Available online at: www.mbai.org.in doi:10.6024/jmbai.2020.62.2.2092-10

Ecological and diurnal relationship between phytoplankton diversity and environmental variables in South Andaman Island

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Received: 12 May 2019 Accepted: 10 Nov 2020 Published: 15 Nov 2020

Original Article

Abstract

The phytoplankton diversity, distribution, density and their relationships to physicochemical variables were investigated using multivariate analyses. Day and night samples were collected monthly between November 2011 and April 2012 from two different stations, Chatham and Junglighat in South Andaman Island. A total of 204 species and 65 genera were identified at these two stations. Diatoms (135 species), dinoflagellates (63 species), cyanobacteria (4 species) and silicoflagellates (2 species) were the most important taxonomic groups represented. *Bacteriastrum furcatum, Guinardia flaccida, Leptocylindrus danicus, Rhizosolenia alata, Rhizosolenia imbricata,* and *Meuniera membranacea* were the major diatoms abundant in the coastal waters. The relationships between the phytoplankton and the environmental factors were studied by canonical correspondence analysis with special attention to the sampling time (day and night). The distribution patterns of the phytoplankton communities during day and night were analyzed indirectly by detrended correspondence analysis. Seasonal and spatial variations in the phytoplankton density were largely resulted from light and temperature. The long-term trends in phytoplankton community dynamics would provide information about the change in trophic status of the system, as well as a foundation for distribution studies of these species in marine ecosystems.

***Keywords**: Phytoplankton community, diatoms, dinoflagellates, environmental variables, multivariate analysis, South Andaman.*

Introduction

Phytoplankton are the primary producers of marine food web (McManus and Woodson, 2012). They act as major source of energy for the higher trophic levels in aquatic ecosystems (Boney, 1975; Ananthan *et al.,* 2004; Tas and Gonulol, 2007; Cloern *et al.*, 2014; Degerman *et al.*, 2018). Hence, the knowledge regarding their dynamics is essential for developing predictive ecosystem models as well as ecological assessment. Phytoplankton assemblages have also been used as indicators to water quality (Salmaso *et al.*, 2006; Chellappa *et al.*, 2009; Pourafrasyabi and Ramezanpour, 2014), pollution and human interference in the marine environment. Differences in geographic specific anthropogenic activities, seasonal variations and pollutants have an effect on water quality, and thus, influences the phytoplankton community dynamics of estuaries (Shekhar *et al.*, 2008; Muylaert *et al.*, 2009; Baliarsingh *et al.*, 2016). The variation in physical, chemical and biological conditions determine changes in phytoplankton composition, abundance and diversity over different spatial and temporal scales (Priddle *et al.,* 1994; Walsh *et al.,* 2001; Moore and Abbott, 2002). This variability in the phytoplankton community structure in turn reflects in the efficiency of the food web and the global biogeochemical cycles (Smetacek, 1996; Walsh *et al.,* 2001). Hence this study was under taken to assess the relative importance of the environmental variables on phytoplankton community.

Material and methods

Phytoplankton samples were collected from the surface of two different coastal stations during November 2011 to April 2012. Station 1 (11°41'13"N and 92°43'28"E), Chatham, is a chief port in South Andaman, connected with open ocean where major shipping activities and oil spill occurs. Station 2 (11° 39 '21"N and 92° 43'56"E), Junglighat, is one of the major fish landing centers in South Andaman, which receives a large amount of sewage discharge from the adjacent areas (Fig. 1). Diurnal variations of phytoplankton species assemblage was determined by investigating samples collected during day and night.

Samples were collected in a 1-liter plastic container by filtering 50L of water through phytoplankton net (mesh size 20μm) 50

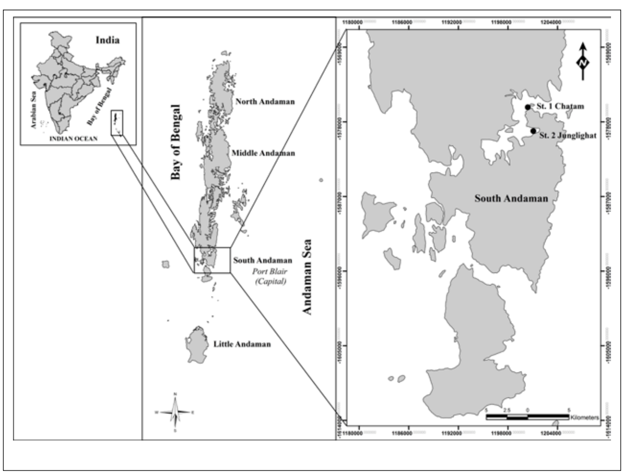

Fig. 1. Map showing the study area and sampling locations in South Andaman

ml of concentrated sample was collected from all stations and immediately preserved with 4% formalin and fixed with Lugol's iodine solution (Achary *et al*., 2010; Guillard, 1978). Samples were allowed to settle for two days and the supernatant water was siphoned, leaving the settled cells in the bottom (Villalobos, 2010). The concentrated samples (1ml from each sample) were counted in a Sedgwick-Rafter counting chamber under an inverted microscope (Guillard, 1978). Species identification was done using standard keys (Venkataraman, 1939; Cupp, 1943; Guillard, 1978; Tomas, 1997). Along with phytoplankton samples, *in situ* measurements of water temperature, salinity, dissolved oxygen, nutrients (NO_2, NO_3, PO_4 and SiO_4) and pH (Strickland and Parson, 1972) were also undertaken.

Data were analyzed using multivariate techniques by PAST (version 2.17c) statistical package. Unconstrained (DCA) and constrained ordination (CCA) methods were applied to explore the relationship between environmental variables and phytoplankton composition. Detrended correspondence analysis (DCA) was used to determine the major variation in species composition (presence/absence data) and to reveal patterns in community structure. Canonical correspondence analysis (CCA) was used to assess the relative importance of first and second major gradients of environmental variables inferring the species distribution patterns.

Results

Physicochemical variables

The fluctuations in physicochemical parameters of the coastal waters during the studied period were investigated. Temperature variations were significant at both the sampling periods. The surface temperature ranged between 26°C and 26.8°C. pH value had a range from 8.1 to 8.2. The monthly concentrations of NO_2, NO_3, PO_4 and SiO_4 ranged from 1.6 to 2.1 μmol L^{-1}, 0.2 to 3.1μmol L^{-1}, 0.2 to 0.3 μmol L^{-1} and 6.7 to 8.5 μmol L^{-1}

Table 1. Surface water environmental variables in the coastal waters of South Andaman Island.

Stations	St.1				St.2			
Parameter	Day	Night	Mean	SD	Day	Night	Mean	SD
Temperature (°C)	26.4	26.3	26.4	0.06	26.8	26.0	26.4	0.59
Salinity	31.5	31.8	31.7	0.24	32.3	31.8	32.0	0.29
pH	8.2	8.2	8.2	0.01	8.1	8.1	8.1	0.01
Dissolved Oxygen (mg/l)	4.3	4.1	4.2	0.11	4.1	4.1	4.1	0.03
Nitrite (mμol/l)	1.9	1.6	1.7	0.18	2.1	1.8	1.9	0.21
Nitrate (mμol/l)	3.1	2.8	3.0	0.23	0.5	0.2	0.3	0.18
Phosphate (mμol/l)	0.2	0.2	0.2	0.03	0.3	0.2	0.3	0.09
Silicate (mμol/l)	7.7	6.9	7.3	0.54	8.5	6.7	7.6	1.27
Chlorophyll *a* (μg/l)	0.009	0.008	0.01	0.00	0.01	0.01	0.01	0.001

respectively. The lowest nutrient concentration (0.02 μmol L^{-1}) was registered at Station 1 during the month of Apr 2012. In Station 2, silicate (14.41 μmol L^{-1}) and nitrate (3.82 μmol L^{-1}) concentrations showed higher values in Dec 2011 (Table 1).

Phytoplankton community

Station 1 and Station 2 showed difference in phytoplankton composition throughout the sampling periods. The first set included all the samples from Nov 2011 to Apr 2012, the second set included monthly samples and the third comprised of samples taken during day and night for diurnal variation. A total of 204 species and 65 genera were identified from two stations. Station 1 comprised of 203 species and 63 genera, whereas 137 species and 50 genera were observed at Station 2. Diatoms (135 species, 45 genera), dinoflagellates (63 species, 16 genera) cyanobacteria (4 species, 4 genera), and silicoflagellates (2 species, 1 genera) were predominant taxonomic groups observed in these coastal waters. During the sampling period, phytoplankton density of station 2 was extremely high as compared to station 1, with a mean density of 9500 cell.mL^{-1}. *Bacteriastrum furcatum*, *Guinardia flaccida, Leptocylindrus danicus, Rhizosolenia alata, Rhizosolenia imbricata* and *Meuniera membranacea* were the main diatoms abundant in these coastal waters.

Relationship between phytoplankton assemblage and environmental influences

The relationship between the phytoplankton and the environmental factors were studied by canonical correspondence analysis (CCA) with special attention to the sampling periods (day and night). CCA analysis clearly shows the influence of nutrients such as nitrate, silicate and phosphate as well as the salinity and temperature on the phytoplankton productivity during day and night samples

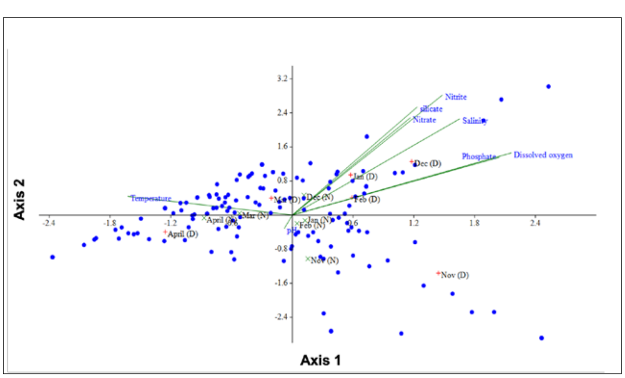

Fig. 2. CCA biplot of the environmental variables and phytoplankton distribution over the first and second ordination axes with a clear phase between day (D) and night (N) at St. 1.

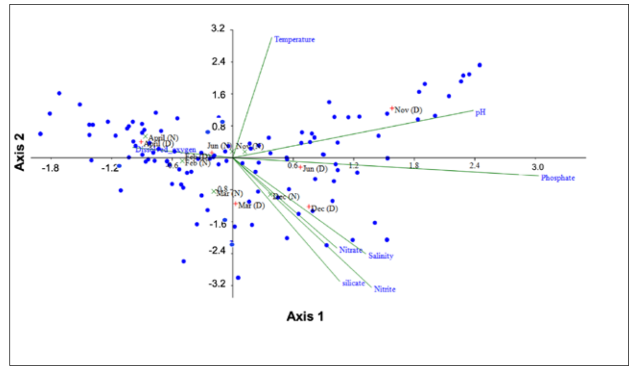

Fig. 3. CCA biplot of the environmental variables and phytoplankton distribution over the first and second ordination axes with a clear phase between day (D) and night (N) at St. 2.

(Fig. 2 & 3). Dec, Jan and Feb were correlated with the highest concentrations of nutrients (Nitrate, Nitrite, Silicate and Phosphate), while other months (Mar and Apr) were related to temperature at St. 1. Nov and Jan were correlated with temperature and pH at St.2 (Fig. 2 & 3). The higher biomass of the phytoplankton was observed in day samples at both stations (Night 12783 and day 19169 cell/ml). During Dec/Jan/Feb at St.1 and Dec/Jan/Mar at St.2, the phytoplankton composition and diversity was very less due to the high saline (32.3) and high temperature (26.8°C) during the summer. These periods might have low radiation and frequent mixing of the water column. The results revealed that the major leading factor influencing the phytoplankton might be light and temperature which support the primary production and development of abundant biomass.

The phytoplankton community variation on the day and night scale was confirmed statistically by detrended correspondence analysis (DCA) at two sampling stations. The ordination of the sites revealed six month intervals of the day and night variations. Eigenvalues for axis 1 (0.60, 0.62) was larger than that of axis 2 (0.35, 0.30) for St. 1 and St. 2 respectively (Fig. 4 and 5). The two sampling sites along the first and second axis in the DCA showed the diurnal variability of plankton community assemblages. Centric diatoms were dominant in the samples collected during day time (*Bacteriastrum furcatum, B. hyalinum, Guinardia striata, Guinardia flaccida, Leptocylindrus danicus, Rhizosolenia alata* and *R. imbricata*), whereas cyanobacteria (*Trichodesmium erythraeum*) and dinoflagellates (*Ceratium furca, C. fusus, Prorocentrum micans, Protoperidinium depressum*) dominated in night samples. The diurnal phytoplankton community assemblages were distinct in both the sampling stations and the variation was more during March than other month intervals. Some species that did not demonstrate almost any light dependency, appeared in both day and night samples. Further, some phytoplankton species, *Asterionella glacialis, Chaetoceros*

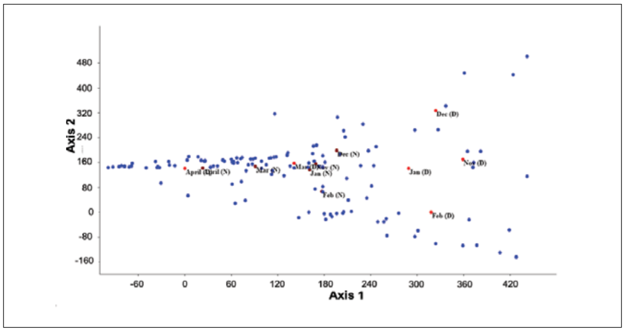

Fig. 4. Detrended Correspondence Analysis (DCA) of phytoplankton species in the coastal waters for St. 1, with distinct influence pattern during day (D) and night (N).

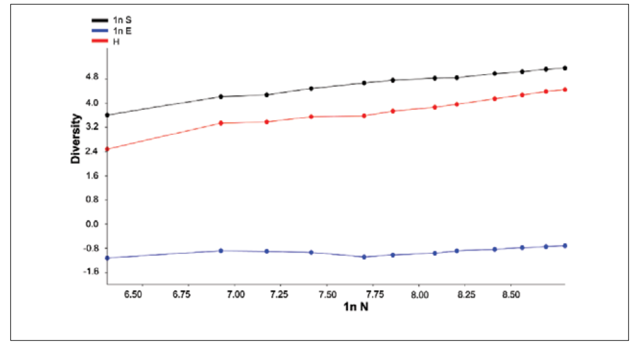

Fig. 6. SHE analysis plot for phytoplankton genera richness (ln S), Shannon–Wiener index (H), and evenness (ln E) at St.1.

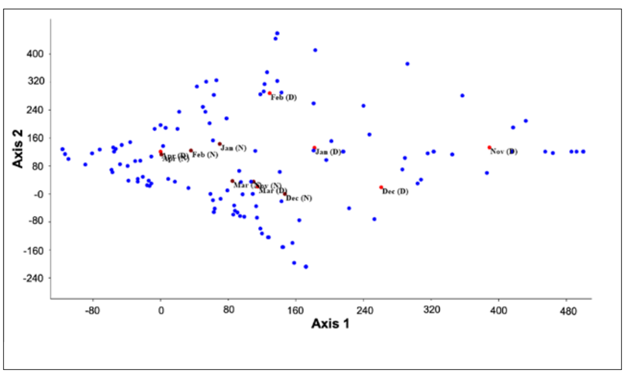

Fig. 5. Detrended Correspondence Analysis (DCA) of phytoplankton species in the coastal waters for St. 2, with distinct influence pattern during day (D) and night (N).

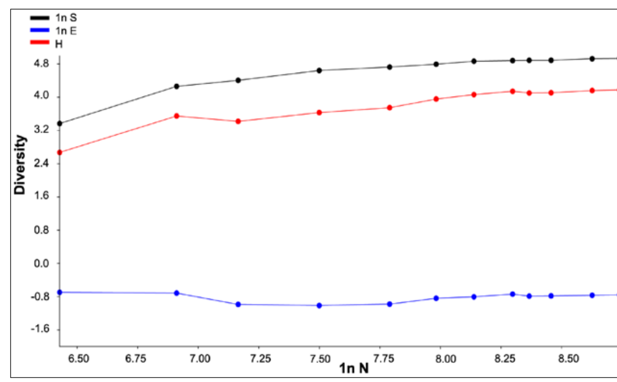

Fig. 7. SHE analysis plot for phytoplankton genera richness (ln S), Shannon–Wiener index (H), and evenness (ln E) at St.2.

orientalis, Cymbella sp., *Mastogloia smithii, Nitzschia closterium, Pleurosigma angulatum, Rhizosolenia robusta* and *Thalassiosira decipiens* that were present only in very low percentage throughout the sampling period did not show any particular trend. Rare species or those that appear with low frequency do not really add more information to the present analysis. The present findings clearly depicts that changes in light conditions can influence phytoplankton composition of the two sampling sites. Phytoplankton tend to dominate considerably during daytime. SHE (S (species richness), H' (information), and E (evenness)) analysis examined the relationship between the species richness, the diversity, and the evenness in the sampled community, in order to determine if the community data resembles a log series. A SHE diagram, which plots lnS, H and lnE vs. lnN on a single graph, was constructed for six months. All SHE measures have illustrated minor fluctuations in the values throughout six-month sampling intervals. The fluctuations in SHE values for lnS and H was relatively constant throughout the study period at St.1 and St.2 (Fig. 6 and 7). lnE shows relatively small oscillations. This implies that the phytoplankton community fitted better to a log-normal distribution which suggests a non-fully random niche partition.

Discussion

The phytoplankton community structure and species succession have been regulated by temperature, salinity and trophic conditions (Madhav and Kondalarao 2004; Gasiunaite *et al.*, 2005; Vinithkumar *et al.,* 2011; Karthik *et al.,* 2012; Begam *et al.*, 2015; Karthik and Padmavati, 2017; Karthik *et al.*, 2017). Other environmental determinants have been reported to be low light intensity, high nutrient availability (Popovich *et al.*, 2008; Jha *et al.*, 2014; Karthik *et al.*, 2014a; Franklin *et al.*, 2018), zooplankton grazing (Huang *et al.,* 2004) and a strong tidal mixing of the water column (Trigueros and Orive, 2001). In our study, the observed variation in coastal water temperature followed an irregular pattern. The salinity gradient also played a major role in determining the distribution of communities of phytoplankton. Coastal species and communities are well adapted to the variations in salinity that are related to tidal cycles and seasonal rainfall patterns. Such variation reduces competition among different phytoplankton groups, possibly causing high rates of primary productivity (Lueangthuwapranit *et al.,* 2011).

Dramatic changes in both the total abundance and species composition of phytoplankton in St.1 and St. 2 were observed during the study period. Bacillariophyceae dominated in the two stations and subsequently increased their density significantly towards March 2012. Marked changes in this dominant algal group alternating with dinophyceae and dictyochophyceae were also observed in the other regions of Andaman coast (Vinithkumar *et al.,* 2011; Sankar and Padmavathi, 2012; Begum *et al*., 2012; Elangovan *et al*., 2012; Karthik *et al.*, 2012; Goswami *et al*., 2020). Diatoms (92%) dominated over dinoflagellates (7%) in cell concentrations and in species diversity in station 1 when compared to station 2. Major changes were seen at the genus level of the phytoplankton community from the coastal waters at St.1 and St.2 as compared with the former reports (Sankar and Padmavathi, 2012; Karthik *et al.,* 2012; Karthik and Padmavati 2014; Karthik *et al.,* 2014a; Karthik *et al.,* 2014b). Diatoms (*Bacteriastrum hyalinum, Guinardia striata, Meuniera membranacea, Rhizosolenia alata, R. imbricata*) were found in higher concentrations at station 1, whereas diatoms (*Bacteriastrum furcatum, Guinardia flaccida, Leptocylindrus danicus, Rhizosolenia alata, R. imbricata*) were present at station 2. Lowest phytoplankton density was observed during the month of Nov 2011 and Jan 2012. Similar results were also recorded during the same period (Sarojini and Sarma, 2001; Karthik *et al.,* 2012; Chakraborty *et al.,* 2014). Although dinoflagellates were found consistently in relatively low concentrations in the coastal waters, they have occasionally been reported as the major species responsible for red-tide blooms (Eashwar *et al.,* 2001; Dharani *et al.,* 2004; Kumar *et al.,* 2012; Sahu *et al.,* 2014; Karthik and Padmavati, 2017). The phytoplankton community presented lower diversity and abundances during night time. A reduction of light energy could be the major reason for extreme decline of algal biomass (Kirk, 1994; Shikata *et al.,* 2008; Karthik *et al*., 2020).

Although the total number of species was found to be high compared with other coastal waters of Andaman (Sarojini and Sarma, 2001; Madhav and Kondalarao, 2004; Vinithkumar *et al.,* 2011; Sankar and Padmavathi, 2012; Elangovan *et al.,* 2012; Karthik *et al.,* 2012) only a few species can be considered as common or frequent. The criteria used to separate rare species yielded a total of 12 rare species *Bacteriastrum furcatum, Chaetoceros curvisetus, Coscinodiscus centralis, Ditylum brightwellii, Leptocylindrus danicus, Pleurosigma elongatum, Pseudonitzschia australis, Rhizosolenia alata, Rhizosolenia imbricata, Ceratium furca, Protoperidinium divergens* and *Protoperidinium depressum*. These rare species most probably are those with low populations and make little contribution to community processes that do not colonize successfully the site due to competition, unfavorable conditions and/or predation; they are maintained in the ecosystem at low densities or through repeated immigration (MacArthur and Wilson, 1967; Hutchinson, 1961). Finally, the results support the view that temporal variation, even in the coastal waters, located in a region of high seasonal weather variation, enhances the global phytoplankton diversity and explains in part, the coexistence of a much larger number of species in a specific environment (Reynolds, 2006). The importance of temporal variation in the conditions of the coastal waters has been one of the main factors that explain this coexistence of a large number of species (Hutchinson, 1961).

Relationship between phytoplankton density and the physicochemical variables were investigated using multivariate analysis, focusing on the determination of significant factors affecting the changes in the density of phytoplankton species. The developments of mixed assemblages of coastal water species varied monthly throughout the study period and varied predominantly during the monsoon periods, when heavy rainfalls regulated the increasing amount of nutrient runoff from domestic sewage into the coastal waters leads to nutrient content accumulation and influencing primary productivity. This explains the cause behind high values recorded for nutrients especially nitrate and silicate at both stations. Consequently, some species such as *R. alata* and *R. imbricata* were most dominated in this study sites. In the 2 stations sampled during the monsoon season in March, the algae community was found to distribute regularly along a nutrient gradient. Along with nutrient axis, the phytoplankton assemblage dominated by sensitive and clean water species was replaced by nutrient-tolerant phytoplankton taxa, indicating that algal growth was affected mainly by nutrient status. The absence of monsoon in South Andaman during January to April 2012 has been attributed especially to low precipitation, and discharge regulation, which probably influenced the low values of species richness, especially in our study area. It indicated that a good relationship existed between phytoplankton community and monsoon water quality parameters.

The major coastal water inhabitants in the two stations, as in the other coastal waters, were diatoms and dinoflagellates, which were positively correlated with the salinity factor. Some species such as *Eucampia zoodiacus, Leptocylindrus danicus, Nitzschia closterium, Nitzschia sigma, Guinardia flaccida, Odontella mobiliensis* and *Rhizosolenia alata* were observed that is repeated at almost the same time in all the intervals of month. In case of *Amphora acuta, A. alata, A. ostrearia, Bacillaria paxillifera, Climacosphenia elongates* and *Entomoneis sulcata,* low densities without a clear cyclical pattern was observed. In the present investigation it was observed that species like *Rhizosolenia alata* and *Rhizosolenia imbricata* were showed population peaks of short duration, most probably as a result of changing environmental conditions, and disappeared quickly. It is also possible that the community goes through a period of rapid change as a response to environmental conditions, and then remains fairly constant for a long time without major shifts in species composition as long as conditions remain stable (Villalobos, 2010). A similar behavior has been observed in both stations, where rapid changes were followed by periods of relative stability, such as the case for *Bacteriastrum hyalinum, B. furcatum, Guinardia striata, Guinardia flaccida* and *Leptocylindrus danicus* which resist to all variations. Despite all the variations, the analysis of phytoplankton species composition was more at St. 2, which was similar to the composition of the phytoplankton observed in the coastal waters (Madhav and Kondalarao, 2004; Karthik *et al.,* 2012). Further some species (*Meuniera membranacea* and *Hemidiscus hardmannianus*) were dominated in a short period of time. These species were not detected prior to its dramatic increase, and remained at low abundances afterwards.

The degree of influence that environmental conditions had on the dominant taxa during March and April show that specific taxon abundances observed are not the whole picture with respect to defining the environment. From the present data, it seems that the minor variations during the day to day weather changes, especially fluctuations in wind strength, are more important in determining the water column behavior and changes in the plankton community. This short term variation can preclude the establishment of a well-defined successional variation in the plankton communities as stated by the general theory of plankton succession (Sommer, 1989; Padisak, 2003; Reynolds, 2006). Our findings in the present investigation on phytoplankton were similar to the results of previous studies related to seasonal changes (Perumal *et al.,* 2009; Muduli *et al.,* 2011), salinity (Sridhar *et al.,* 2006; Mohanty *et al.,* 2010) and nutrient availability (Karthik *et al.,* 2012).

Seasonal variability of phytoplankton communities in the south Andaman Island is dependent on light, temperature, and nutrients. Diatoms and dinoflagellates have strong relationship with environmental parameters such as light and temperature. Plankton families such as Lauderiaceae, Stephanopyxidaceae, Coscinodiscaceae and Rhizosoleniaceae have displayed diurnal occurrence in the study areas. The occurrence of 12 rare plankton species in the study areas is needed to be monitored with reference to physio-chemical properties. The variations in the plankton composition in south Andaman Island are to be monitored further to identify the influencing factors of local or global climate change.

Acknowledgements

Authors are thankful to the Head of the Department, Ocean Studies and Marine Biology, Pondicherry University, Port Blair for providing facilities. We also express our sincere gratitude to the fishermen who helped immensely during the sampling.

References

Achary, M. S., G. Sahu, A. K. Mohanty, M. K. Samatara, S. N. Panigrahy, M. Selvsnsysgam, K. K. Satpathy, M. V. R. Prasad and R. C. Panigrahy. 2010. Phytoplankton abundance and diversity in the coastal waters of Kalpakkam, east coast of India in relation to the environmental variables. The *Bioscan.,* 2: 553–568.

Ananthan, G. A., P. Sampathkumar, P. Soundarapandian and L. Kannan. 2004. Observation on environmental characteristics of Ariyankuppam estuary and Verampattinam coast of Pondicherry. *J. Aqua. Biol.,* 19: 67-72.

Baliarsingh, S. K., S. Srichandan, S. K. Pati, K. C. Sahu, S. K. Dash, A. A. Lotliker and T. S. Kumar. 2016. Phytoplankton community structure along offshore transects of some Indian estuaries of east coast: An experience with a summer cruise. *Indian J. Geo-Mar. Sci.,* 45: 960–973.

Begum M., B. K. Sahu, A. K. Das, N. V. Vinithkumar and R. Kirubagaran. 2015. Extensive Chaetoceros curvisetus bloom in relation to water quality in Port Blair Bay, Andaman Islands. *Environ. Monit. Asses.*, 187: 226.

Boney, A. D. 1975. *Phytoplankton.* Edward Arnold Ltd. London, 116 pp.

Chakraborty, A., G. Padmavati, A. K. Ghosh, R. S. Singh and P. K. Pal. 2014. Phytoplankton diversity in the coastal waters of Port Blair, South Andaman, India. *Geophytol.,* 44: 9-18.

Chellappa, N. T., F. R. A. Camara and O. Rocha. 2009. Phytoplankton community: indicator of water quality in the Armando Ribeiro Goncalves reservoir and Pataxó channel, Rio Grande do Norte. Brazil. *Braz. J. Biol.,* 69: 241-251.

Cloern, J. E., S. Q. Foster and A. E. Kleckner. 2014. Phytoplankton primary production in the world's estuarine-coastal ecosystems. *Biogeosciences.,* 11: 2477.

Cupp, E. E. 1943. *Marine plankton diatoms of the west coast of North America.* University of California Press Berkeley and Los Angeles, Berkeley, p. 1-238.

Degerman R, R. Lefébure, P. Byström, U. Båmstedt, S. Larsson and A. Andersson 2018. Food web interactions determine energy transfer efficiency and top consumer responses to inputs of dissolved organic carbon. *Hydrobiologia.,* 805: 131-146.

Dharani, G., A. A. Nazar, L. Kanagu, P. Venkateshwaran, T. S. Kumar, K. Ratnam and M. Ravindran. 2004. On the recurrence of *Noctiluca scintillans* bloom in Minnie Bay, Port Blair: Impact on water quality and bioactivity of extracts. *Curr. Sci.,* 87: 990-994.

Eashwar, M., T. Nallathambi, K. Kuberaraj and G. Goveindarajan. 2001. *Noctiluca* blooms in Port Blair Bay, Andamans. *Curr. Sci.,* 81:203-206.

Elangovan, S. S., M. A. Kumar, R. Karthik, R. Siva Sankar, S. Jayabarathi and G. Padmavati. 2012. Abundance, species composition of microzooplankton from the coastal waters of Port Blair, South Andaman Island. *Aquat. Biosyst.,* 8: 1-9.

Franklin, J. B., T. Sathish, N. V. Vinithkumar, R. Kirubagaran and P. Madeswaran. 2018. Seawater quality conditions of the south Andaman Sea (Bay of Bengal, Indian Ocean) in lustrum during 2010s decade. *Mar. Poll. Bull.,* 136: 424–434.

Gasiunaite, Z. R., A. C. Cardoso, A. S. Heiskanen, P. Heiskanen, P. Kauppila, I. Olenia and H. Schubert. 2005. Seasonality of coastal phytoplankton in the Baltic Sea: influence of salinity and eutrophication. *Estu. Coas. Shelf. Sci.,* 65: 239-252.

Guillard, R. R. L. 1978.*Counting slides. Phytoplankton Manual,* UNESCO, Paris, p. 182-189.

Goswami, P., S. Gupta, A. K. Das, N. V. Vinithkumar, G. Dharani and R. Kirubagaran. 2020. Impact of a dinoflagellate bloom on the marine plankton community structure of Port Blair Bay, Andaman Island. *Reg. Stud. Mar. Sci.,* 101320.

Huang, L., W. Jian, X. Song, X. Huang, S. Liu, P. Qian and M. Wu. 2004. Species diversity and distribution for phytoplankton of the Pearl River estuary during rainy and dry seasons. *Mar. Poll. Bull.,* 49: 588-596.

Hutchinson, G. E. 1961.*The paradox of the plankton.* American Naturalist, p. 137-145.

Jha, D. K, N. V. Vinithkumar, B. K. Sahu, A. K. Das, P. S. Dheenan, P. Venkateshwaran, M. Begum, T. Ganesh, P. M. Devi and R. Kirubagaran. 2014. "Multivariate statistical approach to identify significant sources influencing the physico-chemical variables in Aerial Bay, North Andaman, India. *Mar. Poll. Bull.,* 85: 261–267

Karthik, R., M. Arun Kumar, S. Elangovan, R. Siva Sankar and G. Padmavati. 2012. Phytoplankton Abundance and Diversity in the Coastal Waters of Port Blair, South Andaman Island in Relation to Environmental Variables. *J. Mar. Biol. Oceanog.,* 1: 1-6.

Karthik, R., A. M. Kumar and G. Padmavati. 2014a. Silicate as the Probable Causative agent for the Periodic blooms in the coastal waters of South Andaman Island. *Appl. Env. Res.,* 36: 37-45.

Karthik, R., G. Padmavati and R. Jayabarathi. 2014b. Dinoflagellate Bloom of *Ceratium furca* in the Coastal Waters of South Andaman. *Int. J. Curr. Res.,* 6 pp.

Karthik, R. and G. Padmavati, G. 2014. Dinoflagellate Bloom Produced by *Protoperidinium divergens* Response to Ecological Parameters and Anthropogenic Influences in the Junglighat Bay of South Andaman Islands. *Appl. Env. Res.,* 36: 19-27.

Karthik, R. and G. Padmavati. 2017. Intense rare bloom of *Chaetoceros tortissimum* (Gran) in relation to water quality assessed using multivariate statistical approach at Chouldari Bay, South Andaman Island. *Cah. Biol. Mar.,* 58: 423-433.

Karthik, R., G. Padmavati S. S. Elangovan and V. Sachithanandam. 2017. Monitoring the Diatom bloom of *Leptocylindrus danicus* (Cleve 1889, Bacillariophyceae) in the coastal waters of South Andaman Island. *Indian J. Geo-Mar. Sci.,* 46: 958-965.

Karthik, R., R. S. Robin, I. Anandavelu, R. Purvaja, G. Singh, M. Mugilarasan, T. Jayalakshm, V. D. Samuel and R. Ramesh. 2020. Diatom bloom in the Amba River, west coast of India: A nutrient-enriched tropical river-fed estuary. *Reg. Stud. Mar. Sci.,* 101244.

Kirk, J. T. O. 1994. Light and Photosynthesis in Aquatic Ecosystems Second ed. *Cambridge University Press, Cambridge, Great Britain,* 509 pp.

Kumar, A. M., R. Karthik, S. Sai Elangovan and G. Padmavati. 2012. Occurrence of *Trichodesmium erythraeum* bloom in the coastal waters of south Andaman. *Int. J. Curr. Res.,* 4: 281-284.

Lueangthuwapranit, C., U. Sampantarak and S. Wongsai S. 2011. Distribution and Abundance of Phytoplankton: Influence of Salinity and Turbidity Gradients in the Na Thap River, Songkhla Province, Thailand. *J. Coas. Res.,* 27: 585-594.

Mac Arthur, R. and J. O. Wilson. 1967. *The theory of island biogeography.* Princeton, New York, USA.

McManus, M. A and C. B. Woodson. 2012. Plankton distribution and ocean dispersal. *J. Experim. Biol.,* 215: 1008-1016.

Madhav, V. G. and B. Kondalarao. 2004. Distribution of phytoplankton in the coastal waters of east coast of India. *Indian J. Mar. Sci.,* 33: 262-268.

Mohanty, A. K., K. K. Satpathy, G. Sahu, K. J. Hussain, M. V. R. Prasad and S. K. Sarkar. 2010. Bloom of *Trichodesmium erythraeum* (Ehr.) and its impact on water quality and plankton community structure in the coastal waters of southeast coast of India. *Indian J. Mar. Sci.,* 39: 323-333

Moore, J. K. and M. R. Abbott. 2002. Surface chlorophyll concentrations in relation to the Antarctic Polar Front: seasonal and spatial patterns from satellite observations. *J. Mar. Syst.,* 37: 69-86.

Muduli, P. R., N. V. Vinithkumar, M. Begum, R. S. Robin, K. V. Vardhan, R. Venkateasn and R. Kirubagaran. 2011. Spatial Variation of Hydrochemical Characteristics in and Around Port Blair Bay Andaman and Nicobar Islands, India. *Worl. Appl. Sci. J.,* 13: 564-571.

Muylaert, K, K. Sabbe and W. Vyverman. 2009. Changes in phytoplankton diversity and community composition along the salinity gradient of the Schelde estuary (Belgium/The Netherlands). *Estuarine, Coast. Shelf Sci.*, 82: 335–340.

Padisak, J. 2003. Phytoplankton, In O'Sullivan PE, Reynolds CS (ed). The lakes handbook, Vol. I: limnology and limnetic ecology. *Blackwell, Oxford, United Kingdom.* p. 251-308.

Perumal, N. V., M. Rajkumar, P. Perumal and K. T. Rajasekar. 2009. Seasonal variations of plankton diversity in the Kaduviyar estuary, Nagapattinam, southeast coast of India. *J. Envir. Biol.,* 30: 1035-1046

Popovich, C. A., C. V. Spetter, J. E. Marcovecchio and R. H. Freije. 2008. Dissolved nutrient availability during winter diatom bloom in a turbid and shallow estuary (Bahía Blanca, Argentina). *J. Coas. Res.,* 24: 95-102.

Pourafrasyabi, M. and Z. Ramezanpour. 2014. Phytoplankton as bio-indicator of water quality in Sefid Rud River, Iran (South of Caspian Sea). *Caspian J. Environ. Sci.,* 12: 31-40.

Priddle, J., F. Brandini and M. Lipski.1994. Pattern and variability of phytoplankton biomass in the Antarctic Peninsula region: an assessment of the BIOMASS cruises. Southern Ocean ecology: the BIOMASS perspective, Campridge University Press, *Cambridge.* p. 49-61.

Reynolds, C. S. 2006. *The ecology of phytoplankton.* Cambridge University Press.

Sankar, R. S. and G. Padmavathi. 2012. Species Composition, Abundance and Distribution of Phytoplankton in the Harbour Areas and Coastal Waters of Port Blair, South Andaman. *Int. J. Ocean. Mar. Ecolo. Sys.,* 1: 1-8.

Salmaso N, G. Morabito, F. Buzzi, L. Garibaldi, M. Simona and R. Mosello. 2006. Phytoplankton as an indicator of the water quality of the deep lakes south of the Alps. *Hydrobiologia.,* 563: 167-187.

Sarojini, Y. and N. S. Sarma. 2001. Vertical Distribution of phytoplankton around Andaman and Nicobar Islands, Bay of Bengal. *Indian J. Mar. Sci.,* 30: 65-69

Shikata, T., S. Nagasoe, T. Matsubara, S. Yoshikawa, Y. Yamasaki, Y. Shimasaki and T. Honjo. 2008. Factors influencing the initiation of blooms of the raphidophyte *Heterosigma akashiwo* and the diatom *Skeletonema costatum* in a port in Japan. *Limnol. Oceanogr.,* 53: 2503–2518.

Shekhar, T. S., B. R. Kiran, E. T. Puttaiah, Y. Shivaraj and K. M. Mahadevan. 2008. Phytoplankton as index of water quality with reference to industrial pollution. *J. Environ. Biol.,* 29: 233–236.

Smetacek, V. 1996. *Biodiversity and production in the water mass.* In: Hempel G (ed) The Ocean and the poles, G Fischer Verlag, Jena. p. 207-216.

Sommer, U. 1989.*Plankton Ecology.* Succession in plankton communities, Springer.

Sridhar, R., T. Thangaradjou, S. S. Kumar and L. Kannan. 2006. Water quality and phytoplankton characteristics in the Palk Bay, southeast coast of India. *J. Envir. Biol.,* 27: 561-566.

Strickland, J. D. H. and T. R. Parsons. 1972. A practical handbook of seawater analysis. *Fish Res Boar. Cana. Otta*., 167pp.

Tas, B. and A. Gonulol. 2007. An ecologic and taxonomic study on phytoplankton of a shallow lake. *Turkey. J. Environ. Biol.,* 28: 439-445.

Tomas, C. R. 1997. *Identifying marine phytoplankton.* Academic Press.

Trigueros, J. M. and E. Orive. 2001. Seasonal variations of diatoms and dinoflagellates in a shallow, temperate estuary, with emphasis on neritic assemblages. *Hydrobiologia.,* 444: 119-133.

Venkataraman, G. 1939. A systematic account of some south Indian diatoms. *Proce. Pla. Sci.,* 10: 293-368.

Villalobos, G. 2010. Temporal variation of phytoplankton in a small tropical crater lake, Costa Rica. *Revi. de Biolo.Trop.,*58: 1405-1419.

Vinithkumar, N. V., M. Begam, G. Dharani, A. Biswas, A. K. Abdul Nazar, R. Venkatesan, R. Kirubagaran and S. Kathiroli. 2011. Distribution and biodiversity of phytoplankton in the coastal seawaters of Andaman and Nicobar Island, India. *Rec. Adva. Biodiver. Ind.,* 16: 137-148.

Walsh, J. J., D. A. Dieterle and J. Lenes. 2001. A numerical analysis of carbon dynamics of the Southern Ocean phytoplankton community: the roles of light and grazing in effecting both sequestration of atmospheric CO2 and food availability to larval krill. Deep Sea Rese Part I: *Oceano. Res. Pape.,* 48: 1-48.