



Spatial and temporal variations in phytoplankton in coral reef and seagrass ecosystems of the Palk Bay, southeast coast of India

R. Sridhar¹, T. Thangaradjou^{*2} and L. Kannan³

¹Ministry of Environment and Forests, Paryavaran Bhawan, CGO Complex, Lodhi Road, New Delhi - 110 003, India

^{2,3}Centre of Advanced Study in Marine Biology, Faculty of Marine Science, Annamalai University, Parangipettai - 608 502, India

(Received: October 24, 2009; Revised received: February 17, 2010; Accepted: February 26, 2010)

Abstract: Spatial and temporal behavior of distribution of phytoplankton of the coral reef and seagrass environment of the Palk Bay was studied during April 2002 to March 2003. A total of 133 species of phytoplankton was recorded during the study period, of which, 98 species belong to Bacillariophyceae, 15 species belong to Dinophyceae, 12 species belong to Cyanophyceae and 8 species belong to Chlorophyceae. Diatoms (57.14 to 94.10%) contributed more towards the percentage composition of different groups of phytoplankton at the two stations, followed by dinoflagellates (3.12 to 28.57%), blue-greens (2.43 to 12.5%) and greens (3.7 to 7.69%). Higher phytoplankton population density was recorded during the summer season at both stations (St.1. 62,000 cells l⁻¹ and St.2. 55,000 cells l⁻¹). Coral reef environment was two-fold more productive (2.10-130.21 mg C m⁻³ hr⁻¹) than the seagrass environment (3.30 - 85.56 mg C m⁻³ hr⁻¹). Chlorophyll 'a' concentration showed higher values at station 1, corresponding to the higher phytoplankton population density recorded at this station along with primary productivity.

Key words: Phytoplankton, Palk Bay, Coral reef, Seagrass, Ecosystem

PDF of full length paper is available online

Introduction

Plankton is one of the important components of any marine ecosystem. This is obvious from the abundant occurrence of planktonivorous animals in the marine ecosystems. Among plankton, phytoplanktons are the primary source of food in the marine pelagic environment, initiating the food-chain which may culminate even in large marine mammals (Waniek and Holliday, 2006). From the ecological point of view, investigations on the phytoplankton species composition and community structure are very important to understand the status of the phytoplankton in the coral reef and seagrass environment.

More than 95% of the primary production in the oceanic waters is contributed by only phytoplankton (Lewis, 1974). However, the shallow neritic zones of the coastal areas are comparably more productive due to the combined production of unicellular algae, macro-algae, symbiotic algae of coral reefs and the seagrasses. Among all, the drifting micro-algal (phytoplankton) population plays a major role in determining the productivity of the coastal and marine environment.

Phytoplankton species composition, population density, richness and primary productivity will vary from coast to coast and sea to sea depending upon the varying hydro-biological features. It is worth mentioning that Reynolds (1993) has stated that the changes in species composition and dominance of phytoplankton can be mediated by a variety of mechanisms including ambient

temperature, light penetration, nutrient supply, and removal by zooplankton etc. However, such information on phytoplankton of the Palk Bay is very much limited. Banse *et al.* (1996) studied the possible causes of the seasonal phytoplankton blooms along the southeast coast of India and reported that the seasonal increase of nutrient supply primarily increased the growth rate of the phytoplankton. Krishnamoorthy and Subramanian (1999) reported that the west coast current and conglomeration of open ocean influenced the highest species diversity of meroplankton in the Palk Bay and Gulf of Mannar. Sridhar *et al.* (2006) reported the seasonal behavior of distribution of phytoplankton in the Palk Bay region. This has necessitated the present attempt to study the phytoplankton community structure in the Palk Bay with reference to the ambient water quality.

Materials and Methods

Study area: In India, the Palk Bay is a shallow basin located in the southeast coast with an average depth of 9 m mainly with muddy bottom at shore regions (Fig. 1). The present investigation on the assessment of the bioresources was carried out at two different stations viz. Devipattinum and Munaikadu in the Palk Bay, Bay of Bengal along the southeast coast of India. Munaikadu (Station 1) is one of the fishing villages with frequent landings and it is located in the coastal area of Ramnad district of Tamil Nadu state. The reefs developed around this area are distributed discontinuously. Different types of reef formations viz. fringing reef, patch reef and coral pinnacles have been observed in this region. The sea appears to be calm during most of the months with less tidal influence.

* Corresponding author: umaradjou@gmail.com

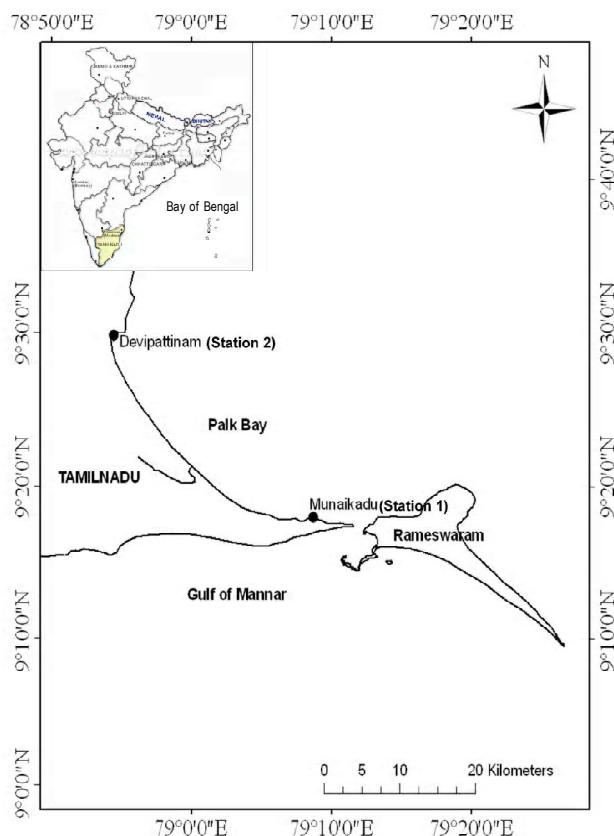


Fig. 1: Map showing the study areas

Devipattinam (Station 2) is another coastal village situated in the Palk Bay, 30 km from Ramnad. The sea appears to be calm with lesser tidal influence. The sea bottom at this coast is dominated by sandy to muddy soil and supports luxuriant growth of seagrasses. There is rich mangrove in the southern side of this station.

Sampling and analysis: Phytoplankton samples were collected from the surface waters of stations 1 and 2 at monthly intervals, during April 2002 to March 2003 by towing a plankton net (mouth diameter 0.35 m), made of bolting silk (No. 30, mesh size: 48 μ m) for half an hour. The collected samples were preserved in 4% neutralized formalin and used for qualitative analysis. For the quantitative analysis of phytoplankton, the settling method described by Sukhanova (1978) was adopted. Numerical plankton analysis was carried out using Utermohl's inverted plankton microscope. Phytoplankton were identified using the standard works of Venkataraman (1939), Cupp (1943), Subrahmanyam (1946), Desikachary (1959, 1987), Hendey (1964), Steidinger and Williams (1970), Taylor (1976) and Anand *et al.* (1986). Species diversity index (Shannon and Wiener, 1949), species richness (Gleason, 1922) and evenness index (Pielou, 1966) of phytoplankton were worked by using the respective formulae. Chlorophyll 'a' concentration was estimated, following the method of Strickland and Parsons (1972). Primary productivity was estimated, adopting the light and dark bottle technique as described by Strickland and Parsons (1972) and expressed as $\text{mg C m}^{-3} \text{hr}^{-1}$. For the easy

interpretation of the data the entire study period was divided into summer (April-June), premonsoon (July-September), monsoon (October-December) and postmonsoon (January-March) seasons. Correlation co-efficient and Analysis of Variance (ANOVA) were worked out for various parameters.

Results and Discussion

In general, open coasts, estuaries, mangroves and backwaters are well studied for their planktonic community structure and only little is known about the plankton community of the coral reef waters (Duyf *et al.*, 2002) and the information is very much lacking in the case of seagrass ecosystems.

In the present study, a total of 133 species of phytoplankton (Table 1) were recorded from both the stations, of which, station 1 recorded 92 species and station 2 recorded 89 species. Both the stations recorded higher number of diatom species (71 at station 1; 68 at station 2), which is a common feature in the tropical phytoplankton community structure. *Coscinodiscus* spp. occurred frequently at both the stations while the other genera like *Chaetoceros*, *Nitzschia* and *Navicula* were also represented by more number of species at both the stations. Panigrahi *et al.* (2004) have reported that the abundance and diversity of diatoms in the neritic zone of the Bay of Bengal are common features. Dominance of diatoms in reef waters has also been reported by Kannan *et al.* (1998) from the Gulf of Mannar region and Sorokin (1990) from the Great Barrier Reef.

Dinoflagellates constituted the second largest group followed by blue-greens and greens. The higher species composition of blue-greens and greens recorded from the seagrass environment (station 2) might have been favoured by the higher nutrient levels recorded at this station when compared to the coral reef waters of station 1.

Percentage composition of different groups of phytoplankton varied at the two stations viz. diatoms - 57.14 to 94.10%; dinoflagellates - 3.12 to 28.57%; blue-greens - 2.43 to 12.5% and greens - 3.7 to 7.69%. Percentage composition of diatoms was higher during the premonsoon season and it was less during the monsoon season. Such a dominance of phytoplankton especially that of diatoms during the premonsoon season and decrease during the monsoon season have also been reported by Raghuprasad (1958) from the Palk Bay region. In contrast, Kannan *et al.* (1998)

Table - 1: Number of phytoplankton species and the percentage composition recorded at stations 1 and 2

Group	Number of species recorded			% composition
	St. 1	St. 2	Total	
Diatoms	71	68	98	57.14-94.10
Dinoflagellates	14	7	15	3.12-28.57
Blue-Greens	4	9	12	2.43-12.50
Greens	3	5	8	3.70-7.69
	92	89	133	

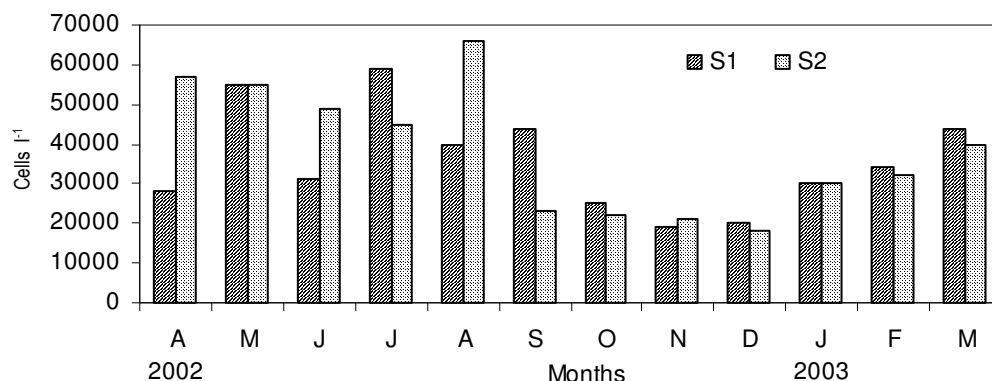


Fig. 2: Monthly variations in phytoplankton population density (cell l⁻¹) recorded at stations 1 and 2

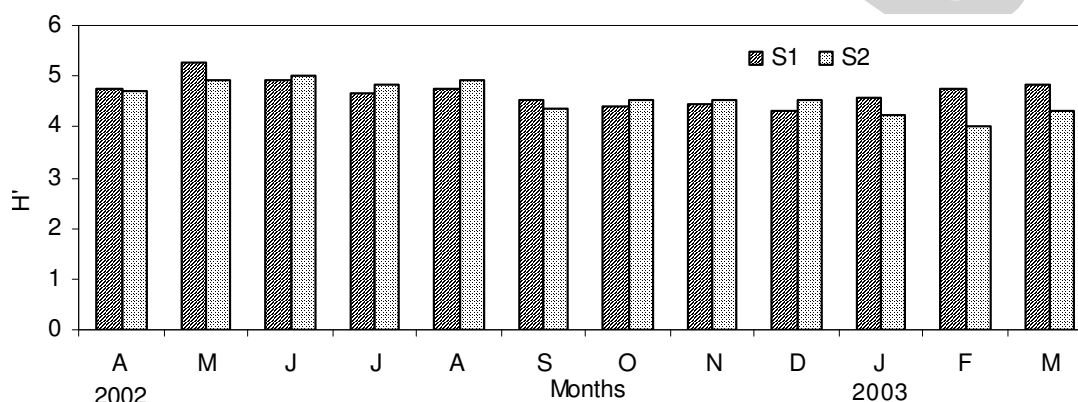


Fig. 3: Monthly variations in phytoplankton diversity (H') recorded at stations 1 and 2

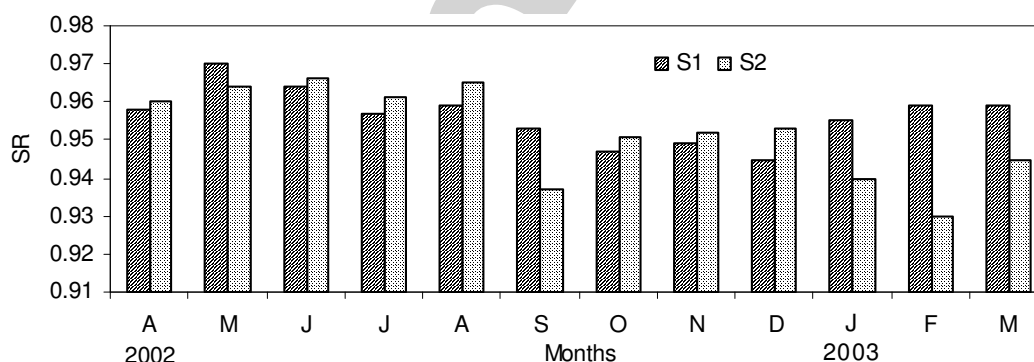


Fig. 4: Monthly variations in phytoplankton species richness (SR) recorded at stations 1 and 2

has recorded higher diatom percentage composition during the monsoon season with the minimum during the premonsoon season in the Gulf of Mannar region. This difference in diatom maxima might have been caused by the secondary nutrient peaks noticed in the premonsoon season during the study period. Recently, Choudhury and Pal, (2010) also recorded such dominance of diatoms from the Bay of Bengal region. The higher concentrations of silicate (5.8 μM), phosphate (4.7 μM) and nitrate (4.7 μM) recorded during August 2002 (premonsoon season) as a result of the southwest monsoon, might have triggered the diatom bloom.

Dinoflagellates recorded their maximum percentage composition during the postmonsoon season at station 1 (16.44%)

and monsoon season (20.72%) at station 2. Such higher values of dinoflagellate percentage composition in the reef waters have been reported by Kannan *et al.* (1998) and Sorokin (1990). In the present study, the bloom forming blue-green algal species *Trichodesmium erythraeum* was recorded from station 2 and this indicates that there are possibilities for the occurrence of toxic blooms in this part of the Bay in future. During rainy seasons green algae would have been washed away from the nearby freshwater bodies and survive for a short period in the coastal waters.

Monthly data showed that, at station 1, minimum density (19000 cells l⁻¹) was recorded during November 2002 and the maximum (59000 cells l⁻¹), during July 2002. While at station 2, the

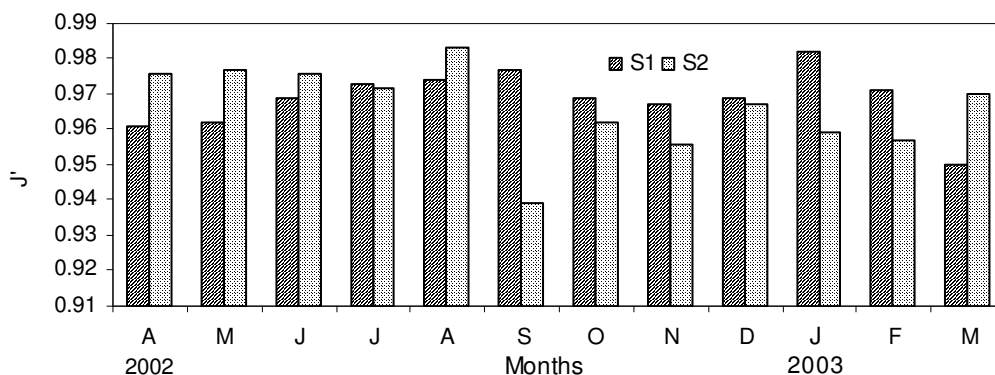


Fig. 5: Monthly variations in phytoplankton species evenness (J') recorded at Stations 1 and 2

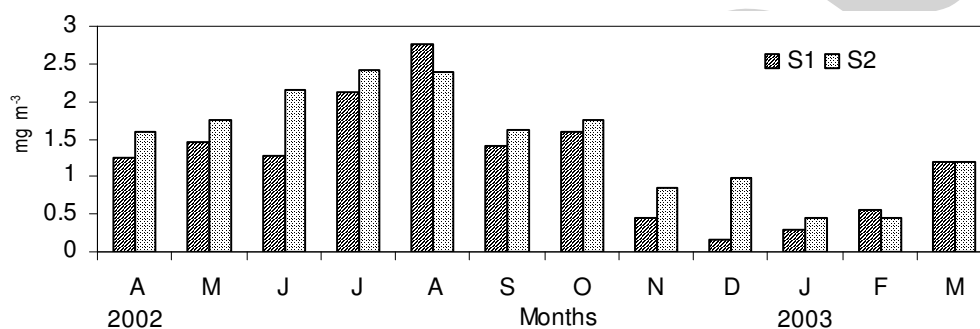


Fig. 6: Monthly variations in chlorophyll 'a' concentration (mg m^{-3}) recorded at Stations 1 and 2

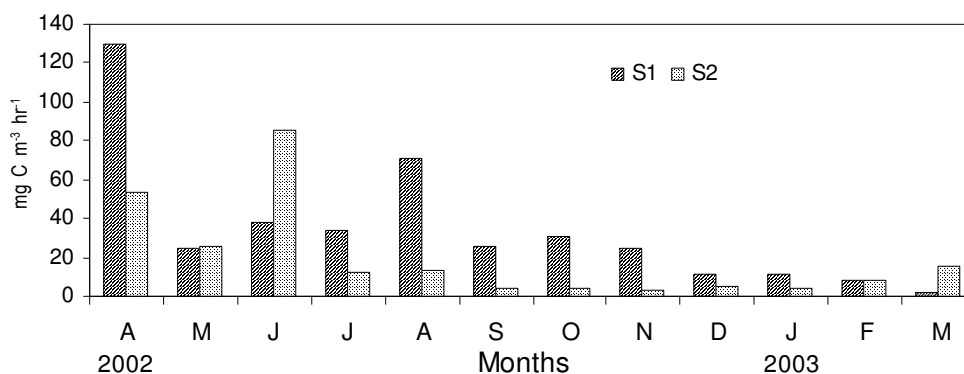


Fig. 7: Monthly variations in primary productivity ($\text{mg C m}^{-3} \text{ h}^{-1}$) recorded at Stations 1 and 2

minimum ($18000 \text{ cells l}^{-1}$) and the maximum ($66000 \text{ cells l}^{-1}$) population densities were recorded during December and April 2002 respectively (Fig. 2). The seasonal mean of phytoplankton population density ($19,000\text{--}62,000 \text{ cells l}^{-1}$) recorded presently in the Palk Bay is very low when compared to the adjacent Gulf of Mannar and other reef ecosystems of the world. In the present study, higher seasonal phytoplankton population density was recorded during the summer season at both station 1 ($62,000 \text{ cells l}^{-1}$) and station 2 ($55,000 \text{ cells l}^{-1}$). Such occurrence of higher population density of phytoplankton during the summer season was reported by Raghuprasad (1958) from the Palk Bay, Gowda and Panigrahi (2004) from the coastal waters of Gopalpur, Chandran (1985) from the Vellar estuary and Jayaraman (1954) from the Mandapam coast, all lying along the east coast of India. Devassy and Bhattathiri

(1974) have also recorded summer phytoplankton population density maxima along the Goa and Cochin coasts of India. Such occurrence of higher population density of phytoplankton during the summer season might have decreased the nutrient concentrations during this season. This is evidenced by the significant negative correlation obtained between the phytoplankton population density and nitrate ($p < 0.05$) at both the stations and silicate ($p < 0.05$) at station 1. The increase in phytoplankton population density in the reef waters would definitely affect the ecosystem by curtailing the light availability to the coral reef algal symbionts, as reported by Stambler (1999). This is evident from the significant positive correlation obtained between the population density and light extinction coefficient at station 1. Likewise, significant negative correlation ($p < 0.05$) obtained between particulate organic carbon

(POC) and population density of phytoplankton at station 2 reveals the contribution of phytoplankton to the POC of the coastal waters.

Phytoplankton species diversity index varied from 3.99 to 5.28 (Fig. 3), species richness index ranged from 0.93 to 0.97 (Fig. 4) and species evenness index varied from 0.93 to 0.98 (Fig. 5). ANOVA has clearly indicated that there is no significant difference in population density between stations 1 and 2. Diversity index was higher during the summer season at both the stations owing to the higher population density. Likewise, diversity index was lower during the monsoon season. This is evidenced by the significant positive correlation ($p < 0.05$) obtained between diversity index and population density at both the stations. The diversity index also showed significant positive correlation with temperature at station 1 ($p < 0.05$) and station 2 ($p < 0.01$), indicating that temperature might have influenced the presence of specific species at varying temperatures. Supporting this fact, temperature influenced parameter, salinity also showed significant positive correlation ($p < 0.001$) with diversity index. This is also evidenced by the dominance of stenohaline species such as *Nitzschia*, *Chaetoceros* and *Pleurosigma* at station 1 and *Navicula* and *Rhizosolenia* at station 2 during the summer months. This lends support to the findings of Panigrahi *et al.* (2004) who have reported the presence of *Navicula*, *Nitzschia* and *Pleurosigma* species at higher saline stations of the Bay of Bengal.

Species richness also showed similar trend as that of the diversity. Richness showed significant positive correlation with population density ($p < 0.05$) and diversity ($p < 0.001$) at both the stations. This would indicate that diversity and richness are largely influenced by the population density. Species evenness showed similar trend as that of diversity. Higher evenness values were recorded during the summer season and lower values were recorded during the monsoon season at both the stations. As in richness, evenness also showed positive correlation with the population density.

Higher dominance index was noticed during the premonsoon season at both the stations due to the dominance of *Triceratium reticulatum*. The dominance of this species during this season might have been favoured by the secondary nutrient peaks due to the southwest monsoon.

Several authors have opined that estimation of chlorophyll 'a' content of phytoplankton in water will be more informative than measuring the cell numbers. Chlorophyll 'a' concentration ranged from 0.15 to 2.76 mg m⁻³ at the two stations (Fig. 6). At station 1, the minimum (0.15 mg m⁻³) was recorded during December 2002 and the maximum (2.76 mg m⁻³), during August 2002. At station 2, the minimum (0.44 mg m⁻³) was recorded during January 2003 and the maximum (2.42 mg m⁻³) was recorded during July 2002.

In the present study, chlorophyll 'a' concentration ranged from 0.15 to 2.18 mg m⁻³ at station 1 (coral reef environment) which was less when compared to the adjacent Gulf of Mannar

Biosphere Reserve waters where has recorded higher values ranging from 1 to 3.63 mg m⁻³. However, presently observed concentrations are higher when compared to that of Lakapota atoll (0.26-0.77 mg m⁻³) and Contone atoll (0.8 mg m⁻³) reported by Sourina and Richard (1976). Griffiths (1976) also recorded lesser concentration (0.15-0.20 mg m⁻³) in the waters of Lizard island of the Great Barrier Reef. So, higher concentrations of chlorophyll 'a' recorded in the present study, in the coral reef waters may affect the coral health by decreasing the light availability to zooxanthallae. However, Perumal *et al.*, 2009 have recorded even higher concentrations estuarine region (3.4-12.8 mg m⁻³).

Sarupria and Bhargava (1998) have recorded an annual average of 13.0 mg m⁻³ of chlorophyll 'a' concentration in the EEZ of the Bay of Bengal of India. Such higher concentrations of chlorophyll 'a' might have been contributed by the phytoplankton of other adjacent coastal waters rather than the coral reef environment alone. This has been evidenced by the comparatively higher chlorophyll 'a' concentration recorded at the seagrass environment (station 2).

In the present study, higher chlorophyll 'a' concentration was recorded during the summer season at station 1 and postmonsoon season at station 2. Such higher chlorophyll 'a' concentration recorded during the summer season could be ascribed to the higher phytoplankton population density recorded during the same season. This is evident from the significant positive correlation obtained between population density and chlorophyll 'a' concentration. In contrast, at station 2, chlorophyll 'a' concentration was higher during the postmonsoon season. This would have been due to the higher chlorophyll 'a' content of certain species of phytoplankton or presence of comparatively larger (cell) sized phytoplankton such as *Coscinodiscus concinnus*, *Hemidiscus hardmannianus*, *Pleurosigma directum*, *Rhizosolenia alata* and *R. styliformis* at this station. Duyl *et al.* (2002) have also opined that enhanced nutrient supply might trigger the size increase in cells, which would ultimately increases the chlorophyll 'a' concentration. They have stated that pigment concentration relates to the biomass of algae rather than their numbers and gives an indication of relative contribution of each group of phytoplankton to total chlorophyll 'a' or biomass. The significant positive correlations obtained between phytoplankton diversity and chlorophyll 'a' concentration ($p < 0.001$) and phytoplankton richness ($p < 0.01$) have clearly brought out the contribution of specific groups of phytoplankton to the chlorophyll 'a' concentration.

During the present study period, the gross primary productivity ranged from 2.10 to 130.21 mg C m⁻³ hr⁻¹ (Fig. 7). At station 1, the minimum (2.10 mg C m⁻³ hr⁻¹) was recorded during March 2003 and the maximum (130.21 mg C m⁻³ hr⁻¹) was recorded during April 2002. At station 2, the minimum (3.30 mg C m⁻³ hr⁻¹) was recorded during November 2002 and the maximum (85.56 mg C m⁻³ hr⁻¹) was recorded during June 2002.

Phytoplankton primary productivity in lakes, estuaries and open oceans plays an important role in elements cycling, water quality and food supply to heterotrophs (Cloern, 1996). However, the productivity range will vary considerably depending upon the ecosystem. The coral reef environment is said to be more productive than that of the seagrass environment. It should be noted that seagrasses are highly productive as individual components of an ecosystem, whereas, the productivity of coral reef waters is contributed by many components such as phytoplankton, seaweeds, seagrasses and symbiotic zooxanthellae. This has been clearly brought out by the significant differences obtained between the stations, as revealed by statistics (ANOVA) at 5% level.

Mean seasonal data of primary productivity recorded during the present study indicate higher primary production during the summer season and lower primary production during the monsoon season at both the stations. Raghuprasad (1958) also reported higher phytoplankton production during the summer season in the Palk Bay region. Coral reef waters (station 1) were two-fold more productive than the seagrass waters (station 2). Such higher primary production in coral reef waters during the summer season would have been contributed by the higher phytoplankton population density ($62000 \text{ cells l}^{-1}$) recorded at this station during this season. The present range of primary production in the reef waters of the Palk Bay is comparable to that of other reef areas of India and the world (Bhattathiri and Devashree, 1979; Nair and Gopinathan, 1983; Sorokin, 1990; Kannan et al., 1998).

Primary production by phytoplankton in seagrass environment (station 2) was comparatively low. This correlates well with the lower seasonal phytoplankton population density ($55,000 \text{ cells l}^{-1}$) recorded at this station. Such lower phytoplankton density and subsequent decrease in productivity could be attributed to the competition between the seagrasses whose biomass is greater at this station ($1496.15 \text{ g fr.wt. m}^{-2}$) and phytoplankton in absorbing the water nutrients. It should be noted that seagrasses are capable of absorbing more amount of nutrients through all the parts of their body, than the phytoplankton. The significant negative correlation obtained between nitrate and primary production and phytoplankton population density would explain this fact. However, in the present study, no significant correlation could be seen between productivity and hydrobiological parameters except pH at station 1 and surface water temperature, POC and nitrate at station 2. Several authors (Sathyanarayana et al., 1990; Varshaney et al., 1983) have also stated that the primary productivity is only the measurement of rate of primary production and it need not necessarily have any positive correlation with instantaneous hydrobiological conditions.

Higher phytoplankton population density are largely responsible for the higher primary productivity rates of the coastal waters including the coral reef areas. Productivity of the coral reef waters in the present study was higher, contributed by many components such as phytoplankton, seaweeds, seagrasses and symbiotic zooxanthellae. Higher Chlorophyll 'a' is correlated at station

1, along with higher phytoplankton population density and primary productivity during summer. Higher chlorophyll 'a' content at station 2 during the postmonsoon season could be due to the presence of comparatively larger (cell) sized phytoplankton during this season.

Acknowledgments

Authors thank Dr. T. Balasubramanian, Director, CAS in Marine Biology and authorities of Annamalai University for providing the facilities and support. Authors also thank the Ministry of Environment and Forests, Government of India, New Delhi for the financial support.

References

- Anand, N., E. Mohan, R.S.S. Hopper and T.D. Subramanian: Taxonomic studies on blue-green algae from certain marine environments. *Seaweed Res. Utiln.*, **9**, 49-56 (1986).
- Banse, K., Sumitra-Vijayaraghavan and M. Madhupratap: On the possible causes of the seasonal phytoplankton blooms along the southeast coast of India. *Ind. J. Mar. Sci.*, **25**, 283-289 (1996).
- Bhattathiri, P.M.A. and V.P. Devassy: Biological characteristics of the Laccadive Sea. In: The Laccadive Sea (Lakshadweep). *NIO Tech. Rept.*, 80-92 (1979).
- Choudhary, A.K. and R. Pal: Phytoplankton and nutrient dynamics of shallow coastal stations at Bay of Bengal, Eastern Indian Coast. *Aquat. Ecol.*, **44**, 55-71 (2010).
- Cloern, J.E.: Phytoplankton bloom dynamics in coastal ecosystems – A review with some general lessons from sustained investigation of San Francisco Bay (California, USA). *Rev. Geophys.*, **34**, 127-168 (1996).
- Cupp, E.E.: Marine plankton diatoms of the west coast of North America. *Bull. Scripps Inst. Oceanogr.*, **5**, 1-237 (1943).
- Desikachary, T.V.: Cyanophyta. Indian Council of Agricultural Research, New Delhi (1959).
- Desikachary, T.V.: Atlas of diatoms. Monographs. Vol. II, III and IV, Madras Science Foundation, Madras (1987).
- Devassy, V.P. and P.M.A. Bhattathiri: Phytoplankton ecology of the Cochin backwaters. *Ind. J. Mar. Sci.*, **3**, 46-50 (1974).
- Dridambaram, R.: Seasonal and tidal variation of phytoplankton in to gradient zone of vellar estuary. *Mahasagar*, **18**, 37-48 (1985).
- Duyf, F.C.V., G.J. Gast, W. Steinhoff, S. Kloff, M.J.W. Veldhuis and R.P.M. Bak: Factors influencing the short-term variation in phytoplankton composition and biomass in coral reef waters. *Coral Reefs*, **21**, 293-306 (2002).
- Gleason, H.A.: On the relation between species and area. *Ecol.*, **3**, 156-162 (1922).
- Griffiths, D.J.: The photosynthetic activity of phytoplankton in the water of coral reefs. *Aust. J. Plant Physiol.*, **3**, 53-56 (1976).
- Hendey, N.I.: Bacillariophyceae (Diatoms). In: An introductory account of the smaller algae of British coastal waters. Fishery Inves. Ser., IV London. p. 317 (1964).
- Jayaraman, R.: Seasonal variations in salinity dissolved oxygen and nutrient salts in the inshore waters of the Gulf of Mannar and Palk Bay near Mandapam. *Indian J. Fish.*, **1**, 345-364 (1954).
- Kannan, L., K. Kathiresan and A. Purushothaman: Biodiversity of microbial flora (Bacteria and Phytoplankton) of the coral reef of the Gulf of Mannar. In: Biosphere reserves and management (Ed.: R.K. Maikhuri). Himavikas Oceanography Publication, 12, 207-220 (1998).
- Krishnamoorthy, P. and P. Subramanian: Organisation of commercially supporting meroplankton in Palk Bay and Gulf of Mannar biosphere areas, southeast coast of India. *Ind. J. Mar. Sci.*, **28**, 211-215 (1999).
- Lewis, W.M. Jr.: Primary production in the plankton community of a tropical lake. *Ecol. Monog.*, **44**, 377-409 (1974).

- Nair, P.V.R. and C.P. Gopinathan: Primary production in coastal waters. *In: Mariculture potential of Andaman and Nicobar Islands – An Indicative Survey. CMFRI Bull.*, **34**, 1-108 (1983).
- Panigrahi, S.N., B.C. Acharya and S.N. Das: Distribution of diatoms and dinoflagellates in tropical waters of Orissa and West Bengal with emphasis on neritic assemblages. *In: Proc Natn. Sem. New Frontiers in Marine Bioscience Research.* pp. 535-543 (2004).
- Perumal, N.V., M. Rajkumar, P. Perumal and K. Thillai Rajasekar: Seasonal variations of plankton diversity in the Kaduvayar estuary, Nagapattinam, southeast coast of India. *J. Environ. Biol.*, **30**, 1035-1046 (2009).
- Pielou, E.C.: The measurement of diversity in different types of biological collection. *J. Theoret. Biol.*, **13**, 1-144 (1966).
- Raghuprasad, R.: Plankton calendars of the inshore waters at Mandapam, with a note on the productivity of the area. *Ind. J. Fish.*, **5**, 170-188 (1958).
- Reynolds, C.S.: Scales of disturbance and their role in plankton ecology. *Hydrobiol.*, **249**, 157-171 (1993).
- Sarupria, J.S. and R.M.S. Bhargava: Seasonal distribution of chlorophyll 'a' in the exclusive economic zone (EEZ). *Ind. J. Mar. Sci.*, **27**, 292-297 (1998).
- Sathyanarayana, D., I.M. Rao and B.R. Prasada Reddy: Primary productivity, plant pigments and particulate carbon of Visakhapatnam harbour – A seasonal study. *Proc. Intl. Symp. Mar. Pollut.*, 287-300 (1990).
- Shannon, C.E. and W. Wiener: The mathematical theory of communication. Univ. of Illinois Press, Urbana (1949).
- Sorokin, Y.I.: Plankton in the reef ecosystems. *In: Ecosystem of the world 25: Coral reef (Ed.: Z. Dubinsky).* Elsevier Science Publishing Company, New York, USA. pp. 290-327 (1990).
- Sourina, A. and M. Richard: Phytoplankton and its contribution to primary production in two coral reef areas of French Polynesia. *J. Exp. mar. Biol. Ecol.*, **21**, 129-140 (1976).
- Sridhar, R., T. Thangradjou, S. Senthil Kumar and L. Kannan: Water quality and phytoplankton characteristics in the Palk Bay, southeast coast of India during pre-tsunami period. *J. Environ. Biol.*, **28**, 561-566 (2006).
- Stambler, N.: Coral reefs and eutrophication. *In: Marine pollution. Proc. Sym. Marine pollution, Monaco.* pp. 360-361 (1999).
- Steidinger, K.A. and J. Williams: Dinoflagellates. *Hourglass Cruises*, **2**, 1-251 (1970).
- Strickland, J.D.H. and T.R. Parsons: A practical handbook of seawater analysis. *Bull. Fish Res. Bd. Canada*, **167**, 1-310 (1972).
- Subrahmanyam, R.: The diatoms of the Madras coast. *Proc. Indian Acad. Sci.*, **24**, 85-197 (1946).
- Sukhanova, Z.N.: Settling without the inverted microscope. *In: Phytoplankton manual (Ed.: A. Sourina).* UNESCO, Page Brothers (Nourich) Ltd., 97 (1978).
- Taylor, F.J.R.: Dinoflagellates from the International Indian Ocean Expedition. A report on material collected by the R.V. "Anton Bruun" 1963-1964. *Bibliotheca Botanica*, **132**, 1-226 (1976).
- Varshney, P.K., R.V. Nair and S.A.H. Abidi: Primary productivity in nearshore waters of Thal, Maharashtra coast. *Ind. J. Mar. Sci.*, **12**, 27-30 (1983).
- Venkataraman, G.: A systematic account of some Indian diatoms. *Proc. Indian Acad. Sci.*, **10**, 293-368 (1939).
- Waniek, J.J. and N.P. Holliday: Large-scale physical control on phytoplankton growth in the Irminger Sea, Part II: Model study of the physical and meteorological preconditioning. *J. Mar. Sys.*, **59**, 219-237 (2006).