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Surface productivity and related hydrography off Visakhapatnam during premonsoon and winter months of 1987-1989

K Vijayakumaran, B Narayana Rao & K Radhakrishna*
Research Centre of Central Marine Fisheries Research Institute, Visakhapatnam 530 003, Andhra Pradesh, India

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Time-scale studies on surface productivity and related hydrography from two fixed stations off Visakhapatnam were carried out during premonsoon and winter months of 1987-1989. The interrelations between certain hydrochemical parameters, primary production and plant pigments were investigated. Upwelling was found to occur near the coast during March-May period. Replenishment of phsophate during upwelling was indicated. An exceptionally high value of phaeopigments (10.16 mg/m^3) was recorded. Significant positive correlation between pigments and productivity and negative correlation between pigments and secchi disc depth were observed.

Measurements of primary production employing the ^{14}C technique in Bay of Bengal were made during the Galathea Expedition[1]. Similar studies were carried out during the International Indian Ocean Expedition (IIOE) from many parts of the Bay of Bengal[2-5]. Qasim[6,7] reviewed the work on primary production and phytoplankton pigments of Indian Ocean based mostly on the data collected during IIOE. Further studies[8-12] by different workers have been confined to a few months, e.g. March-April, July, August and September periods. But time-scale studies from fixed stations have not been taken up so far.

Studies on the hydrography of coastal waters off Visakhapatnam were initiated during 1952-1958 and physical, chemical and biological aspects were reported[13-18]. Short-term studies[19-21] on the distribution of oxygen and other hydrological features in Bay of Bengal made subsequently were confined mostly to offshore waters. Sarma *et al.*[22] investigated the seasonal variation in certain hydrochemical parameters and their interrelationships. In the present paper an integrated study of certain hydrochemical parameters and productivity parameters and their interrelationship is attempted. The study was carried out from January 1987 to January 1989 in the near-shore surface waters at fixed stations. Due to non-availability of a vessel, data could not be collected for June-November period of both the years.

* Present address: Indian Council of Agricultural Research, Krishi Bhavan, New Delhi-110 001, India

Materials and Methods

Weekly surface samples were collected from two stations (Fig. 1), one at 55 m depth (st. 1) and the other at 35 m depth (st. 2). Surface temperature was measured using a bucket thermometer. Standard procedures were adopted for estimating dissolved oxygen, salinity (corrected using Knudsen's tables) and inorganic nutrients[23,24]. Primary production was estimated by simulated *in situ* incubation of samples for six hours after ad-

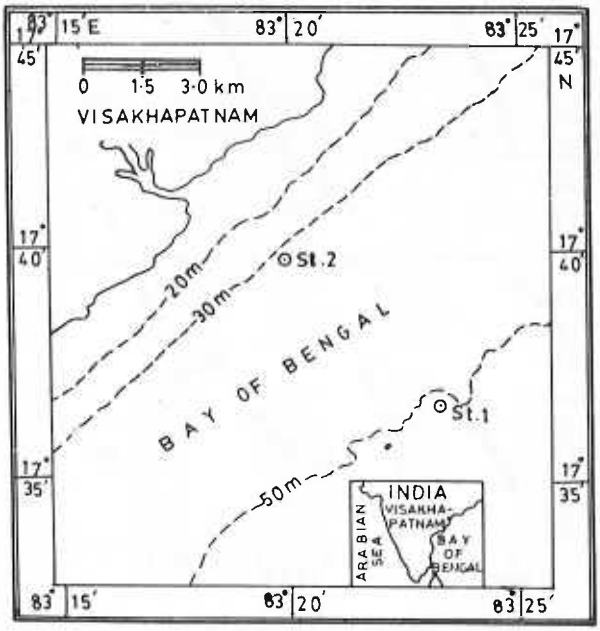

Fig. 1—Location map of the stations

dition of (5 μci)^{14}C. Samples were filtered through Sartorius membrane filters (pore size 0.45 μm) and photosynthetic uptake of radiocarbon was estimated[23,25] by counting the filters on a G-M counter. Samples for plant pigments were filtered using whatman GF/D glass fibre filters and pigments extracted in 90% acetone were estimated by spectrophotometry[24] (ECIL/GS 866 C).

Results

Surface temperature—The surface temperature ranged between 23.8°C (April 1987) and 31°C (May 1988) with an average of 27.34°C. The lowest mean temperatures were recorded during December-January which gradually increased during February-March, dropped during April and peaked in May (Fig. 2c).

Salinity—The monthly mean values of salinity exhibited a more or less similar pattern during both the years. The values varied from 26.35 × 10^{-3} to 35.1 × 10^{-3} with an average of 31.88 × 10^{-3}. The values steadily rose from December to April and dropped slightly in May (Fig. 2b).

Dissolved oxygen—Dissolved oxygen values ranged between 2.94 and 5.74 ml/l with an average of 4.73 ml/l. In general the surface waters were well oxygenated throughout the period of study with maximum during Dcember-January and minimum during April-May (Fig. 2a).

Secchi disc depth—The secchi disc depth showed wide variation from 2.7 m to 23 m with an average of 12.4 m. The average value for st. 2 was 10 m and that for st. 1 was 14.9 m (Fig. 3).

Nutrients—Phosphate concntrations varied between undetectable levels and 5.75 μg-at/l with a mean value of 0.90 μg-at/l. The phosphate concentrations showed spatial and temporal variations. Generally higher values prevailed during April and lower values during January. Silicate contents were low during February and high during May at both the stations. The values ranged between 0.5 μg-at/l and 50 μg-at/l with an average of 12.1 μg-at/l. Nitrite was very low during most of the period and it varied between undetectable levels and 2.07 μg-at/l with an average of 0.32 μg-at/l. The highest mean values were recorded at both the stations in April 1988. Nitrate also showed wide fluctuations ranging from unde-

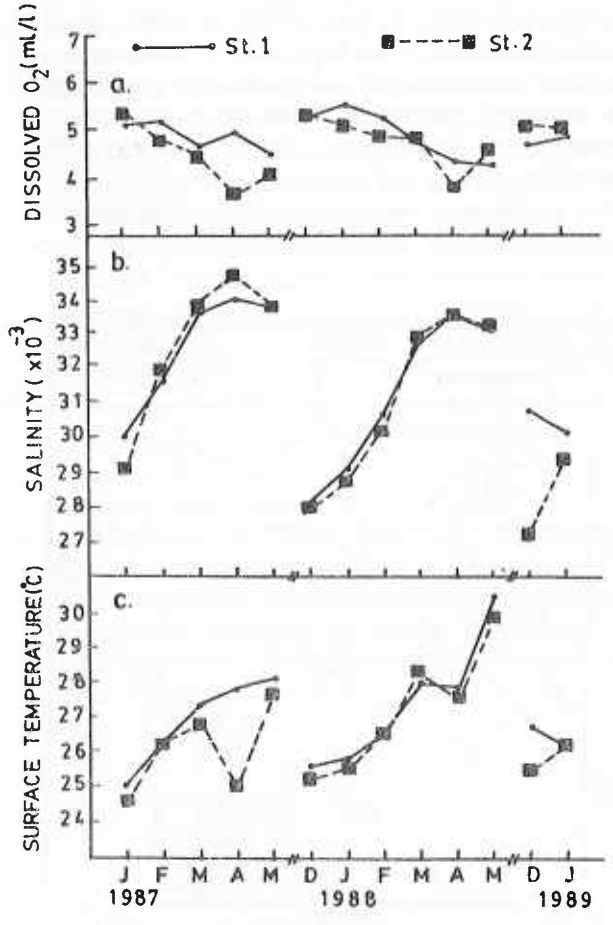

Fig. 2—Dissolved oxygen, salinity and temperature in the surface waters off Visakhapatnam

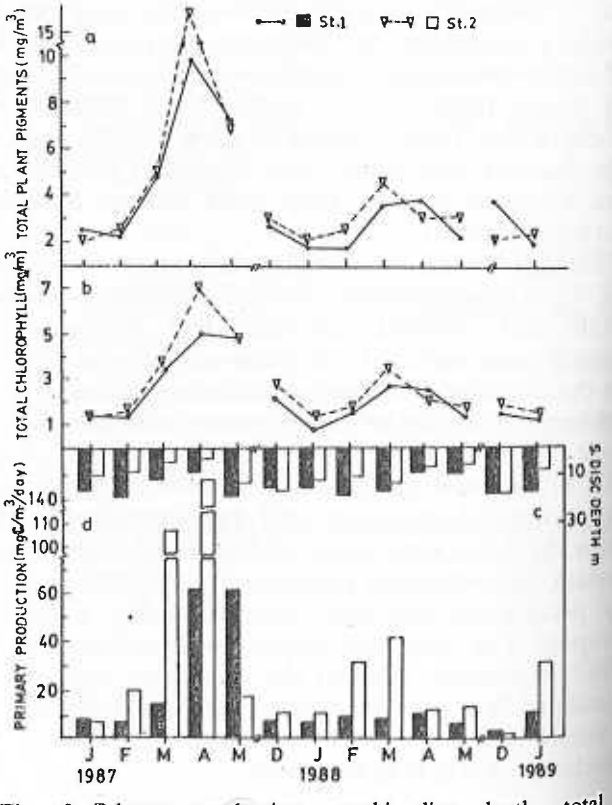

Fig. 3—Primary production, secchi disc depth, total chlorophylls and total pigments in the surface waters off Visakhapatnam

tectable levels to 3.3 µg-at/l with a mean of 0.6 µg-at/l. High mean values were observed generally during March-May period of both the years. However, the highest monthly mean was observed during December 1988 at st. 2 (Table 1).

Primary production—Primary production ranged from 0.72 to 226.5 mgC/m^3/d with an average of 26.96 mgC/m^3/d, the highest value being recorded at st. 2 in April 1987. The near-shore station recorded higher mean value (34.67 mgC/m^3/d) compared to the deeper station (19.04 mgC/m^3/d). In 1987 the monthly averages were higher during March and April at st. 2 and during April and May at st. 1. In 1988, st. 2 recorded higher mean values during February and March and st. 1 during April. Though December and January were the months of poor productivity, moderately high productivity was recorded at both the stations during January 1989 (Fig. 3).

Plant pigments—Chlorophyll-*a* ranged between 0.077 mg/m^3 and 5.149 mg/m^3 with an average of 0.94 mg/m^3. Station 2 recorded slightly higher average value (1.047 mg/m^3) than st. 1 (0.83 mg/m^3). The monthly mean values were high during March, April and May in 1987 and February, March and April in 1988. The peaks at both stations were during April of 1987 and March of 1988 (Table 2). Chlorophyll-*b* ranged from undetectable levels to 2.72 mg/m^3 (average 0.89 mg/m^3). The mean valueds at the two stations did not vary much. The monthly mean showed a trend similar to that of chl-*a*. Chlorophyll-*c* varied between undetectable levels and 3.77 mg/m^3 with an average of 0.88 mg/m^3. The

Table 1—Monthly averages of nutrients in the surface waters off Visakhapatnam

Period	Phosphate (µg-at/l)		Silicate (µg-at/l)		Nitrite (µg-at/l)		Nitrate (µg-at/l)	
	St.1	St. 2	St.1	St. 2	St.1	St. 2	St.1	St. 2
Jan. '87	0.78	0.61	11.7	7.8	0.43	0.07	0.7	0.2
Feb. '87	0.58	1.55	7.3	5.9	0.14	0.14	0.3	0.2
March '87	2.33	0.74	13.6	15.8	0.43	0.79	0.9	0.7
April '87	1.58	2.45	9.9	21.2	0.14	0.71	0.4	1.2
May '87	0.74	1.16	27.2	12.3	0.21	0.93	0.4	1.2
Dec. '87	0.68	0.55	21.5	22.9	0.36	0.07	0.5	0.1
Jan. '88	0.58	0.61	9.9	10.9	0.14	0.07	0.4	0.1
Feb. '88	0.71	0.65	5.3	3.5	0.43	0.21	0.4	0.3
March. '88	0.78	0.52	8.5	6.3	0.29	0.14	0.9	0.4
April. '88	1.55	0.94	6.1	7.1	0.50	1.14	0.9	0.6
May. '88	0.48	0.23	16.7	11.5	0.03	0.0	0.2	0.9
Dec. '88	0.29	0.68	20.3	14.1	0.0	0.21	0.5	2.6
Jan. '89	0.0	0.29	16.0	13.3	0.0	0.0	0.4	1.1

Station 1 = 55 m depth, station 2 = 35 m depth

Table 2—Monthly averages of plant pigments in the surface waters off Visakhapatnam

Period	Chl-*a* (mg/m^3)		Chl-*b* (mg/m^3)		Chl-*c* (mg/m^3)		Carotenoids (m-SPU/m^3)		Phaeopigments (mg/m^3)	
	St. 1	St. 2	St. 1	St. 2	St. 1	St. 2	St. 1	St. 2	St. 1	St. 2
Jan. '87	0.343	0.551	0.415	0.161	0.517	0.585	0.289	0.288	0.876	0.506
Feb. '87	0.486	0.706	0.463	0.490	0.416	0.370	0.327	0.499	0.535	0.408
March '87	0.984	1.440	1.362	1.189	1.073	1.042	0.546	0.730	0.688	0.552
April '87	1.948	2.978	1.647	1.989	1.409	2.124	1.520	2.227	3.279	6.237
May '87	1.687	1.683	1.562	1.618	1.540	1.484	1.330	1.270	0.896	0.683
Dec. '87	0.785	0.970	0.820	1.120	0.670	0.740	0.000	0.005	0.481	0.000
Jan. '88	0.269	0.400	0.380	0.780	0.278	0.251	0.516	0.347	0.430	0.013
Feb. '88	0.521	0.602	0.673	0.653	0.468	0.536	0.029	0.103	0.073	0.662
March '88	0.863	0.980	1.006	1.135	1.030	1.389	0.020	0.028	0.554	0.844
April '88	0.863	0.596	0.735	0.726	0.955	0.862	0.084	0.088	1.095	0.751
May '88	0.387	0.595	0.689	0.691	0.389	0.648	0.019	0.003	0.701	1.120
Dec. '88	0.676	1.109	0.000	0.646	0.974	1.383	0.000	0.000	2.029	0.080
Jan. '89	0.386	0.580	0.550	0.554	0.417	0.424	0.002	0.222	0.574	0.574

Station 1 = 55 m depth, station 2 = 35 m depth

average for st. 1 (0.81 mg/m^3) was slightly less than that of st. 2 (0.95 mg/m^3). The trend of monthly averages was similar to that of chl-*a*. Plant carotenoids varied from traces to 3.28 m-SPU/m^3 with an average of 0.44 m-SPU/m^3. The average value at the near-shore station (0.48 m-SPU/m^3) was slightly higher than that observed at the deeper station (0.4 m-SPU/m^3). Although the monthly mean values peaked in April and May in 1987, like chlorophylls, the highest value was observed in January 1988 (Table 2). Phaeopigment values varied greatly between traces and 10.16 mg/m^3 with an average of 0.95 mg/m^3. Station 1 recorded lower average value (0.86 mg/m^3) as compared to st. 2 (1.03 mg/m^3). The monthly mean values were high at both the stations during April and May of both the years.

The monthly mean of total chlorophylls ($a+b+c$) recorded a high of 7.09 mg/m^3 (st. 2, April 1987) and a low of 0.93 mg/m^3 (st. 1, January 1988). March, April and May of 1987 and March and April of 1988 were characterised by higher chlorophyll concentrations (Fig. 3). The total pigments (chlorophylls + carotenoids + phaeopigments) was the highest (15.55 mg/m^3) at st. 2 during April 1987 and the lowest (1.76 mg/m^3) at st. 1 during February 1988. In general, the plant pigments were much higher during March-May than during December-February (Fig. 3).

Discussion

The surface temperature maximum in May and minimum in December observed here are in agreement with the observations of Mojumder[18]. The periods of maximum and minimum salinity were also similar to those observed by earlier workers[14,18]. However, unlike the maximum dissolved oxygen observed during May by Mojumder[18], minimum was recorded during April-May in this study.

The high salinity, low temperature and low dissolved oxygen in the surface waters during March, April and May indicated upwelling[13,14]. There was wide variation in the weekly values of those parameters indicating that upwelling does not occur with the same intensity throughout the period. Shetye *et al.*[26,27] reported upwelling along western boundary of Bay of Bengal being wind driven during southwest monsoon and due to the influence of the western boundary current of the subtropical gyre (STG) during March-April. The density characteristics of the surface waters (Table 3) during some days of March, April and May of 1987 and April of 1988 were that of upwelled water and subsurface shelf water[14].

The concentrations of dissolved oxygen were not always low as expected when upwelling was indicated by low temperature and higher salinity and sigma-t. This is probably due to the replenishment of oxygen by phytoplankton, agreeing with the direct relationship of phytoplankton production and oxygen earlier reported[28]. Thus, high salinity and low temperature (and not necessarily low dissolved oxygen) could be taken as reliable indication of upwelling in near-shore surface waters off Visakhapatnam.

Sarma *et al.*[22], observed upwelling even at shallow (20 m) station while earlier it was reported[29] that upwelling band of cooler and denser water appeared first close to the shore during March and then migrated offshore with the progress of time. It is clear from the lower temperature and higher salinity values during April at the shallower st. 2 that evidence of upwelling is more pronounced near the shore than away from it. This would be obvious from the fact that deflection of surface water starts closer to the shore first, spreading farther along the direction of the wind or current. It was earlier reported[14] that the characteristic band of upwelled water off Visakhapatnam was only two miles at the time of upwelling whereas the band is probably wider near northern Orissa coast.

The mean monthly concentration of phosphate was the highest during March-April (Table 1) of both the years, presumably due to the supply of nutrients during upwelling[30]. A positive correlation ($r=0.24$, $\alpha=0.05$) observed between phosphate values and salinity values in the present study confirms the above statement at least in the case of phosphate. It should be noted that high salinity values in the present study period

Table 3—Sigma-t values of surface waters off Visakhapatnam on certain days of March, April and May of 1987 and 1988

Date	St. no.	Sigma t	Characteristic water mass
16 March '87	1	21.95	—
	2	22.01	UW
26 March '87	1	21.62	—
	2	22.38	UW
04 April '87	1	22.53	UW
	2	23.63	SSW
16 April '87	1	21.67	—
	2	23.84	SSW
24 April '87	1	21.00	—
	2	22.09	UW
22 May '87	1	22.01	UW
	2	22.08	UW
14 April '88	1	22.15	UW
	2	22.14	UW

UW—Upwelled water, SSW—subsurface shelf water

were associated with upwelling. Unlike phosphates, silicates, nitrites and nitrates did not show any significant correlation ($\alpha = 0.01$) with salinity.

Radhakrishna *et al.*[9] reported a mean primary production of 51.2 mgC/m^3/d, which is almost double the mean value obtained here, for surface waters of this region during August-September 1976. However, the range was almost similar in both the cases. Two subsequent studies[11,12] during the same period yielded average primary production as 113.2 and 34.5 mgC/m^3/d. Primary production gave a significant correlation ($r = 0.35$, $\alpha = 0.005$) with salinity. Since high salinity values in the present study were associated with upwelling, the results indicate higher productivity during upwelling.

While the mean and the range of chl-*a* values did not deviate much from the values reported by Radhakrishna *et al.*[10], the mean and maximum value (10.16 mg/m^3) of phaeopigments were much higher in the present study. The values of phaeopigments reported by subsequent workers[11,12] were also much lower than the present value. Since phaeopigments are Mg-free decomposition products of chlorophylls[10], the plankton stock probably has mostly cells in the degradation stage at the point of sampling and hence high phaeopigments. All pigments recorded high values when the productivity was high, the total chlorophylls and total pigments followed the same trend as primary production (Fig. 3). Except chl-*c*, all pigments showed highly significant correlation with primary production and among the pigments the degree of correlation varied.

The monthly mean values of total chlorophylls and total pigments showed a highly significant correlation ($\alpha = 0.001$) with values of phosphate and low significant correlation ($\alpha = 0.1$) with mean values of silicate. Qasim *et al.*[31] have stated that while there was close relationship between cycles of phosphorus and organic production in the backwaters, nitrogen was completely independent of productivity rhythm. Bhattathiri *et al.*[12] reported that nitrite was below detectable level at all stations along western Bay of Bengal during southwest monsoon of 1978. The present study also showed low values of nitrate as well as nitrite compared to silicate and phosphate values. The low nitrate values were ascribed to denitryfying bacteria by earlier workers[17,32].Sarma *et al.*[22] reported low N/P ratios in these waters and mentioned that nitrogen could be a limiting nutrient in these waters. The present study also observed low (<5) N/P ratio which, as a matter of fact, was not due to high values of phosphate. The general negative relations shown by nitrate and nitrite with productivity parameters could be indicative of a rapid uptake of these salts leading to depletion or lowering of concentration at the peak production period.

Prasad & Mishra[33] reported significant correlation between inverse secchi disc depth and chlorophylls. In the present investigation, all pigments and primary production showed an inverse relationship with secchi disc depth. This indicates that these suspended particles play a significant role in the attenuation of light in the euphotic zone in these waters.

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References

1 Steemann-Neilsen E & Jensen E A, *Galathea Report*, 1 (1957) 49.
2 Anon, *Anton Bruun Cruise* 1 : *Final cruise Report*, Vol. 1 (Woods Hole Oceanographic Institute, Woods Hole, USA) 1964.
3 Kabanova Ju G, *Trudy Inst Okeonologii*, 64 (1964) 250.
4 Krey J, in *The biology of the Indian Ocean*, edited by B Zeitschel, (Chapman and Hall Ltd, London) 1973, 115.
5 Prasad R R, Banerji S K & Nair P'V R, *Indian J Animal Sci*, 40 (1970) 73.
6 Qasim S Z, *Indian J Mar Sci*, 6 (1977) 122.
7 Qasim S Z, *Indian J Mar Sci*, 7 (1978) 258.
8 Radhakrishna K, *Indian J Mar Sci*, 7 (1978) 58.
9 Radhakrishna K, Bhattathiri P M A & Devassy V P, *Indian J Mar Sci*, 7 (1978) 94.
10 Radhakrishna K, Bhattathiri P M A & Devassy V P, *Indian J Mar Sci*, 11 (1982) 287.
11 Devassy V P, Bhattathiri P M A & Radhakrishna K, *Mahasagar—Bull Natn Inst Oceanogr*, 16 (1983) 443.
12 Bhattathiri P M A, Devassy V P & Radhakrishna K, *Mahasagar—Bull Natn Inst Oceanogr*, 13 (1980) 315.
13 La Fond E C, *Proc Indian Acad Sci*, 46 (1957) 1.
14 La Fond E C, *Andhra Univ Mem Oceanogr*, 2 (1958) 1.
15 Ganapati P N & Murty V S R, *Proc Eighth Pacific Sci Congr*, 3 (1953) 1145.
16 Ganapati P N & Murty V S R, *Andhra Univ Mem Oceanogr*, 1 (1954) 125.
17 Ganapati P N & Rama Sarma D V, *Andhra Univ Mem Oceanogr*, 2 (1958) 168.
18 Mojumder P, *J Mar Biol Ass India*, 9 (1967) 164.
19 Naqvi S W A, De Sousa S N & Reddy C V G, *Indian J Mar Sci*, 7 (1978) 15.
20 Naqvi S W A, De Sousa S N, Fondekar S P & Reddy C V G, *Mahasagar—Bull Natn Inst Oceanogr*, 12 (1979) 25.
21 Sankaranarayanan V N & Reddy C V S, *Bull Natn Inst Sci India*, 38 (1968) 148.
22 Sarma V V, Narasimha Rao T V, Rama Raju V S, Vijayakumar R & Suguna C, *Mahasagar—Bull Natn Inst Oceanogr*, 21 (1988) 197.
23 Strickland J D H & Parsons T R, *Bull Fish Res Bd Canada*, 167 (1968) pp. 311.

24 Parsons T R, Maita Y & Lalli C M, *A manual of chemical and biological methods for seawater analysis*, (Pergamon Press, Oxford) 1984, pp. 173.
25 Dyson N, Jitts H R & Scott B D, *CSIRO Tech Pap*, 18 (1965) pp 12.
26 Shetye S R, Shenoi S S C, Gouveia A D, Michael G S, Sundar D & Nampoothiri G, *Cont Shelf Res*, 11 (1991) 1397.
27 Shetye S R, Gouveia A D, Shenoi S S C, Sundar D, Michael G S & Nampoothiri G, *J Geophys Res.* 98 (1993) 945.
28 Ganapati P N & Subba Rao D V, *Proc Indian Acad Sci*, 48 (1958) 189.
29 Narasimha Rao T V, Rao D P, Rao B P & Rama Raju V S, *Indian J Mar Sci*, 15 (1986) 84.
30 Bhavanarayana P V & La Fond E C, *Indian J Fish*, 4 (1957) 75.
31 Qasim S Z, Wellershaus S & Bhattathiri P M A, *Proc Indian Acad Sci*, 69 (1969) 51.
32 Jayaraman R, *Indian J Fish*, 1 (1954) 345.
33 Prasad K S & Mishra A K, *J Mar Biol Ass India*, 30 (1988) 157.