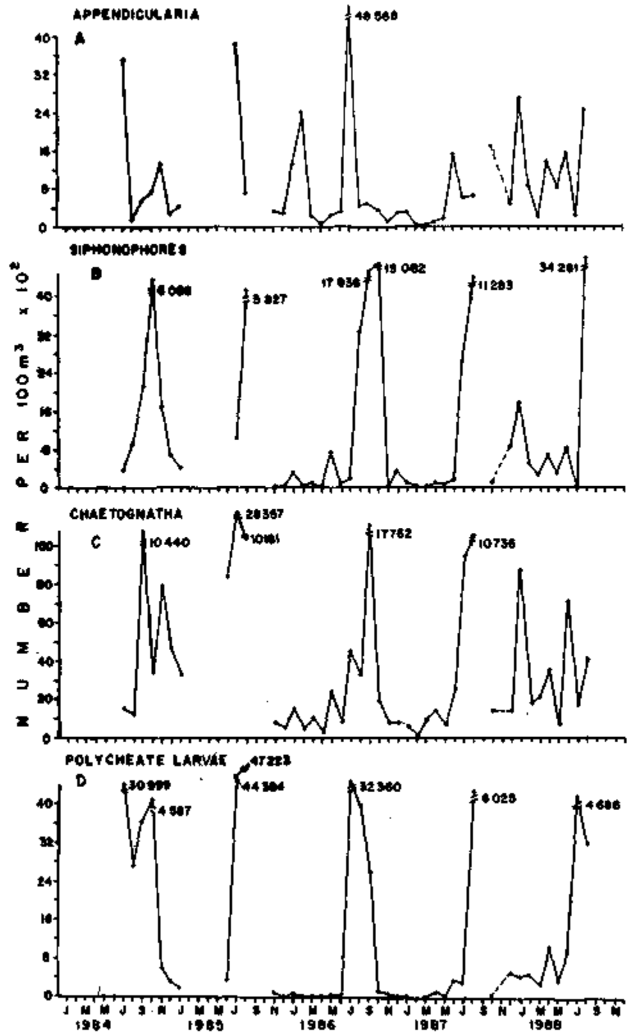

Fig. 10. Seasonal fluctuations in the abundance of zooplankton groups during 1984-88 at Cochin.

plankton off Vizhinjam. A dominant peak in the displacement volume could be noted in October (postmonsoon) followed by a secondary mode in June (monsoon) and a tertiary one in August (monsoon). It could further be seen that there was a premonsoon increase in plankton volume in 1984-85 (May) followed by a monsoon increase during 1985-86 (Aug.) and 1987-88 (June). Of these the first one was caused by phytoplankters *Bellerochea malleus* and *Cerataulina* sp., the second was by hydromedusae and the third through the bloom of *Thalassiosira subtilis*. From this it becomes evident

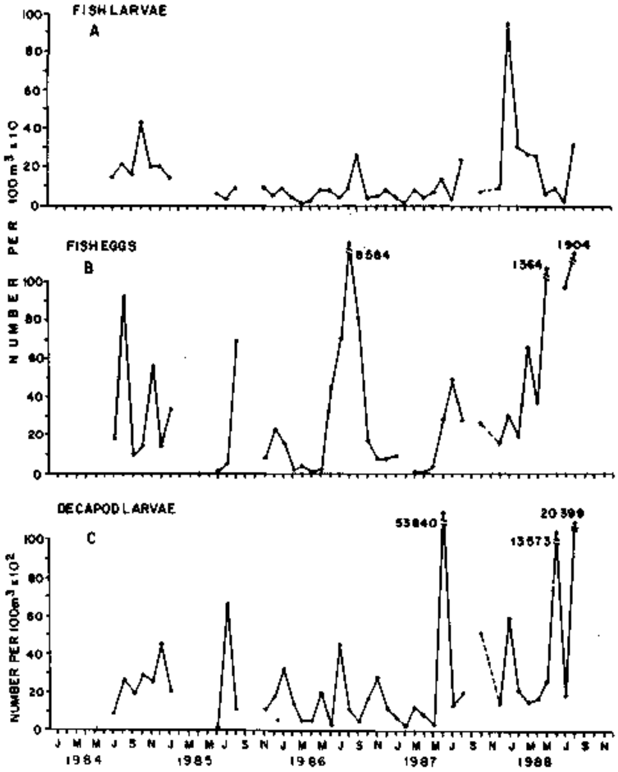

Fig. 11. Seasonal fluctuations in the abundance of zooplankton groups during 1984-88 at Cochin.

that displacement volume of plankton can often get exaggerated by occasional blooms or swarms. Hence, the secondary and tertiary modes, given in Fig. 12 f may be considered to be of minor significance while considering the plankton production for each year in detail.

TABLE 7. *Estimated seasonwise secondary production off Cochin in tonnes of carbon (Area : 1175 Km²)*

Year	Premonsoon	Monsoon	Postmonsoon
1984	-	2,511	2,864
1985	-	6,352	611
1986	210	12,300	1,533
1987	1,655	3,074	1,292
1988	902	2,379	-
Mean seasonal production	922	5,309	1,575
Mean monthly production	231	1,774	315
Seasonal mean production/Km²	0.79	4.52	1.34

Quarterwise analyses of displacement volume of plankton (Table 8) indicate that the postmonsoon period accounted for the maximum values, the only exception being the postmonsoon period of 1986-87 and this is because of the paucity of data for all the months.

The average seasonal values of displacement volume vary considerably from year to year. The average value for the entire period shows that the premonsoon period recorded the minimum (4.9 ml/100 m^3) while the postmonsoon period, the maximum (13.9 ml/100 m^3)The average figures for the premonsoon period of different years (Fig. 13 a-e; Table 8) indicate that the values for 1986-87 and '87-88 were below the average. Likewise, a comparison of the average figures for the season shows that 1986-87 and '88-89 recorded a volume much less than the average for the entire period. The postmonsoon period, with the exception of 1986-87 recorded higher values than the average.

Blooms and swarms and their seasonality : Blooms and swarms may be suggested as the main cause of sudden outburst in plankton biomass in the sea. Though it is not possible to pinpoint any single environmental parameter responsible for such phenomena, they are of regular occurrence in the coastal waters than incidental. Generally blooms and swarms are of common occurrence during the postmonsoon and monsoon months and may be cited as a major reason for the sudden increase in the displacement volume of plankton.

Though blooms and swarms are cited as a cause for fish mortality in certain parts along the coast of India, so far no such deleterious effect on fish population has been recorded from this area. A seasonwise occurrence of blooms and swarms off Vizhinjam during the period 1984-85 to 1988-89 may be outlined as follows:

TABLE 8. *Seasonwise displacement volume of plankton for the period 1984-85 to '88-89 (based on averages) at Vizhinjam*

Season	1984-85	'85-86	'86-87	'87-88	'88-89	Averages
Premonsoon	6.9	5.4	3.3	3.7	5.6	4.9
Monsoon	10.5	13.4	4.5	14.8	6.3	9.9
Postmonsoon	15.9	16.0	3.6*	16.3	18.0	13.9

* Data insufficient

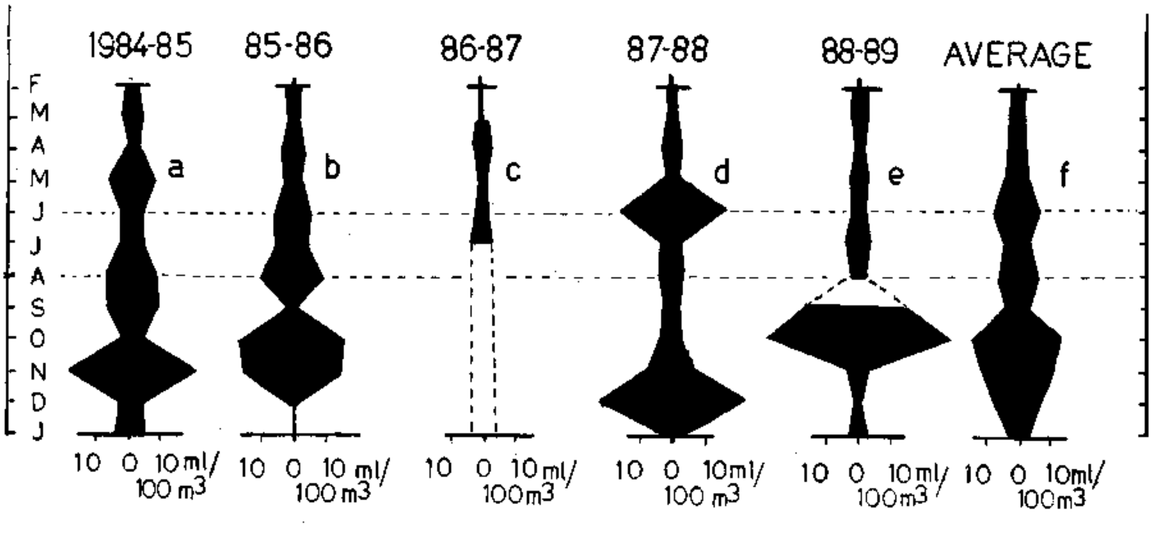

Fig. 12. Monthly displacement volume of plankton for the period 1984-85 to 1988-89; montly mean values for each year (a-e) and average monthly values for the entire period at Vizhinjam.

premonsoon period : During this period 4 blooms was observed off Vizhinjam. In February-March period (1984, '87) *Trichodesmium* caused outbursts occasionally. This was followed by a mixed bloom of *Bellerochea malleus* and *Cerataulina* sp. in May, 1984.

Monsoon period : The monsoon period witnessed 5 blooms, 4 were of a mixed nature and the 5th composed of a single species *Noctiluca miliaris*. Of the 3 swarms noted, one was of polychaete larvae (Aug. 1984) and the second was of hydromedusae (1985). Rhizostome medusae (*Netrostoma coerulescens* Maas) also could be seen washed ashore in plenty during August 1985.

Postmonsoon period : The total number of swarms noted during this period was 9 and blooms 4. It may be noted that the blooms were mostly of a mixed nature. Swarms outnumbered blooms in postmonsoon period while the condition was just the reverse in the monsoon period.

All the 4 blooms that occurred during the postmonsoon period were of *Noctiluca* sp. growing symbiotically with *Protoeuglena noctilucae* Subrahmanyan (1954), a speices of green flagellate. The specimens were of green colour and was first reported from the Gulf of mannar (Subrahmanyan,

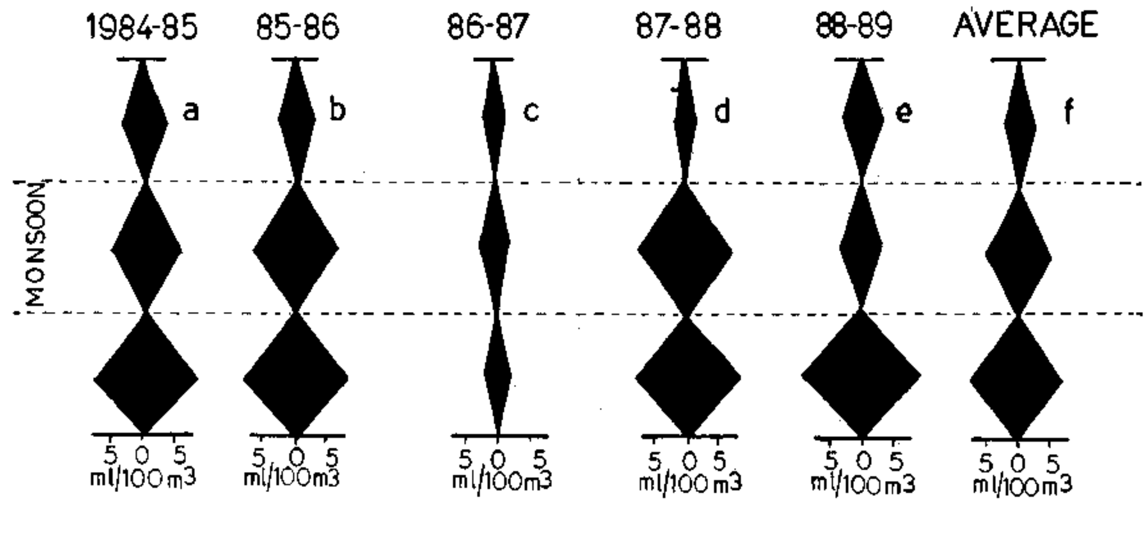

Fig. 13. Seasonwise displacement volume of plankton for each year : seasonal average and average for the entire period (f) at Vizhinjam.

1954) and then from Calicut (Prasad, 1958). This 'green' *Noctiluca* was recorded off Vizhinjam. The bloom of 'green' *Noctiluca* usually occur during November-December (1986, '87 and '88) months, while *Noctiluca* without such green symbionts usually occur during monsoon when hydrographical conditions are entirely different.

The blooms of phytoplankton are rather regular during the monsoon period and as many as 9 species, either as single species or in combinations, occur is this area. The postmonsoon period, on the other hand, is the season of swarms and the organisms involved may be holo or meroplanktonic forms. The most conspicuous among the various groups is medusae (both hydro and rhizostome). Hydromedusae are encountered during October-December period while large rhizomedusae are characteristic of August-September period. Washing ashore of *Netrostoma coerulesoena* Maas in large quantities is quite a regular phenomenon along this coast and their stranding coincides with 'onam' festival, they are known as 'Onachorri' in vernacular. Specimens measuring 10-40 cm diameter (umbrella) are common and the decay of such large specimens create problems to those who frequent the beaches or to nearby dwellers during this season. Cladocerans (*Evadne tergestina* Claus, *Penilia avirostris* Dana), ctenophores (*Pleurobrachia* sp.), copepods (mainly *Temora* sp.) and salps (*Salpa democratica* Forsskal) were the common groups which caused swarms during the postmonsoon period.

Hydrography in relation to blooms and swarms

A comparison of salinity and temperature in relation to bloom/swarm during various years shows that outburst of zooplankters/phytoplankters can occur under the following combinations.

a. Lower temperature and lower salinity

b. Lower temperature and higher salinity

c. Lower temperature and medium salinity

d. Medium temperature and higher salinity

e. Higher temperature and higher salinity

Table 9 shows that blooms/swarms are cyclic phenomena in the coastal waters, but what causes their outburst is not fully understood. It may be due to the interaction of several environmental parameters finally culminating in a condition quite congenial for them to cause a sudden spurt in their population.

Seasonal distribution of planktonic organisms and their numerical abundance

Nearly 31 groups of both mero and holoplanktonic organisms are encountered in the collections off Vizhinjam. Apart from these, a few phytoplankters which contribute to occasional blooms are also considered in the present study. Numerically speaking, copepods contribute more than 80% among the various groups. The availa-

TABLE 9. *Blooms/swarms in relation to salinity and temperature observed off Vizhinjam during 1984-89*

Combination/ species groups	Month	Salinity (ppt)	Temperature (°C)	Season
a. *Lower temperature and lower salinity*				
1. *Noctiluca miliaris*	July, 8 '85	30.6	24.0	Monsoon
b. *Lower temp. and higher salinity*				
2. Polychaete larvae	Aug. '84	34.5	25.5	Monsoon
c. *Lower temp. and medium salinity*				
3. Rhizostome medusae	Sept. '85	33.8	24.0	Postmonsoon
4. Mixed bloom*	June '85	33.5	26.0	Monsoon
5. Mixed bloom **	June '87	34.0	24.0	Monsoon
6. *Temora* sp.	Nov. 84	33.6	25.0	Postmonsoon
7. *Pleurobrachia* sp.	Nov. '84	33.6	25.0	Postmonsoon
d. *Medium temp. & higher salinity*				
8. Mixed bloom***	May '84	34.1	28.3	Premonsoon
e. *Higher temp. & higher salinity*				
9. *Noctiluca* 'Green'	Nov. '87	34.3	30.0	Postmonsoon
10. *Noctiluca* 'Green'	Dec. '87	34.9	30	Postmonsoon
11. *Trichodesmium* sp.	Feb. '84 & Mar. '87	34.9	30.0	Premonsoon

* Species were *Fragilaria oceanica, Rhizosolenia* sp., *Thalassiones* sp. and *Bellerochea malleous.*

** Species were *Thalassiosira subtilis, Chaetoceros* spp. and *Rhizosolenia* sp.

*** Species were *Bellerochea malleus* and *Cerataulina* sp.

bility and the peak period of abundance of all these groups are subject to considerable fluctuations both in time and space. An assessment of the various planktonic groups in relation to season and hydrographical conditions is presented by Rani Mary Jacob *et al.* (1986). The above workers have, after the correlation analyses between pelagic fishery, plankton and hydrography have found that zooplankton volume did not exhibit significant relationship with any of the hydrographical factors investigated.

In order to study the abundance of planktonic organisms during the various seasons, months and years their numerical abundance and peak period of distribution were found out for each group/genus. Normally the main and a subsidiary peak were considered in almost all groups. The seasons (premonsoon, monsoon and postmonsoon) and months in which the primary peak occurs during each year was traced out. The time lapse (in months) between adjacent primary peaks was found out for each group. Thus the primary peaks for mysids were observed during May '84, Aug. '85, Jan. '87, Oct. '87 and June '88 (Table 10). In other words, the peaks were observed during premonsoon, monsoon, postmonsoon, postmonsoon and monsoon seasons respectively in various years. The time lapse between the peaks of 1984 and '85 was 15 months, between '85 and '87 was 17 months, between Jan.'87 and Oct. '87 was 9 months and between Oct. '87 and June '88 was 8 months. In this manner, the details pertaining to 27 groups of plankters were traced out, of which 12 common groups are given in Table 10. It is seen that numerical abundance (peak) is a regular phenomenon in each group. But there is no uniformity with regard to the time (month) of occurrence : so also the time lapse between adjacent peaks is never uniform or predictable. it is also not known whether the primary and secondary peaks in the same group are supported by the same species or by different species. The information now available is rather meagre and this situation can be improved only through tracing the primary and secondary peaks of any group based on the predominance of component species.

It is also evident from the Table that the time lapse between adjacent primary peaks is never constant; the interval can be short or protracted sometimes. What causes this strange phenomenon is still a matter of conjecture; it can be due to any change in the physico-chemical condition of the seawater induced by rain or by run off of nurients of terrestrial origin.

Peaks of plankters and their seasonality

With a view of studying the seasonality in the occurrence of peaks in different groups of plankters the peaks found in each group through different years were traced out in relation to season and the peak occurrence of 27 groups of plankters in the different seasons of the study period is given in Table 11.

TABLE 10. *Successive primary peaks and the time lapse in months between adjacent peaks in 12 groups of plankters off Vizhinjam*

Groups	Peak in 1984-85	Time lapse	Peak in 1985-86	Time lapse	Peak in 1986-87	Time lapse	Peak in 1987-88	Time lapse	Peak in 1988-89
Mysids	May 84	15	Aug. 85	17	Jan. 87	9	Oct. 87	8	June 88
Amphipods	Aug. 84	6	Feb. 85	23	Jan. 87	7	Aug. 87	8	Apr. 88
Chaetognaths	Sep. 84	6	Mar. 85	15	July 86	18	Jan. 88	9	Oct. 88
Copepods	Nov. 84	5	Apr. 85	15	July 86	15	Oct. 87	12	Oct. 88
Decapod larvae	Nov. 84	6	May 85	12	May 86	15	Aug. 87	14	Oct. 88
Cladocerans	Sep. 84	7	Apr. 85	13	May 86	17	Oct. 87	12	Oct. 88
Lucifer	Aug. 84	8	Apr. 85	13	May 86	12	May 87	10	Mar. 88
Polychaete Larvae	Aug. 84	12	Aug. 85	11	July 86	8	Apr. 87	18	Oct. 88
Gastropod larvae	Jan. 84	13	Feb. 85	13	Mar. 86	12	Mar. 87	11	Feb. 88
Fish eggs	Jan. 85	7	Aug. 85	8	Apr. 86	10	Feb. 87	8	Oct. 88
Fish larvae	Jan. 84	11	Dec. 85	6	June 86	8	Feb. 87	8	Oct. 88
Bivalve larvae	Sep. 84	11	Aug. 85	11	July 86	8	Mar. 87	20	Nov. 88

The peaks in majority of plankters occurred in the postmonsoon period (19 nos. in 1984-85, 11 nos. in 1987-88 and 11 nos. in 1988-89) followed by the premonsoon period of 1985-86 (16 nos) and monsoon period of 1986-87 (11 nos.).

Groupwise lucifer, ctenophores, gastropod larvae and cirripede larvae formed their peaks during premonsoon period more frequently, while the peak period of abundance or polychaetes,

TABLE 11. *Peak period of occurrence of different groups of plankters in relation to season at Vizhinjam during 1984-85—1988-89*

Groups/Genus	Seasons in which peaks observed 1984-85	'85-86	'86-87	'87-88	'88-89
Mysids	Pre	Mon	Post	Post	Mon
Cephalochordate larvae	Pre	Nil	Post	Post	Mon
Polychaete	Mon	Post	Mon	Pre	Nil
Polychaete larvae	Mon	Mon	Mon	Pre	Post
Ostracods	Mon	Mon	Nil	Pre	Nil
Amphipods	Mon	Pre	Post	Mon	Pre
Lucifer	Mon	Pre	Pre	Pre	Pre
Stomatopod larvae	Mon	Pre	Mon	Nil	Pre
Chaetognaths	Post	Pre	Mon	Post	Post
Cladocerans	Post	Pre	Pre	Post	Post
Doliolids	Post	Post	Nil	Nil	Nil
Copepods	Post	Pre	Mon	Post	Post
Cumaceans	Post	Pre	Post	Mon	Pre
Decapod larvae	Post	Pre	Pre	Mon	Post
Ctenophores	Post	Pre	Mon	Pre	Nil
Echinoderm larvae	Post	Pre	Mon	Post	Nil
Siphonophores	Post	Mon	Pre	Post	Post
Salps	Post	Pre	pre	Post	Nil
Medusae	Post	Post	Pre	Post	Post
Gastropod	Post	Pre	Pre	Post	Mon
Gastropod larvae	Post	Pre	Pre	Post	Mon
Appendicularians	Post	Pre	Mon	Post	Post
Fish eggs	Post	Mon	Pre	Pre	Post
Fish larvae	Post	Post	Mon	Pre	Post
Bivalve larvae	Post	Mon	Mon	Pre	Post
Cirripede larvae	Post	Pre	Pre	Nil	Mon
Phyllosama larvae	Post	Pre	Mon	Mon	Nil

Pre = Premonsoon, Mon = Monsoon, Post = Postmonsoon, Nil = Not traceable.

polychaete larvae, ostracods, phyllosoma larvae occurred during monsoon period. The peaks of cephalochordate larvae, chaetognaths, cladocerans, doliolids, copepods, echinoderm larvae, medusae, siphonophores, appendicularians and fish larvae were found during the postmonsoon period. The above findings clearly show that the postmonsoon period provides optimum conditions for many of the common plankters to multiply in this area.

In groups like phyllosoma larvae and amphipods the peak period of occurrence was equally distributed among premonsoon and monsoon periods (2 each out of 5 years observed), in 5 groups (cumaceans, decapod larvae, salps, gastropods and fish eggs) the frequency of their peaks was equally distributed among pre and postmonsoon periods (2 each). Bivalve larvae, on the contrary, were abundant (peak) during monsoon and postmonsoon months (2 each). It is thus evident that the peak occurrence of any group can occur at any season of the year and the time lapse (in months) between successive peaks is never constant.

Plankton peaks in relation to salinity : Fig. 14 shows that plankters off Vizhinjam occur at a wide range in salinity (30-35 ppt) and hence distributed althrough the year. But a few other groups cannot tolerate such a wide range and hence occur during certain months of the year when salinity conditions are quite congenial for them to flourish. Peaks of many groups, as seen from Fig. 14 occur between 34.0 to 35.0 ppt range though in a few instances atleast one peak may occur below the above given range. This shows that the peaks of various plankters are concentrated at a higher range of salinity rather than in their lower ranges. In those groups which have narrow ranges, the peaks generally occur at higher levels of salinity. It is evident here that peak distribution of many of the groups of plankters is related to salinity and may take place at any season of the year when the salinity conditions are at the higher range, 34.0 to 35.0 ppt.

Plankton peaks in relation to temperature : Fig. 15 gives the peak occurrence of different groups of plankters in relation to temperature. Unlike in Fig. 14 (dealing with salinity) here no overcrowding of peaks in relation to higher or lower ranges is seen. The peak occurrence of many of the plankton groups was noted at lower temperature (25°C)

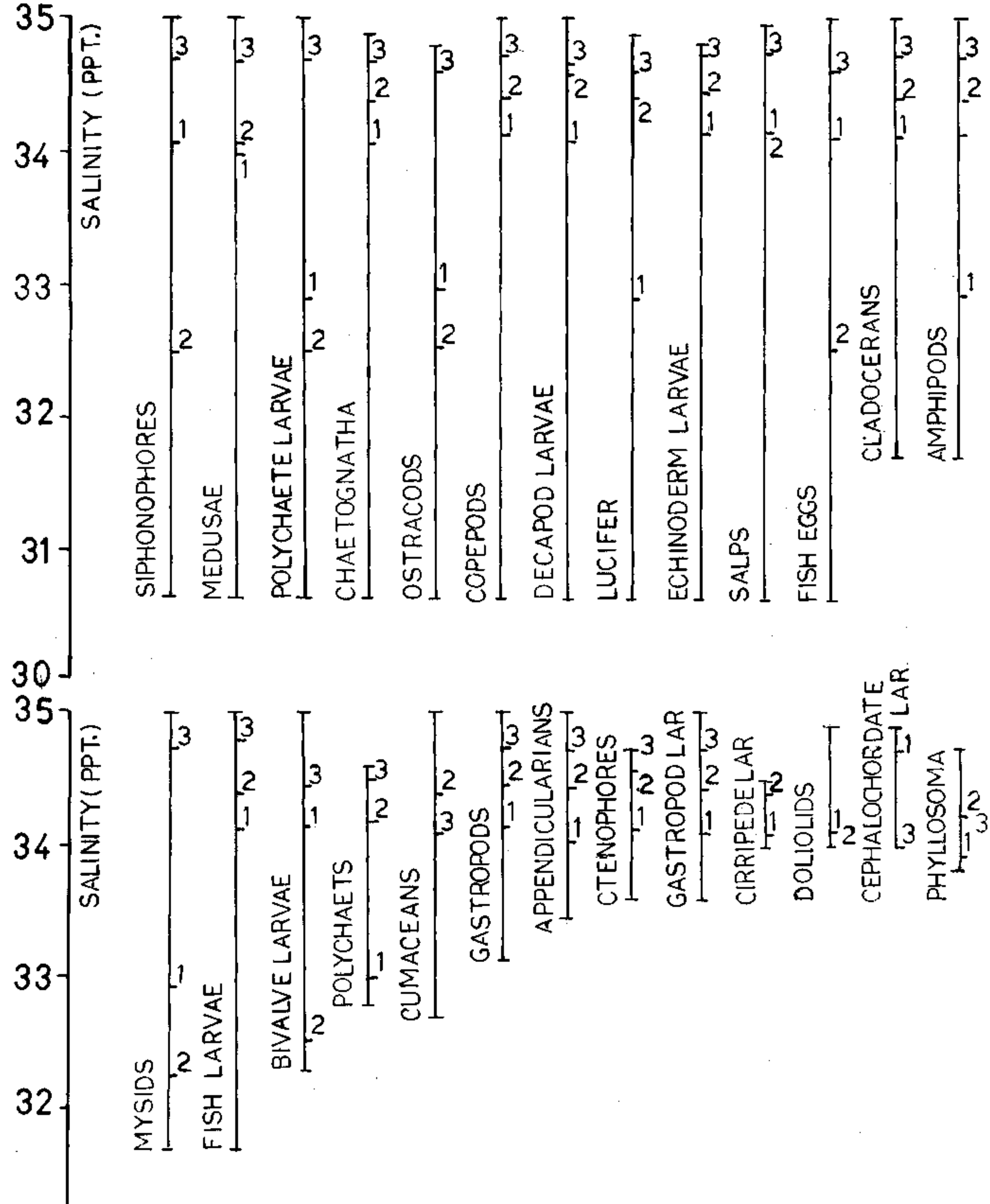

Fig. 14. Peaks in different groups of plankters in relation to salinity at Vizhnjam. Vertical lines denote range and horizontal lines mark the occurrence of peaks in 3 years, *viz.* 1984-85 (marked 1), 1985-86 (marked 2) and 1987-88 (marked 3).

during the first year *i.e.* 1984-85. But in 1985-86 a good number of peaks centered around higher temperature (29.0-30.0°C). In the third year (*i.e.* 1987-88) more peaks were discernible at 28°C. Generally the peak distribution of various planktonic groups are not directly related to temperature and can occur at any season.

Fish landing in relation to season

Some important groups of pelagic and a few demersal fishes that form sizable fraction of the total annual landings have been analysed in detail for a period of one year (1984-85) for pelagic groups, while the data for a period of 9 years (1979-87) have been utilised for demersal groups. Out of 19 pelagic groups considered, the peak landing of 17 groups could be noticed during the year 1984-85. While tracing out the peak landing of these 17 groups in relation to season, it was observed that during the premonsoon, monsoon and postmonsoon periods the number of peaks (primary) observed were 5, 8 and 4 respectively. In the case of secondary peaks in respect of the above groups, only 12 could be traced out. Secondary peaks, in any of the groups/species, did not occur during the monsoon period, but their occurrence during pre and postmonsoon periods were numerically found to be 4 and 8 respectively.

The important species constituting the groups showing premonsoon peaks (primary) were Lesser sardines, mackerel, *Euthynnus affinis, Auxis thazard* and *Sardinella longiceps*. A secondary peak for this group was also discernible in the postmonsoon period. The groups/species recorded during the monsoon period were *Stolephorus* spp., mullet, *Selar mate, Dussumieria* sp., carangids, leiognathids and *Alenetta* sp. Of these groups, a secondary peak was seen in the postmonsoon period only in the case of *Selar mate*, carangids and leiognathids, while in the case of mullet and *Dussumieria* sp. the secondary peaks was in the postmonsoon period. Groups/species like *Decapterus* sp., *Chirocentrus* sp., *Auxis rochei* and *Caranx crumenophthalmus* exhibited their peaks during the postmonsoon period and in all these cases their secondary peaks were in the premonsoon period. Perches, which form a sizeable fraction of the demersal landing at Vizhinjam, have been studied for a period of 9 years (Thomas *et al.*, 1989). Details such as seasonal abundance, landings by both mechanised and nonmechanised sectors have worked out for 8 families of perches (and perch-like fishes). When perches are considered a single group, the peak landings could be noticed during the monsoon period (Aug.), but when families are considered individually Nemipterids, Siganids, Ambassids showed peak landings during the monsoon period; Theraponids, during the premonsoon period and Lethrinids, Priacanthids, Lutjanids and Serranids in the post-monsoon period.

Lakshadweep

Temperature : Lower temperature was recorded in the postmonsoon season and maximum in the pre-monsoon period (Fig. 8 A & C). The trend in the variation was almost similar at both stations. Mean temperature varied from 27.3°C in November to 31.3°C in April. In general, high temperature prevailed during March-May.

Salinity : Monthly variations in salinity are presented in Fig. 8 C & D. The values showed fluctuations from 32.26‰ in June to 34.93‰ in March. In general, lower salinity was observed at Station 1. The low value obtained during June in the shallow water (Station 1) might be due to the land run off as a result of monsoon.

Dissolved oxygen : Monthly averages are presented in Fig. 8 E & F. The values ranged from 3.98 ml/l in March to 4.66 ml/l in June. The fluctuation was not much at both stations. The values were generally higher in the surface waters during monsoon months.

Zooplankton : The plankton biomass was comparatively high during January and March 1987; while in 1986 and 1988, the biomass was less in these months. The pooled data for 1985-88 showed that the biomass varied from 0.9 ml/haul in October to 12.9 ml/haul in January.

Discussion

Since the period of investigation and the methods in biological sampling differed at each centre of study, the results emerged at each centre are discussed separately in relation to the monsoon.

The annual average rainfall recorded for the Cochin sector during 1986-88 (2600 mm) falls far below the normal annual rainfall (3230 mm) of this region. Silas and Pillai (1975) stated that the southwest monsoon season along the southwest coast records more than 75% of the annual rainfall;

whereas in the present investigation, the percentages of monsoon rainfall were 51.9, 61.8 and 57.5% only and the values being 1295, 1490 and 1665 mm during 1986, 1987 and 1988 respectively indicating the low intensity of monsoon and its fluctuation from year to year.

650 mm from May to June was found to increase the productivity from 0.597 to 0.975 g C/m^3/day. The results also indicated that the sudden increase in rainfall in August 1987 (603 mm) after an intermittent break in July (237 mm) was coinciding with an increase in primary productivity from 0.860

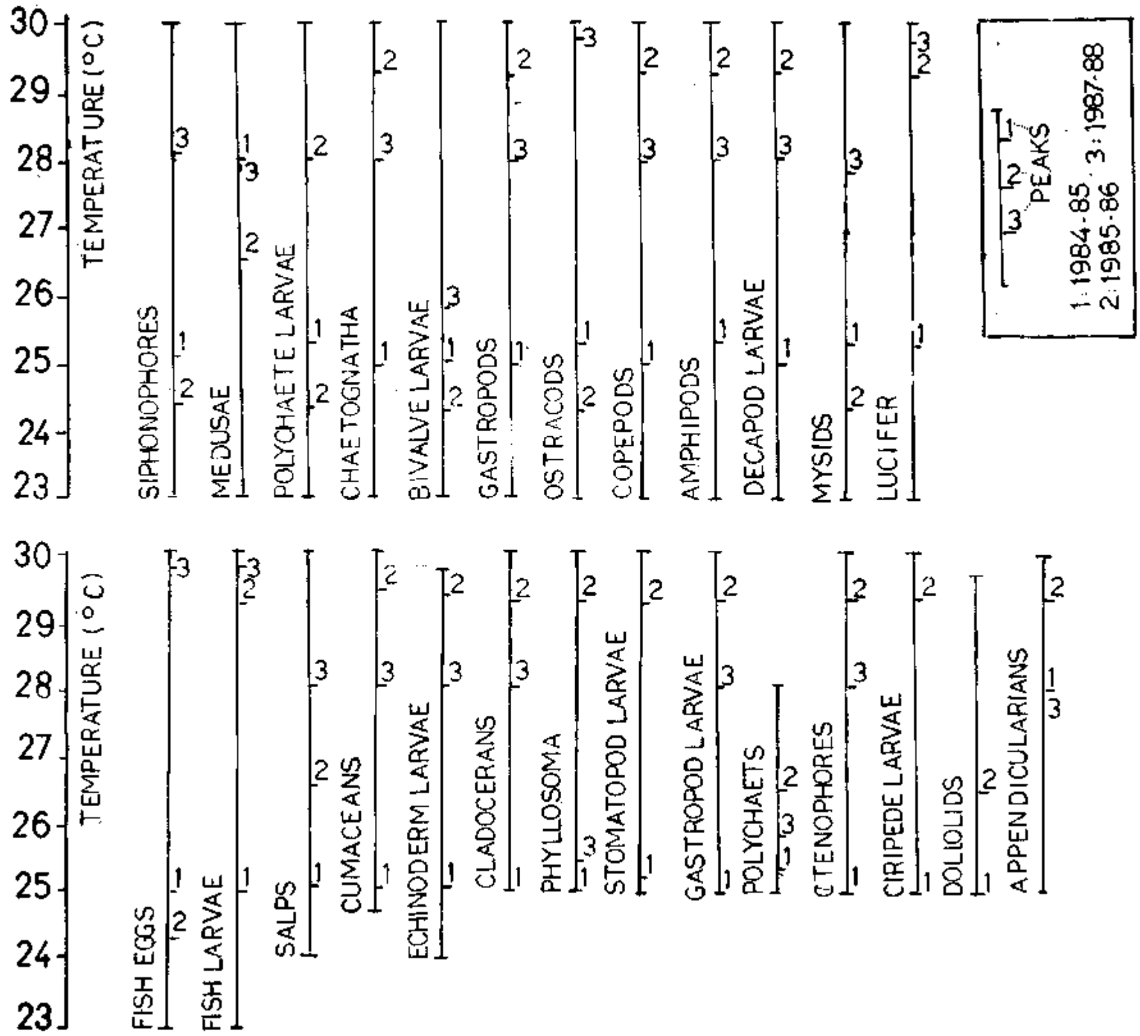

Fig. 15. Peaks in different groups of plankters in relation to temperature at Vizhinjam. Range and peaks marked as in Fig. 14.

The monthly and seasonal fluctuations observed in the rainfall data seem to show some relationship with the phytoplankton productivity in the inshore waters off Cochin. During 1986, the increase in rainfall recorded during April, May and June as 54, 291 and 610 mm respectively coincided with a progressive increase in gross primary productivity as 0.830, 1.042 and 1.624 g C/m^3/day in the surface waters upto 1 m depth. Similarly in 1987, an increase in monsoon rainfall from 109 to

in July to 1.150 g C/m^3/day in August (Fig. 1). The observations seem to favour that the rainfall has significant influence on primary productivity especially at the onset of monsoon and after an intermittent break during the monsoon season.

During 1987, the mean chlorophyll *a* concentration in surface waters showed a decreasing trend during premonsoon, monsoon and postmonsoon seasons while the mean gross and net production rates indicated increasing trend respectively (Fig. 2). This might be attributed to the physiological state and productive potential of the phytoplankton elements present in the samples in the respective seasons. However, the mean chlorophyll *a* values were not less than 1.5 mg/m^3 whenever the mean gross primary productivity was lower than 0.450 g C/m^3/day in any of these seasons during 1986-88 indicating the general productivity of this region. But, the overall seasonal averages of chlorophyll *a* concentration and gross primary productivity for 1986 in the surface and column waters showed higher values during the monsoon season.

The results also revealed that the mean productivity at the 10 m depth region was about 50% of that at the 20 m depth region. The above findings indicate that the freshwater influx into the inshore waters beyond a certain level is not favourable for the phytoplankton productivity.

The relatively higher rate of gross primary production during monsoon season, the decreasing trend in productivity with increasing intensity of rainfall within the monsoon season of 1986-88 and the highest production rate recorded at the 20 m depth region than at the relatively low saline (10 m) and the high saline (30 m) depth regions confirm that optimum conditions are necessary for high production of phytoplankton. Gopinathan (1972) has stated that salinity, temperature and nutrients are the main factors controlling the abundance of phytoplankton in the inshore waters off Cochin where much dilution occurs, but concluded that temperature as such seems to have no direct influence on primary productivity. The influence of salinity on the phytoplankton abundance has been dealt by Qasim *et al.* (1972). In the present investigation, dissolved phosphates and nitrates were available sufficiently in the inshore waters during monsoon season when the primary production values were maximum. The higher values of phosphates and nitrates in surface waters during monsoon and low values recorded during premonsoon and postmonsoon seasons seem to have direct relationship with gross primary productivity. According to Subrahmanyan (1960, 1967), optimum condition such as a fall in water temperature from 30-31°C to 23-25°C and a fall in salinity of water from 35‰ or more to 30- 31‰ due to monsoon and abundance of nutrients (phosphate, nitrate and silicate) due to upwelling and river discharges are the important factors for high production of phytoplankton. The results revealed that the mean productivity values for the premonsoon, monsoon and postmonsoon were well above the average estimate given by Nair *et al.* (1973) for the inshore waters along the west coast of India. Such higher values recorded in all the seasons along the inshore waters off Cochin might be attributed to the influence of the Cochin Backwater system.

In the present investigation, the highest concentration of nitrates in surface and bottom waters at 30 m depth station, the decreasing trend in surface values from 30 m to 20 m and bottom values from 30 m to 10 m depth stations during the monsoon season, the lower concentration of the same in surface and bottom during premonsoon season at these stations and the increase in primary productivity at 20 m depth station than at the nearshore 10 m depth station clearly indicate that the dissolved nitrates brought by the upwelling process towards the coast by the influence of southwest monsoon have great role in primary productivity than those brought by the freshwater discharge through land drainage. Further, the day-to-day changes in the tidal bulge and the southerly drift of surface waters by the ocean current system during southwest monsoon and its course in the northerly direction during the other seasons along the southwest coast and the resultant mixing processes have significant role in the day-to-day and seasonal fluctuations in the environmental features and primary productivity.

The estimation of gross and net primary production revealed considerable percentage of loss in the primary level itself by the respiratory metabolism. The percentage of loss in gross production was 62% during monsoon season while it was about 49% and 42% during premonsoon and postmonsoon period respectively. The high percentage of loss during monsoon season might be attributed to the physiological state and stress caused by the unstable nature of the environment.

The annual net primary production in the euphotic waters off Cochin has been estimated as 731.43 t Carbon/Km^2 which amounts to 2.004 t Carbon/Km^2/day or 2.004 g C/m^2/day. Nair *et al.* (1973) have reported values over 2.0 g C/m^2/day during monsoon and postmonsoon months along the southwest coast within 50 m depth and estimated an annual net production of 260 tonnes Carbon/Km^2. According to Qasim (1977), the average column production for the entire Arabian Sea is 0.468 g $C/m^2/day$. The above results indicate that the inshore waters off Cochin are highly productive.

Of the annual net production estimated, seasonwise analysis revealed that the premonsoon (120 days), monsoon (92 days) and postmonsoon seasons (153 days) contributed 207.0, 186.3 and 338.13 tonnes Carbon/Km^2 respectively indicating that the postmonsoon season provides the optimum environmental condition to obtain the highest net primary productivity along the inshore waters off Cochin. From the present investigation, the limiting factor for primary production appears to be the physiological state of the phytoplankton elements in relation to the fluctuations in the environmental factors. Apart from this, the grazing of phytoplankton by zooplankters and tertiary feeders also might play a vital role in the fluctuation of phytoplankton production and distribution.

As noticed by earlier workers on the waters off the southwest coast of India (Subrahmanyan, 1969; Qasim, 1973; Mathew and Nair, 1980) the maximum primary productivity in the Vizhinjam inshore waters takes place during the southwest monsoon months. Later, another peak of production takes place at any time during the premonsoon or postmonsoon periods, but this often is of a lesser magnitude compared with the peak in the monsoon period.

The concentration of phosphates at Vizhinjam is higher than that at the other centres like Calicut (Subrahmanyan, 1959), North Kanara Coast (Ramamurthy, 1963; Noble, 1968; Annigeri, 1977) and Ashtamudi estuary (Mathew and Nair, 1980). However, nitrite, nitrate and silicate contents are lower than those in these centres.

Subrahmanyan (1958) and Subrahmanyan *et al.* (1975) have shown that along the west coast of India, a fall in the surface temperature and salinity associated with enrichment of water during the monsoon period are some of the conditions responsible for the growth of phytoplankters. A similar pattern is observed in Vizhinjam waters accounting for a fairly high productivity during the monsoon period. However, in the other seasons although high rate of production is noticed during certain months there is no lowering of salinity, but a sharp decline in temperature was noticed especially in the postmonsoon period of the year 1984-85. Further in the earlier account (Jacob and Vasantha Kumar, 1987), although positive correlation between phosphate and primary productivity and significant negative correlation between nitrite and net productivity were evident, no such significant relationship was revealed between primary productivity and either temperature or salinity. The present study also shows that the peaks of productivity and nutrients do not occur simultaneously with the peak of rainfall and thus it is reasonable to think that these peaks are not caused by the rainfall though it seems to affect them.

At Cochin, most of the constituent groups of zooplankton were abundant either in July or August. Therefore, the biomass invariably recorded a primary peak in the monsoon season. A secondary peak of biomass could be discerned in September (postmonsoon season) in '84 and '86. The increase in the biomass observed in March '87 was caused by the swarm of *Salpa democratica* (16,000/100 m^3) and the absence of any such increase during the rest of the period make the changes in the biomass during the premonsoon season unpredictable. Close relationship between the peak abundance of zooplankton biomass during July-September and upwelling has been established by Menon and George (1977) and Murty (1987). Mathew *et al.* (1984) also observed high values of zooplankton biomass in the mudbank region of Alleppey during July-August.

While the primary peaks of the biomass recorded during July both in '85 and '86 and August '88 coincided with the copepod maximum for the respective years, those of July '84 and August '87 occurred when the abundance of copepods was extremely low. It may be noted that the abundance of larval polychaetes, doliolids, small-sized ctenophores, appendicularians, larvae of cirripedes, cladocera and fish larvae along with the blooms of *Fragilaria oceanica* contributed to the increased biomass observed in July '84, while the swarming of ostracods, especially the *Pyrocypris* sp. alongwith a large number of siphonophores, polychaetes, chaetognaths, fish eggs and larvae, cladocera and the blooms of *Fragilaria oceanica* caused the increase in the biomass in August '87.

While the secondary peak of biomass in September '84 contained nearly 7 times more number of copepods than the primary peak of that year, the secondary peak in '86 was poor in copepods, but rich in siphonophores, chaetognaths and ostracods. Besides, when a significant increase in biomass occurred in March '87 due to the swarming of *salps*, the abundance of copepods was low.

Eventhough the number exceeded one hundred thousand copepods in April and June in '88, the biomass remained as low as 17 ml and 18 ml respectively. Similarly in October 87 when the abundance of copepods was an impressive 55,000 the biomass was a meagre 11 ml. It is interesting to note that the declining trend exhibited by the biomass between September '84 and January '85 and from September '86 to February '87 was so strikingly similar to those of the copepods recorded during the corresponding periods, that every decrease of the latter from one month to the next resulted in an almost proportional fall in the former during the same months.

Swarms of cladocera occurred thrice during July-August in the southwest monsoon seasons between '84 and '88. While *Penilia avirostris* was dominant during July—August and November, *Evadne tergestina* was more abundant during March-June and October. However, in August '88 the abundance of *Evadne tergestina* was more than that of *Penilia avirostris*. Cladocera are of great importance to pelagic fisheries and are believed to play an important role in the phosphate regeneration of the sea (Barlow and Bishop, 1965).

It is seen that the lucifers increased in abundance in the monsoon seasons of the four out of five years. But for a prolonged period between February '86 and May '87 lucifers showed no increase at all even during the most productive monsoon period.

The regularity in the occurrence of appendicularian abundance in July observed for three consecutive years from '84 to '86 disappeared during '87-'88. Besides, the abundance observed in January '88 was numerically superior to that recorded in August '88. The low abundance observed in July '87 and their occurrence in greater intensity in the postmonsoon season in January '88 instead of June-August of that year indicate that the monsoon induced changes in the environment are solely responsible for promoting proliferation of appendicularians during the season.

During 1985, 1987 and 1988, though the abundance of siphonophores occurred in August there was a wide disparity in the maximum in different years. It may be seen that the maximum abundance of '88 was nearly six times greater than the maximum of '85 both occurring in the same monsoon season. During 1984 and 1986 the abundance of siphonophores was extremely poor in the monsoon season, but the same was impressively high in the postmonsoon season during September-October.

It is significant that the abundance of chaetognaths recorded a peak in the postmonsoon season in the first year and in the monsoon season in the next, alternating in that order from '84 to '87, but was relatively less in January '88 and June '88. All these show that chaetognaths are equally prolific both in the monsoon and the postmonsoon season.

The occurrence of the larvae of penaeids and *Acetes* in large numbers during October-December and April-June is in agreement with the findings of Kuttyamma and Kurian (1982).

Except in '84, the number of larval decapods observed in the monsoon months, was more particularly in June both in '87 and '88, than those recorded in the pre and postmonsoon seasons. It is likely that the conditions prevailing as early as June in the monsoon are favourable for the larval decapods to thrive abundantly.

The occurrence of larval polychaetes in large numbers in July/August in all the five years (except the increase in September '84), shows that the polychaetes greatly prefer the monsoon season for their multiplication in the nearshore region off Cochin. It may be seen that the maximum of the monthly mean abundance of the larval polychaetes recorded during the different years showed an increase from '84 to '85, but declined during the rest of the period of this study recording a mere 4,686 in July '88.

Excepting during August '88 when it was 320, the number of fish larvae occurring in the monsoon season was normally less than those observed in the postmonsoon months. It appears to indicate that the hatching rate of the eggs is more in the postmonsoon months than during monsoon.

The occurrence of fish eggs in large numbers during monsoon probably indicates that the amount of eggs being added to the medium is more and that merely enriches the plankton during the season since there is no significant increase in the number of fish larvae observed in the same season. David Raj and Ramamirtham (1981) reported increasing trends in fish eggs and larvae during the premonsoon months, but occasionally during the monsoon months.

The secondary production estimates off Cochin showed an increase in the postmonsoon of '84 over the monsoon of the same year. However this was not due to an actual increase in the rate of production, but one caused by the number of months included in the different seasons. On the other hand, the increase in the secondary production of the premonsoon in '87 over that of the postmonsoon of the same year shows a greater rate of production during the former season than in the latter season. However, the estimates for the premonsoon of '86 to '88 show that the season is not as productive as the postmonsoon whereas, the secondary production estimates for the monsoon period show high production in the season. Therefore, it is concluded that the secondary production in the monsoon is the maximum followed by the postmonsoon and the premonsoon.

The production during the monsoon season of '86 was the highest at 12,330 t of carbon/92 days. The mean production for the monsoon season of the five year period worked out at 4.52 t of carbon/km^2. The monthly mean for the monsoon season amounted to 1,774 t of carbon. However, the mean production for the entire area worked out to be 7,815.85 t of carbon/year or 6.652 t of carbon/km^2/year. Qasim *et al.* (1978) studied the biological productivity of the coastal waters upto 50 m depth in an area of 43 x 10 km extending from Dabhol to Tuticorin for a very brief period of one month during March 1977. They reported that the rate of secondary production was 60 t of carbon/km^2/year.

At Vizhinjam salinity showed considerable variations from year to year; in some years high salinity was characteristic of premonsoon period, while of postmonsoon period in other years. However, pooled annual as well as seasonwise data indicate that high salinity is characteristic of premonsoon period.

Displacement volume of plankton indicates that it is always at the highest during the postmonsoon and lowest during the premonsoon periods. Peaks of planktonic groups noted were more during the postmonsoon period as compared to the premonsoon period.

Temperature, like salinity, showed a sharp decline by the onset of southwest monsoon and increased as the season advanced. But during the postmonsoon period the temperature seldom reached a level as noted during the premonsoon months. Different zooplankters occurring off Vizhinjam, as seen from their distribution in relation to various months of any given year, are capable of tolerating wide fluctuations in temperature and salinity; but there are some groups which cannot tolerate such wide range and they prefer a particular period of the year which is congenial for them to flourish. Peaks of several groups coincide with periods of higher salinities while those with peaks exclusively in lower salinities are very rare. It is not well understood that peak of any given group that occurs in different salinity has the same species composition or not. Further studies on the qualitative composition of peaks with regard to varying salinities are needed.

In the case of temperature, such a preference to higher levels by plankters for their peak distribution is never noticed. On the contrary, the peaks can occur at any period within their overall range. This clearly shows that salinity is the major factor that governs the peak occurrence of planktonic organisms. This may, hence, be cited as the major reason for the occurrence of peaks in different seasons in different years when the salinity conditions are at a higher level.

Maximum values of dissolved oxygen content were noted during premonsoon months and the lowering trend during monsoon was rather negligible. The figures for pre and postmonsoon months were equal in some years.

Phosphate and nitrate contents showed peaks during postmonsoon months while nitrite, during the monsoon period. Blooms outnumbered swarms during the monsoon period, but the condition was just the reverse in the postmonsoon period.

While assessing the pelagic fish landings seasonwise it could be seen that the monsoon period accounted for the maximum landings followed by the postmonsoon period. The bulk in landing effected during monsoon period may be attributed to the peak landing in 8 groups/species while landings of the postmonsoon period may be said to be the cumulative effect to peak (primary) landings in 4 groups and the secondary peaks in another 8 groups/species.

In the Lakshadweep, during the present investigation, the zooplankton biomass was at its maximum during January-March (premonsoon period) and it was low in all the other months. The fluctuation in the biomass from 0.9-12.9 ml/haul in the lagoon (present investigation) and that in the adjacent open sea from 2.0-16.0 ml/haul (Mathew and Gopakumar, 1986) indicates that the zooplankton biomass is relatively less in the lagoon than in the adjacent open sea. During the studies conducted by Tranter and George (1972) at Kavaratti and Kalpeni Atolls also, it was observed that the biomass depleted enroute from the open sea to the lagoon and they concluded that the coral reef community nourished the incoming plankton. Madhupratap *et al.* (1977) observed that higher diversity in the zooplankton biomass occurred in the waters surrounding the atolls than in the lagoons. The abundance in the zooplankton biomass during January-March in the lagoon indicates that the environmental features prevailing in these months would provide the ideal environment for high zooplankton production.

ACKNOWLEDGEMENTS

The authors are thankful to Dr. P. S. B. R. James, Director, CMFRI Cochin for suggesting the problem, providing the facilities, the valuable suggestions and for the encouragement. They are also thankful to Dr. K. Radhakrishna and Dr. A. V. S. Murty for their critical comments and valuable suggestions.

REFERENCES

ANNIGERI, G. G. 1979. Observations on the hydrographical features of the coastal waters of North Kanara during 1965-1966. *J. mar. biol. Ass. India*, 21 (1 & 2) : 128-132.

ANON. 1976. Progress Report. UNDP/FAO, Pelagic Fishery Project, 17 : 22 pp.

BARLOW, P. J. AND W. J. BISHOP 1965. Phosphate regeneration by zooplankton in Cayuga Lake. *Limnol. Oceanogr.*, 10 : 15-24.

CUSHING, D. H. 1973. Production in the Indian Ocean and the transfer from the primary to the secondary level. In: B. Zeitzschel (Ed.) *The Biology of the Indian Ocean. Ecological Studies*. 3, Springer-Verlag, Berlin, pp. 475-486.

DAVID RAJ, I. AND C. P. RAMAMIRTHAM 1981. Distribution of zooplankton biomass, fish eggs and larvae along the west coast of India. *J. mar. biol. Ass. India*, 23 (1 & 2) : 86-140.

DEVIDAS MENON, M. AND K. C. GEORGE 1977. On the abundance of zooplankton along the southwest coast of India during the years 1971-75. *Proc. Symp. Warm Water Zooplankton*, NIO/UNESCO, pp. 205-213.

GOPINATHAN, C. P. 1972. Seasonal abundance of phytoplankton in the Cochin Backwater. *J. mar. biol. Ass. India*, 14 (2) : 568-577.

JACOB, RANI MARY AND R. VASANTHA KUMAR 1987. Primary productivity in the nearshore waters of Vizhinjam, Trivandrum. *Ibid.*, 26 (1 7 2) : 66-70.

KUTTYAMMA, V. J. AND C. V. KURIAN 1982. Distribution of postlarvae of marine prawns in the southwest coast of India. *Indian J. mar. Sci.*, 11 (3) : 270-272.

LORENZEN, C. J. 1967. Determination of chlorophyll and phaeopigments: Spectrophotometric Equations. *Limnol. Oceanogr.*, 12 : 343-346.

MADHUPARTAP, M., M. V. M. WAFAR, P. HARIDAS, B. NARAYANAN, P. GOPALA MENON AND P. SIVADAS 1977. Comparative studies in the abundance of Zooplankton in the surrounding sea and lagoons in Lakshadweep. *Indian J. Mar. Sci.*, 6 : 138-141.

MATHEW, C. V. AND G. GOPAKUMAR 1986. Observations on certain environmental parameters in relation to surface tuna fishery at Minicoy Island, Lakshadweep. *J. mar. biol. Ass. India*, 28 (1&2) : 163-168.

MATHEW, K. J. , C. P. GOPINATHAN, D. S. RAO AND A. V. S. MURTY 1984. Ecology of mud banks - Zooplankton. *Bull. Cent. Mar. Fish. Res. Inst.*, 31 : 35-39.

——, T. S. NAOMI, GEETHA ANTONY, D. VINCENT, R. ANILKUMAR AND K. SOLOMON 1989. Studies on zooplankton biomass and secondary and tertiary production of the EEZ of India. *Proc. First workshop Scient. Results FORV Sagar Sampada*, DOD/ICAR, pp. 59-69.

MATHEW, THRESIAMMA AND N. BALAKRISHNAN NAIR 1980. Phytoplankton of the Ashtamudi Estuary, Kerala. *Indian J. Mar. Sci.*, 9 : 253-257.

MURTY, A. V. S. 1987. Characteristics of neritic waters along the west coast of India with respect to upwelling, dissolved oxygen and zooplankton biomass. *Indian J. mar. Sci.*, 16 (2) : 129-131.

NAIR, P. V. R. 1970. Primary productivity in the Indian Seas. *Bull. Cent. Mar. Fish. Res. Inst.*, 22 : 1-58.

NAIR, P. V. R., SYDNEY SAMUEL, K. J. JOSEPH AND V. K. BALACHANDRAN 1968. Primary production and potential fishery resources in the seas around India. *Proc. Symp. Living Resources of the seas around India, CMFRI Special Publication*, pp. 184-198.

NOBLE, A. 1968. Studies on seawater off the North Kanara Coast. *J. mar. biol. Ass. India*, **10** (2) : 197-223.

QASIM, S. Z. 1973. Productivity of backwaters and estuaries. *In* : B. Zeitzschel (Ed.) *The Biology of the Indian Ocean. Ecological Studies* 3. Springer-Verlag, Berlin, pp. 143-154.

——, 1977. Biological productivity of the Indian Ocean. *Indian J. mar. Sci.*, **6** : 122-137.

—— AND C. V. G. REDDY 1967. The estimation of plant pigments of Cochin Backwater during the monsoon months. *Bull. Mar. Sci.*, **17** (1) : 95-110.

——, P. M. A. BHATTATHIRI AND V. P. DEVASSY 1972. The influence of salinity on the rate of photosynthesis and abundance of some tropical phytoplankton. *Mar. Biol.*, **12** : 200-206.

——, M. V. M. WAFAR, SUMITRA VIJAYARAGHAVAN, JOSEPH P. ROYAN AND L. KRISHNAKUMARI 1978. Biological productivity of coastal waters of India from Dabhol to Tuticorin. *Indian J. mar. Sci.*, **7** : 84.

RADHAKRISHNA, K. 1969. Primary productivity studies in the shelf waters off Alleppey, southwest coast of India, during the postmonsoon, 1967. *Mar. Biol.*, **4** : 174-181.

RAMAMURTHY, S. 1963. Studies on hydrological factors in North Kanara Coastal Waters. *Indian J. Fish.*, **10 A** (1) : 75-93.

RANI MARY JACOB, K. RAMACHANDRAN NAIR AND R. VASANTHA KUMAR 1981. Zooplankton in relation to hydrography and pelagic fisheries in the inshore waters of Vizhinjam, Trivandrum. *J. mar. biol. Ass. India*, **23** (1 & 2) : 62-76.

—— AND R. VASANTHA KUMAR 1987. Primary productivity in the nearshore water of Vizhinjam, Trivandrum. *Ibid.*, **26** (1 & 2) : 66-70.

SILAS, E. G. 1972. Investigations on the Deep Scattering Layers in the Laccadive Sea. *Proc. First Symp. Corals and Coral Reefs*, MBAI, pp. 257-274.

—— AND P. P. PILLAI 1975. Dynamics of zooplankton in a tropical estuary (Cochin Backwater) with a review on the plankton fauna of the environment. *Bull. Dept. Mar. Sci. Univ. Cochin*, **7** : 329-355.

STEEMANN NIELSEN, E. AND E. A. JENSEN 1957. Primary organic production - the autotrophic production of organic matter in the oceans. *Galathea Rep.*, **1** : 49-136.

STRICKLAND, J. D. H. AND T. R. PARSONS 1968. A practical hand book of seawater Analysis. *Bull. Fish. Res. Bd. Canada*, **167** : 1- 311.

SUBRAHMANYAN, R. 1954. A new member of the Englemineae, *Protoeuglena noctilucae* gen. et sp. nov., occurring in *Noctiluca miliaris* Suriray, causing green discolouration of the sea and mortality among marine organisms off the Malabar Coast. *Indian J. Fish*, **1** : 182-203.

—— 1958. Ecological studies on the marine phytoplankton on the west coast of India. *Mem. Indian bot. soc.*, **1** : 145-151.

—— 1959. Studies on the phytoplankton of the west coast of India. *Proc. Indian Acad. Sci.*, **50 B** (4) : 113-252.

—— 1960. Observations on the effect of the monsoons in the production of phytoplankton. *J. Indian bot. soc.*, **39** (1) : 78-89.

—— 1967. Phytoplankton. *Souvenir, 20th Anniversary*. CMFRI, pp. 89-93.

—— 1969. Fisheries oceanography in India. *Indian Farming*, **19** (9) : 47-52.

——, C. P. GOPINATHAN AND C. THANKAPPAN PILLAI 1975. Phytoplankton of the Indian Ocean - some ecological problems. *J. mar. biol. Ass. India*, **17** (3) : 608-612.

THOMAS, P. A., S. LAZARUS, S. G. VINCENT, MADAN MOHAN AND T. A. OMANA 1989. Perch fishery at Vizhinjam for the period 1979 to 1987 (MS).

TRANTER, D. J. AND JACOB GEORGE 1972. Zooplankton abundance of Kavaratti and Kalpeni Atolls in the Laccadive Sea. *Proc. Symp. Corals and Coral reefs, MBAI*, pp. 239-256.