JEB
Journal of Environmental Biology

Journal Home page : www.jeb.co.in
E-mail : editor@jeb.co.in

ISSN: 0254-8704 (Print)
ISSN: 2394-0379 (Online)
CODEN: JEBIDP

Tidal variation of phytoplankton in the coastal waters of South Andaman, India

Arindam Chakraborty[1,2]*, Gadi Padmavati[2] and Amit K. Ghosh[1]

[1]Birbal Sahni Institute of Palaeobotany, Lucknow-226 007, India

[2]Department of Ocean Studies and Marine Biology, Pondicherry University, Port Blair-744 112, India

*Corresponding Author E-mail: flywidari@gmail.com

Publication Info

Paper received:
07 October 2013

Revised received:
26 February 2014

Accepted:
24 March 2014

Abstract

Tidal variations of phytoplankton were studied at two stations i.e., Station 1 (Science Centre) and Station 2 (Junglighat Bay) during the period of December 2010 to February 2011 in the coastal waters of South Andaman Islands, India. Phytoplankton biomass (Chlorophyll-a) was observed low (avg. 0.02- 0.1 mg m^{-3}) at the stations during the sampling period. Low values of dissolved oxygen and biochemical oxygen demand were recorded during low tide. In all 114 species belonging to 42 genera of diatoms, 16 genera of dinoflagellates and 4 genera of cyanobacteria were identified. Phytoplankton population density ranged from 827cells l^{-1} to 11,790 cells l^{-1} and was high during high tide in comparison to low tide. Diatoms were dominant (70.86−88.0%) and contributed more towards phytoplankton biomass followed by dinoflagellates (10.8−19.53%) and cyanobacteria (0.73−9.4%). Dinoflagellates were visualised more in the samples when diatom population had declined. Diversity indices such as species diversity (H') ranged from 0.68−3.1; species richness (d) varied from 2.18−6.54 and Pielou's evenness (J´) ranged from 0.24−0.94. H' was more during high tide than at low tide at Station 2. On the other hand, low diversity and equitability in phytoplankton population were observed at Station 1 during the month of January, 2011. It may be due to dominance of mono specific cells of *Rhizosolenia* sp. The study indicates low production of phytoplankton in coastal waters. Variation of tides may leave implications on sampling, because it has an influence on species diversity and proportion of specific micro algal groups at different times.

Key words

Andaman, Diversity, Phytoplankton, Tidal variation

Introduction

Phytoplankton, at the base of trophic chain in a marine ecosystem, are one of the most fundamental biological components of aquatic ecosystem (Cloern, 1999; Sin *et al.,* 1999) which in turn, maintain biogeochemical cycles (Falkowski, 1994). Phytoplankton are the primary source of food in marine pelagic environment, initiating food chain which may terminate even in large marine mammals (Waniek and Holliday, 2006). These microscopic plants range in size from 1/1000 of a millimetre to 2 mm and float or swim in upper 100 m of the ocean. They depend on sunlight for photosynthesis but some also occur below the photic zone. In addition to sunlight and oxygen, they also require carbon in the form of carbon dioxide, along with some basic nutrients such as nitrogen, phosphate, silicate etc. From ecological point of view, research on phytoplankton species composition and community structure are significant, both in regional and global perspectives. Phytoplankton play a foremost role in determining global productivity of coastal and marine environment as they contributes more than 40% of the global carbon fixed (Taylor and Brownlee, 2003; Choudhury and Pal, 2012). More than 95% of the primary production in oceanic waters is contributed by phytoplankton (Falkowski, 2004). Marine phytoplankton comes in myriad of shapes, sizes and forms which may be single celled to chains or even colonies. Since phytoplankton serve as the basic food source for animals in sea, their preponderance may be a sign of abundance of commercially important fish and shell fish populations (Sridhar *et al*., 2006; Mathivanan *et al*., 2007; Saravanakumar *et al*., 2008). Study of phytoplankton composition is useful in determining the fertility of

sea. Phytoplankton species composition, population density, richness and primary productivity vary depending upon varying hydro-biological features. It is worth mentioning that Reynolds (1993) has stated that 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. These parameters are important to accurately quantify phytoplankton biomass and to determine community composition at species level. Though considerable works have been carried out on distribution patterns of phytoplankton of Indian Ocean and Bay of Bengal in general, studies pertaining to the Andaman Sea are very few. Previous work on hydrology and phytoplankton diversity of coastal waters of the Andaman Sea is meagre (Sarojini and Sarma, 2001; Dharani *et al.,* 2004; Madhav and Kondalarao, 2004; Vinith Kumar, 2009) and especially, information on phytoplankton of South Andaman Islands is scanty (Sarojini and Sarma, 2001; Karthik *et al*., 2012; SivaSankar and Padmavati, 2012). The major questions in this regard are: what drives the variation in population abundances and how to understand the complex interplay between the inherent population dynamics and external environmental forcing (Bjørnstad *et al.,* 2001; Dakos *et al.,* 2009). It has been revealed that plankton communities are sensitive to variation in environmental conditions (Smayda, 1998; Stomp *et al.,* 2008; Benincà, 2011). Environmental forcing by tidal cycles is a significant driver of phytoplankton community in coastal waters (Brunet and Lizon, 2003; Sharples, 2008; Chen *et al.,* 2010). Tidal studies are of considerable importance for any marine environment as tides exert varying influence on physico-chemical characteristics and on the dynamics of phytoplankton. Till date a number of contributions have been made on tidal variation of phytoplankton community mainly, in the creek systems of India which has a stratification of water from marine to fresh (Palleyi e*t al.* 2008; Anantha, 2008). Most of the previous studies in Andaman and Nicobar Islands were confined to distribution of phytoplankton whereas, very little is known about the influence of diversity on tidal variation. The objectives of this study were to analyse the variation in hydrological parameters, variation in phytoplankton biomass and phytoplankton composition, along with species diversity according to tidal variation.

Materials and Methods

Sampling for the present analysis was carried out for a period of three months (December, 2010 – February, 2011). During this period, the coastal waters in this region remain undisturbed because of the typical equatorial climate, with rainy and dry season, prevails in this part of the globe. The rainy season extends from mid May to early December and the dry season starts from January and persists till April−May. Amongst the two selected stations (Fig.1), Station 1 i.e., Science Centre is situated between Sesostris Bay and Carbyn's Cove. This station represents open sea coastal water. Station 2 *i.e.*, Junglighat Bay is situated near the Haddo harbour and is one of the major fish landing centres in Port Blair. This bay is funnel shaped and patches of mangroves are present around it. The area is enclosed by hillocks on all the three sides and more fresh water seepage occurs in the intertidal region. This sampling station receives large amount of sewage discharge from the adjacent locality. Moreover, several mechanised boats with fishing trawlers halt at this location and release polluted oil. In addition, non-degradable plastics, fish wastes etc. are also discharged in uncontrolled manner.

Phytoplankton samples were collected from near the shore surface waters at Station 1 and Station 2. According to the tidal extremes and heights (highest high tide and lowest low tide i.e., neap tides) of Mobile Geographic website, at monthly intervals. By using a phytoplankton scoop net (30µm), the samples were collected and brought to the laboratory for analyses. For each sampling, 50 l of water samples were passed through the phytoplankton net. The collected samples were further separated into two sub samples. The living specimens (first fraction) were used for taxonomic identification and other sub sample (second fraction) was preserved in 1% Lugol's solution for quantitative analyses. Phytoplankton species were identified with lowest possible taxonomic level, using relevant literatures (Venkataraman, 1939; Subrahmanyan, 1946; Desikachary and Prema, 1987; Tomas, 1997) and a systematic list of flora was prepared. Photomicrographs were taken, using phase contrast microscope (Carl-Zeiss Axiostar) attached with a

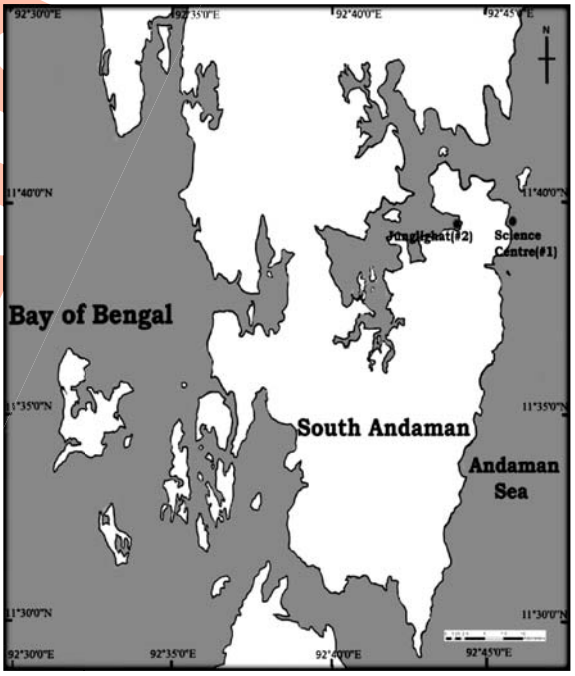


Fig. 1 : Map of Port Blair in South Andaman showing the study area i.e. Science Centre (1) and Junglighat (2)

digital camera (Canon Powershot A80) at magnification of 10X, 40X and 60X. Phytoplankton cell counts from the composite samples were performed using a Sedgewick–Rafter cell counter (Vuorio *et al.*, 2007). The total number of phytoplankton present in one litre of water sample was calculated using the conventional formula (Karthik *et al.*, 2012).

From each station, water samples of equal volume (500 ml) were collected in PVC bottles (500 ml) up to the brim under the surface of water and were capped immediately under water to avoid any exchange of atmospheric air. The samples thus obtained were pooled together in 5 l PVC container and were immediately sealed with a stopper. Later on, these were stored in ice for transportation. Temperature, salinity and pH were measured *in situ* immediately during sampling using Celsius thermometer, refractometer (ERMA, Tokyo) and pH meter (Hanna Instruments) respectively. Dissolved oxygen (DO) content was measured following Winkler's Iodometric Titration method (Winkler, 1888). Water samples were collected in 300 ml DO bottles and Winkler's A and B reagent were added in field, which were then wrapped with aluminium foil. The water samples were brought back to the laboratory for further analysis and precautions were taken to avoid any change in water quality or external contamination. For BOD (Biochemical Oxygen Demand), the bottles were immediately stored in dark condition and left for incubation for 4 to 5 days. The difference of BOD by biological organisms present in those waters was noted. It also provided a primary idea of the pollution status of water.

For estimation of Chlorophyll-a concentration, each sample (5 litres) was filtered through Whatsman GF/C (47mm) under vacuum through a Millipore filtering unit. Chlorophyll-a was extracted in 10 ml of 90% acetone and incubated overnight at 4°C. Later, the extract was centrifuged at 5000 rpm for 10 min and then the concentration was measured by using an UV-Visible Spectrophotometer (UVMAKE). Chlorophyll-a concentration was calculated using equation of Strickland and Parsons (1972). Three diversity indices such as species diversity, species richness and evenness were computed to evaluate the variation in plankton community structure and diversity, using PRIMER 5.0 and verified by PAST 2.0. The cluster analysis and factor analysis were carried out with the help of SPSS 18.0 and XLSTAT software.

Results and Discussion

During the present study, the tidal amplitude of low tide varied from 0.09−0.33 m and high tide varied from 1.90−2.24 m. Temperature is an important hydrographical parameter that influences almost every chemical and biological interaction. Temperature of water varied from 22.5−33°C in the study area, during December 2010 to February 2011. Maximum temperature of 33°C was recorded at Station 2 during high tide (HT) in the month of February and minimum temperature of 22.5°C was recorded at Station 1 during low tide (LT) in the month of January. A sudden rise in water temperature was observed during the month of February (Fig. 2a). The temperature variability was negligible with respect to tides. Salinity is also an important determinant of life forms in oceans, whereas salinity changes profoundly influence its natural resources. Salinity ranged from 30-38 psu at Station 1 and 22-34 psu at Station 2 (Fig. 2a). Lowest salinity (22 psu) was recorded at Station 2 during HT in the month of December, whereas, highest (38 psu) was recorded at Station 1 during HT in the month of January (Fig. 2a). Salinity during HT in the month of December was less than LT due to rainfall. Tidal variation with respect to salinity was not pronounced at both the stations and this phenomenon was also evidenced by Dharani *et al.* (2004). The pH values ranged from 6.8−8.1 at Station 1 and 6.7−8.0 at Station 2 (Fig. 2a). During the month of January, an alkaline condition (pH 8.1 at Station 1 and 8.0 at Station 2) was observed. As visualised, there was no change in pH with respect to tides (Fig. 2a). Dissolved oxygen varied from 4.5−5.6 ml l^{-1} at Station 1 and 3.4−4.4 ml l^{-1} at Station 2 (Fig. 2b). Lowest value was obtained at Station 2 during LT in December (Fig. 2b). Biochemical oxygen demand ranged from 0.67−2.41 ml l^{-1} at Station 1 and 1.4−1.82 ml l^{-1} at Station 2 and showed similar pattern like DO as it gradually increased from December to February (Fig. 2b). Maximum BOD value (2.41 ml l^{-1}) was observed during HT and the minimum value (0.67 ml l^{-1}) was observed during LT at Station 1 (Fig. 2b).

The values of DO and BOD were recorded high during HT at both the stations, when water from open sea was influxed. Chlorophyll-a concentration (algal biomass) is usually considered as an index of productivity (Yao *et al.*, 2010). Chlorophyll-a value (mg m^{-3}) ranged from 0.01−0.04 at Station 1 and 0.03−0.1 at Station 2. It was observed that Chlorophyll-a value at both the sampling stations was generally high during HT from December to February.

Species composition of phytoplankton may be used as a measure of the overall community's stage of development, history and natural fertility of the environment. In the present study, a total of 114 phytoplankton species belonging to 3 classes *viz., Bacillariophyceae* (diatoms), *Dinophyceae* (dinoflagellates) and *Cyanophyceae* (Cyanobacteria) were recorded. *Bacillariophyceae* comprises of 85 species belonging to 43 genera. These are passive floating, silicified and chain forming. *Dinophyceae,* represented by 16 genera of 27 species, are self-propelled and *Cyanophyceae* (Cyanobacteria) comprises of 5 species belonging to 4 genera are photosynthetic bacteria. Amongst these, diatoms were most dominant (70.8−88.0%), followed by dinoflagellates (10.8−19.5%) and Cyanobacteria (0.7−9.4%), respectively. Amongst diatoms, taxa like *Rhizosolenia* sp., *Coscinodiscus* sp., *Navicula* sp., *Nitzschia longissima, Pseudonitzschia* sp., *Pleurosigma* sp., *Leptocylindrus* sp. and *Thalassiothrix* sp., whereas amongst the dinoflagellates *Ceratium* sp., *Gymnodinium* sp., *Protoperidinium* sp., *Dinophysis caudata* and *Prorocentrum* sp. were more abundant. Spatial and

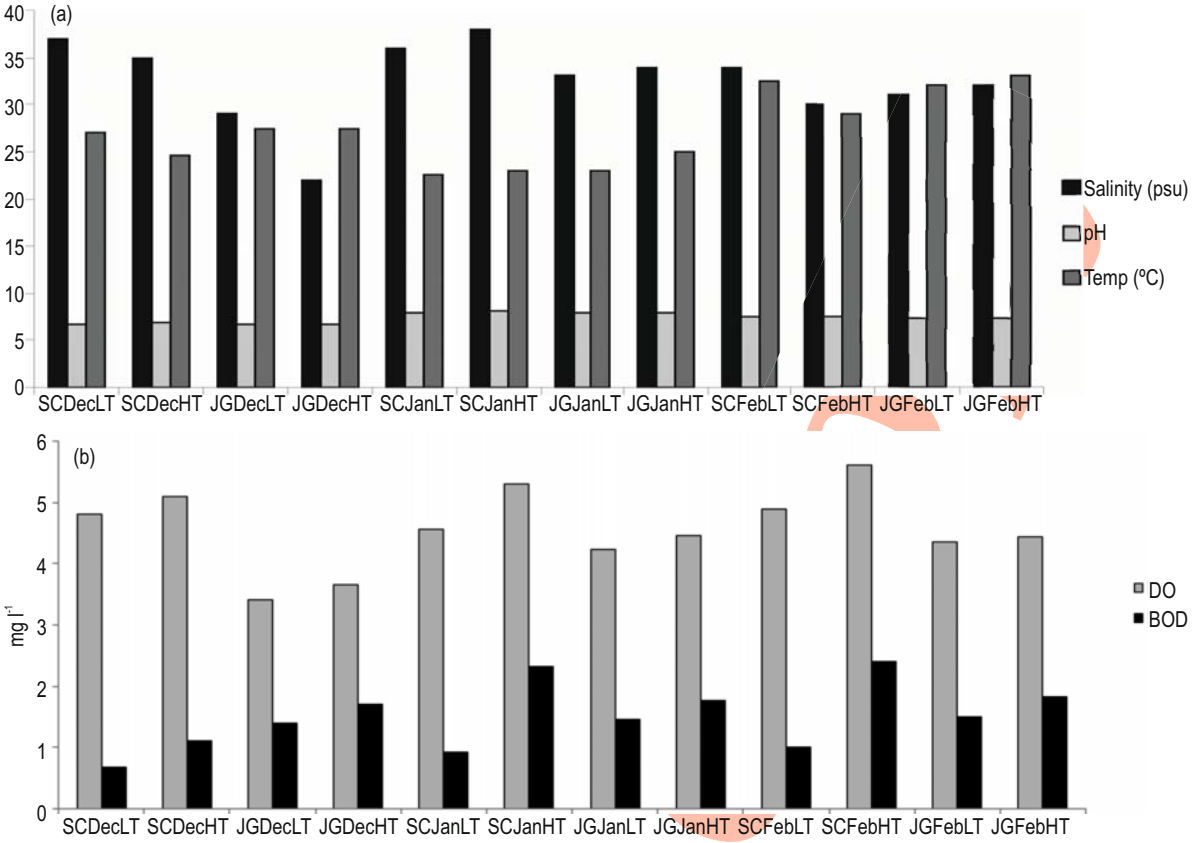


Fig. 2 : Physico-chemical parameters of water from Science Centre (SC) and Junglighat (JG) during December to February for (a) salinity, temperature and pH (b) DO and BOD

temporal variations in phytoplankton population density with respect to tidal changes at both the stations are illustrated in Fig. 3a and 3b. Phytoplankton density varied from 827−11,790 cells l^{-1} during LT and 2100−8520 cells l^{-1} during HT. Maximum population density (11,790 cells l^{-1}) was recorded at Station 2 due to high abundance of *Rhizosolenia* sp. (relative abundance, 90%). Shifts in phytoplankton species composition due to tidal variations were also noticed. The diatom taxa, *Climacosphenia* sp. and *Guinardia striata* were recorded only during LT whereas, *Cylindrotheca* sp. was recorded during HT. The population of species like *Leptocylindrus* sp., *Skeletonema* sp. and *Thalassiothrix longissima* were more during HT and few taxa such as *Navicula* sp., *Phaeodactylum tricornutum*, *Pseudonitzschia* sp., *Rhizosolenia* sp., *Triceratium* sp. and *Toxarium undulatum* were more abundant during LT at both the stations. Dinoflagellate taxa, *Noctiluca scintillans* and *Protoperidinium* sp. were found more dominant during LT whereas, *Ceratium furca* and *Ceratium fuscus* were found only during HT.

Number of phytoplankton species (S) ranged from 14−34 and was abundant during HT. At Station 1 i.e., Science Centre H´ (Shannon-Weiner Diversity) for diversity of phytoplankton species ranged from 2.2−3.1, however, at Station 2 (Junglighat Bay) the H´ was less than other station and range from 0.68−2.67 (Fig. 4). Minimum value (0.68) was recorded during January, 2011 at HT. Low diversity (H´) was observed at Junglighat during January, 2011 due to high abundance of mono specific cells of *Rhizosolenia* sp. The same data set analysed by Simpson diversity (1−D) also revealed the same trend (Fig. 4). According to Berger-Parker diversity index, phytoplankton diversity from Junglighat Bay (Station 2) during January, 2011 showed higher value (0.85 and 0.87). This means that at that particular time phytoplankton community was less diverse. Species richness (Margalef richness, d) varied from 3.87 to 6.4 at Station 1, whereas 2.18 to 6.54 at Station 2 (Fig. 4). Species richness was low (2.18) during low tide at Station 2, January 2011 due to dominance of the species *Rhizosolenia* sp. So with the same trail evenness (Pielou's Evenness, J´) occasionally showed low values (J´= 0.24, 0.28) at Station 2 during January 2011, when the population density was dominated by the bloom of a particular species. Species diversity index (H´) showed maximum value (3.1) at Station 1 during LT in the month of December, during

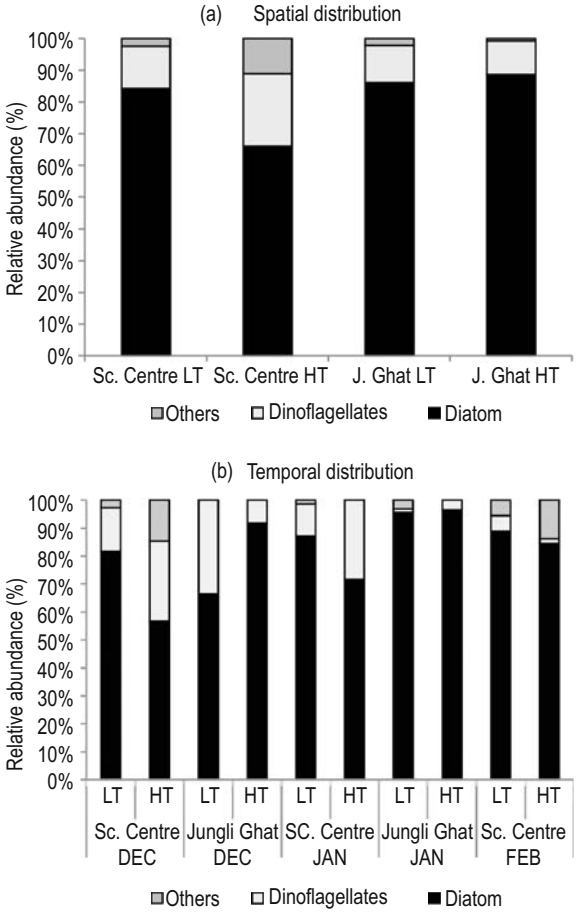


Fig. 3 : (a) Spatial variation and (b)Temporal distributionof phytoplankton during December to February in Science Centre (SC) and Junglighat (JG)

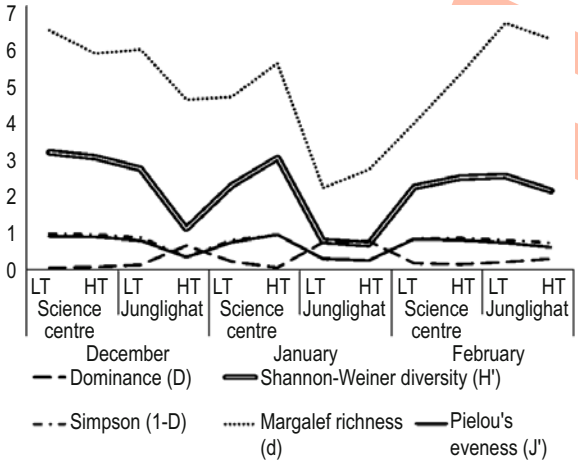
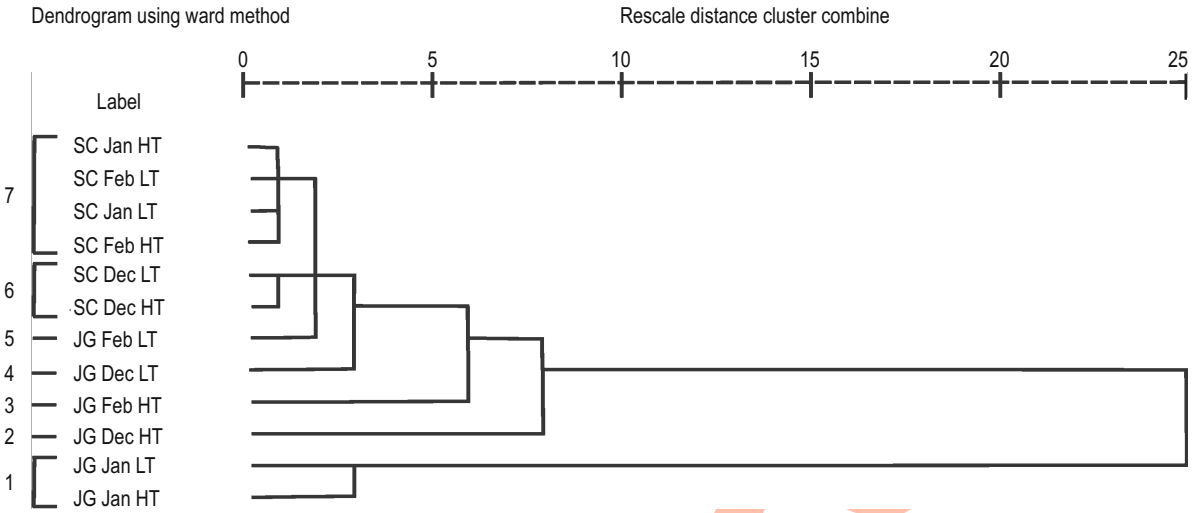


Fig. 4 : Diversity Indices during Low Tide (LT) and High Tide (HT) at two stations

which high equitability of species distribution was also found. The evenness values fluctuated between 0.74 to 0.94 at Station 1 and 0.24 to 0.78 at Station 2 (Fig. 4). The evenness value was generally high during LT. In this consequence, high values of dominance (D= 0.75) was recorded when the species diversity index (H´=0.68) was also low at Station 2. This analysis revealed that the diversity of phytoplankton at Station 1 was more due to influx of fresh oceanic water from the open ocean than the enclosed bay at Station 2.

Cluster analysis was done to observe the holistic picture on abundance and frequency of phytoplankton species between the two stations. The hierarchical cluster analysis (HCA) was carried out by Ward's method. It revealed that the 12 sampling periods could be grouped into 7 clusters, where 10 sampling periods lay in a single cluster and remaining 2 periods lay in other (Fig. 5). The analysis showed that cluster number 1 consisting of two samples *i.e.,* JG Jan LT and JG Jan HT showed dominance of a particular species *Rhizosolenia* sp., whereas samples like JG Dec LT, JG Dec HT, JG Feb LT and JG Feb HT from Station 2 collected during months of December and February formed different clusters 2, 3, 4 and 5. They did not cluster with each other during the sampling period of December from Station 2 (JG Dec LT, JG Dec HT). *Coscinodiscus* sp. was dominant among the diatoms during this month and *Protoperidinium* sp. (dinoflagellates) was also frequent during JG Dec LT. During JG Feb HT *Rhizosolenia alata* (diatom) and *Ceratium extensum* (dinoflagellate) were more in numbers, while in JG Feb LT *Rhizosolenia* sp. was dominant species. Members of the cluster number 6 include two samples collected during the month of December from Science Centre. Custer number 7 consisted of all the samples that were collected from Station 1 during January and February. They showed more or less similar types of species diversity.

Two principle component analysis (PCA) were carried out to extract linear relationships existing among a set of variables. It reduces a single interdependent data set comprising measurements of multiple variables into a transformed variable defined by eigen vectors of the covariance for the data. The eigen values and Scree plot were used to retain the significant factors. One analysis was done using the environmental variables (Fig. 6 a) and the other with the aid of frequency of species (Fig. 6 b). In the first two principal components, variance in environmental parameters accounted for 67.28% and 30.64% respectively. The cumulative variance was 97.93%. The samples of SC Jan LT, SC Jan HT, JG Jan LT, JG Jan HT and SC Dec HT were very closely related due to their similarity in pH. Sampling done at Station 1, during the month of February (SC Feb HT), was dependent on Chlorophyll-a value and that of Station 2, during the month of December (JG Dec LT), was dependent on BOD. Samples like SC Feb LT, JG Feb LT and JG Feb HT were dependent on temperature, whereas sample SC Dec LT was dependent on DO and salinity.

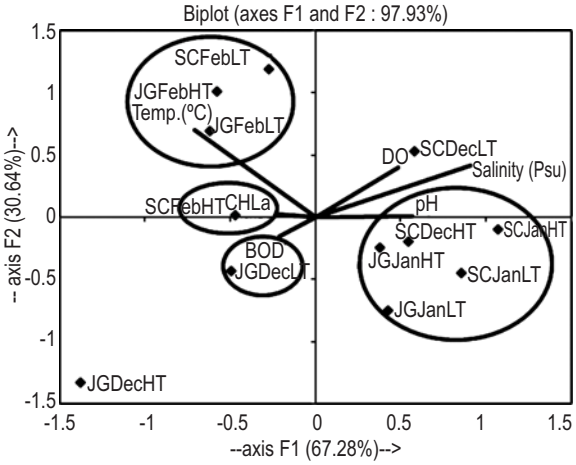


JG : Junglighat; SC : Science centre; Dec: December; Jan: January; Feb : February; LT : Low tide; HT : High tide

Fig. 5 : Dendogram showing cluster analysis depicting affinities of the species and formation of similar taxonomic groups

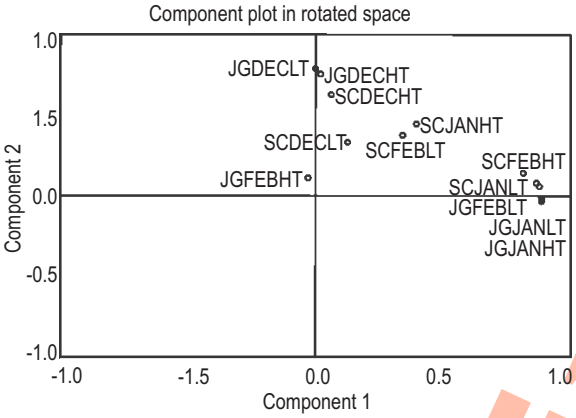
The PCA on frequency of species showed that in the first two principal components, variance in phytoplankton species frequency data accounted for 43.23% and 19.94%. The cumulative variance was 63.17%. Samples like SC Feb HT, SC Jan LT, JG Jan LT, JG Jan HT and JG Feb LT lied in a single cluster where in all the cases *Rhizosolenia* sp. was more dominant. SC Jan HT and SC Feb LT clustered together as in this case the species abundance was very low. JG Dec LT and JG Dec HT lay between axis 1 and 2, where *Coscinodiscus* sp. was dominant. Only JG Feb HT lay on axis 2, which had a dominance of *Rhizosolenia hebetata* species.

As observed in the present analysis, phytoplankton diversity at Station 1 was more than Station 2. This can be related to the fact that phytoplankton diversity in oligotrophic waters was more in comparison to eutrophic water (Dharani *et al*., 2004). The species recorded during this study have been reported earlier from the Indian mainland (Desikachary and Ranjithadevi, 1986; Desikachary and Prema, 1987; Ilangovan, 1987; Paul *et al.,* 2007) and Andaman water (Vinithkumar *et al.,* 2009, SivaSankar and Padmavati, 2012; Karthik *et al*., 2012). The dominance of diatoms in phytoplankton assemblage and more specifically preponderance of centric forms in comparison to pennates with respect to species number are common phenomena in coastal waters (Dharani *et al.,* 2004; Karthik *et al*., 2012). In the present study, same trend was observed. The dominance of diatom without any bloom can be treated as healthy condition (Baliarsingh *et al.,* 2012). In all probabilities, the organic matter content was high at Station 2 due to mangrove vegetation and dominance of single species was probably due to untreated sewage discharge from residential colony into bay water. Elevated level of nutrients especially nitrate, phosphate and silicate enhance the growth of phytoplankton and thereby it ultimately reaches the stage of eutrophication or bloom (Dharani *et al.,* 2004; Karthik *et al.,* 2012). Phytoplankton biomass, in terms of Chlorophyll-a at Station 1, ranged from 0.01–0.04 mg m^{-3} which was lower as compared to an earlier study from this area (Dharani *et. al.,* 2004, Vinithkumar *et al.,* 2009). It may be due to the deficiency of nutrient salts or due to thicker oxidized layer (Sarojni, 2001). Admixture of water during LT and HT reduces chlorophyll-a concentration because the residence time of algae in the photic zone is reduced. Moreover, tidal mixing also causes re-suspension of fine sediments *i.e.,* turbidity that ultimately reduces the light available for photosynthesis and other physiological processes (Dharani *et al.,* 2004). Phytoplankton densities were generally less during LT than HT with an exception in the month of January when it was high at LT at Station 2 (Baliarsingh *et al.,* 2012). Total number of phytoplankton species documented in the present work was comparatively more than the earlier reports from this area (Vinithkumar *et al.,* 2009, SivaSankar and Padmavati, 2012). Diatoms were the most dominant (70.8−88.0%) followed by dinoflagellates (10.8−19.5%) as observed in this study. More or less same trend in phytoplankton diversity was reported earlier from the coastal waters of South Andaman (Vinithkumar *et al.,* 2009, SivaSankar and Padmavati, 2012, Karthik *et al*., 2012). Dominance of particular taxa such as *Coscinodiscus* sp. during December and *Rhizosolenia* sp. in January was observed at Station 2 which was also recorded previously by SivaSankar and Padmavati (2012). *Nitzschia longissima* and *Protoperidinium* sp. which are opportunistic and indicator species of shrimp farm effluents were found during the study period (Alvarez-Góngora and Herrera Silveira, 2005; Jones *et al.,* 2001). *Nitzschia* species are benthic diatoms and their presence in water indicates high concentration of SiO_4^{-4} and resuspension of sediments (Rahaman *et al*., 2013).



SC : Science Centre; JG : Junglighat; LT : Low Tide; HT : High Tide

Fig. 6a : PCA biplot of the environmental variables at two stations of study area



SC : Science Centre; JG : Junglighat; LT : Low Tide; HT : High Tide

Fig. 6b : PCA of phytoplankton species cell count at two stations of study area

Population of dinoflagellates species were more during HT than LT at both stations. Amongst Cyanobacteria, *Oscillatoria* sp., *Trichodesmium* sp. and *Agmenellum quadruplicatum* were recorded in low abundance.

The physico-chemical variables revealed that there were minute fluctuations with changes in the tide level. Minor change in phytoplankton diversity and abundance was observed in the present study. It was also observed by Angara *et al.* (2013). All these aforesaid interpretations have also been confirmed by different statistical analyses done in this present investigation. Further intensive studies on nutrient availability and phytoplankton distribution in this area can definitely throw more light in understanding the pattern of phytoplankton diversity in relation to tides.

Acknowledgments

The authors are grateful to Prof. Sunil Bajpai, Director, Birbal Sahni Institute of Palaeobotany, Lucknow for his kind permission to communicate this research paper and for providing infrastructure facilities of the institute. Sincere thanks are due to Prof. P.M. Mohan, Head, Department of Ocean Studies and Marine Biology, Pondicherry University, Port Blair for providing the requisite laboratory facilities for the study. We are also indebted to Dr. Ruby Ghosh of BSIP for her help in statistical analysis. One of us (A.C) is also highly indebted to DST-Inspire for providing the fellowship.

References

Alvarez-Góngora, C. and J.A. Herrera-Silveira: Variations of phytoplankton community structure related to water quality trends in a tropical Karstic coastal zone. *Mar. Pollut. Bull.*, **52**, 48-60 (2005).

Anantha, G.: Phytoplankton composition and community structure of Ariyankuppam Estuary and Verampattinum Coast of Pondicherry. *J. Fish Aquacul. Sci.*, **3**, 12−21 (2008).

Angara, E.V., G.S. Rillon, M.L. Carmona, J.E.M. Ferreras, M.I.Vallejo, A.C.G.G. Amper and M.L.D.G. Lacuna: Diversity and abundance of phytoplankton in Casiguran waters, Aurora Province, Central Luzon, Northern Philippines. *AACL Bioflux*, **6**, 358-377 (2013).

Baliarsingh, S.K., B.K. Sahu, S. Srichandan and K.C. Sahu: Seasonal variation of phytoplankton community in navigable channel of Gopalpur Port, East Coast of India: A taxonomic study. *Inter. J. Mod. Bot.*, **2**, 40-46 (2012).

Benincà, E., V. Dakos, E.H. Van Nes, J. Huisman and M. Scheffer: Resonance of plankton communities with temperature fluctuations. *Am. Nat.*, **178**, E85–E95 (2011).

Bjørnstad, O.N. and B.T. Grenfell: Noisy clockwork: Time series analysis of population fluctuations in animals. *Science*, **293**, 638–643 (2001).

Brunet, C. and F. Lizon: Tidal and diel periodicities of size-fractionated phytoplankton pigment signatures at an offshore station in the southeastern English Channel. *Estuar. Coast. Shelf Sci.*, **56**, 833–843 (2003).

Chen, Z., C. Hu, F.E. Muller-Karger and M.E. Luther: Short-term variability of suspended sediment and phytoplankton in Tampa Bay, Florida: Observations from a coastal oceanographic tower and ocean color satellites. *Estuar. Coast. Shelf. Sci.*, **89**, 62−72 (2010).

Choudhury, A. K. and R. Pal: Understanding the seasonal dynamics of primary productivity in relation to phytoplankton populations from the Bhagirathi – Hooghly estuary, eastern Indian coast. *J. Algal Biomass Utln.*, **3**, 80–88 (2012).

Clarke, K.R. and R.N. Gorley: PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth (2006).

Cloern, J.E.: The relative importance of light and nutrient limitation of phytoplankton growth: A simple index of coastal ecosystem sensitivity to nutrient enrichment. *Aquat. Ecol.*, **33**, 3−16 (1999).

Dakos, V., E. Benincà, E.H. Van Nes, C.J.M. Philippart, M. Scheffer and J. Huisman: Interannual variability in species composition explained as seasonally entrained chaos. *Proc. Roy. Soc. Lond. B.*, **276**, 2871–2880 (2009).

Desikachary, T.V. and P. Prema: Diatoms from the Bay of Bengal. In: Atlas of Diatoms. Madras Science Foundation, Madras (1987).
Desikachary, T.V. and K.A. Ranjitha Devi: Atlas of Diatoms. Madras Science Foundation, Madras (1986).
Dharani G., S.K. Mukhopadhyay, A.K. Abdul Nazar, K. Ratnam, P. Venkateshwaran, D.M. Peter, J. Santhanakumar, A. Biswas, R. Venkatesan and M. Ravindran: Tidal and diel variation of phytoplankton pigments in Port Blair bay- South Andaman. *In:* Proceedings of MBR 2004 National Seminar on New Frontiers In Marine Bioscience Research, pp. 431-437 (2004).
Falkowski, P.G.: The role of phytoplankton photosynthesis in global biogeochemical cycles. *Photosyn. Res.*, **39**, 235-258 (1994).
Falkowski, P.G., M.E. Katz, A.H. Knoll, A. Quigg, J.A. Raven, O. Schofield and F.J.R. Taylor: The evolution of modern eukaryotic phytoplankton. *Science*, **305**, 354-360 (2004).
Ilangovan, G.: A comparative study on species diversity, distribution and ecology of the Dinophyceae from Vellar estuary and nearby Bay of Bengal. *J. Mar. Biol. Assoc. India*, **29**, 280−285 (1987).
Jones, A.B., M.J. O'Donohue, J. Udy and W.C. Denison: Assessing ecological impacts of shrimp and sewage effluent: biological indicators with standard water quality analyses. *Estuar. Coast Shelf S.,* **52**, 91-109 (2001).
Karthik, R., M.A. Kumar, S.S. Elangovan, R. SivaSankar and G. Padmavati: Phytoplankton abundance and diversity in the coastal waters of Port Blair, South Andaman Island in relation to environmental variables. *J. Mar. Biol. Ocean*, **1**, 2−6 (2012).
Madhav, G.V. and B. Kondalarao: Distribution of phytoplankton in the coastal waters of east coast of India, *Indian J. Mar. Sci.***, 33,** 262-268 (2004).
Mathivanan, V., P. Vijayan, S. Sabhanayakkam and O. Jeyachitra: An assessment of plankton population of Cauvery river with reference to pollution. *J. Environ. Biol.*, **28**, 523-526 (2007).
Palleyi, S., R.N. Kar and C.R. Panda: Seasonal variability of phytoplankton population in the Brahmani Estuary of Orissa, India. *J. Appl. Sci. Environ. Manag.,* **12**, 19-23 (2008).
Paul, J.T., N. Ramaiah, M. Gauns and V. Fernandes: Preponderance of a few diatom species among the highly diverse microphytoplankton assemblages in the Bay of Bengal. *Marine Biol.*, **152**, 63-75 (2007).
Rahaman, S.M.B., J. Golder, M.S. Rahaman, A.F.M. Hasanuzzaman, K.A. Huq, S. Begum, S.S. Islam and J. Bir: Spatial and temporal variation in phytoplankton abundance and species diversity in the Sundarban Mangrove Forest of Bangladesh. *J. Marine Sci. Res. Dev.*, **3**, 126 (2013).
Reynolds, C.S.: Scales of disturbance and their role in plankton ecology. *Hydrobiologia,* **249**, 157−171 (1993).
Saravanakumar, A., M. Rajkumar, G.A. Thivakaran and J. Sesh Serebiah: Abundance and seasonal variations of phytoplankton in the creek waters of western mangrove of Kachchh-Gujarat. *J. Environ. Biol.*, **29**, 271−274 (2008).
Sarojini, Y. and N.S. Sarma: Vertical distribution of phytoplankton around Andaman and Nicobar Islands, Bay of Bengal. *Indian J. Mar. Sci.*, **30**, 65−69 (2001).
Sharples, J.: Potential impacts of the spring-neap tidal cycle on shelf sea primary production. *J. Plankton Res.*, **30**, 183–197 (2008).
Sin, Y., R.L. Wetzel and I.C. Anderson: Spatial and temporal characteristics of nutrient and phytoplankton dynamics in the York River estuary, Virginia: Analysis of long-term data. *Estuaries*, **22**, 260-275 (1999).
Siva Sankar, R. and G. Padmavati: Species composition, abundance and distribution of phytoplankton in the harbour areas and coastal waters of Port Blair, South Andaman. *Inter. J. Oceanog. Mar. Ecol. Sys.*, **1**, 76-83 (2012).
Smayda, T.J.: Patterns of variability characterizing marine phytoplankton, with examples from Narragansett Bay. *ICES J. Mar. Sci.*, **55**, 562–573 (1998).
SPSS Inc. Released 2009. PASW Statistics for Windows, Version 18.0. Chicago: SPSS Inc.
Sridhar, R., T. Thangaradjou, S. Senthil Kumar and L. Kannan: Water quality and phytoplankton characteristics in the Palk Bay, Southeast coast of India. *J. Environ. Biol.*, **27**, 561-566 (2006).
Stomp, M., M.A. van Dijk, H.M.J. van Overzee, M. Wortel, C. Sigon, M. Egas, H. Hoogveld, H. J. Gons and J. Huisman: The timescale of phenotypic plasticity and its impact on competition in fluctuating environments. *Am. Nat.*, **172**, E169–E185 (2008).
Strickland, J.D.H. and T.R. Parsons: A practical handbook of seawater analysis. In: Fisheries Research Board of Canada, 2nd Edn. Ottawa, **167** (1972).
Subrahmanyan, R.: A systematic account of the marine plankton diatoms of the Madras coast. *Proc. Ind. Acad. Sci.,* **24**, 85−197 (1946).
Taylor, A. R. and C. Brownlee: A novel inwardly rectifying chloride current regulates membrane potential in the marine phytoplankton *Coccolithus pelagicus*. *Plant Physiology*, **131**, 1391–1400 (2003).
Tomas, C.R.: Identifying Marine Phytoplankton. *In:* Academic Press, Harcourt Brace and Company, USA, 1-858 (1997).
Venkataraman, G.: A systematic account of some south Indian diatoms. *Proc. Ind. Acad. Sci.*, **10**, 293–368 (1939).
Vinithkumar, N.V., M. Begum, G. Dharani, A. Biswas, A.K. Nazar, R. Venkatesan, R. Kirubagaran and S. Kathiroli: Distribution and biodiversity of phytoplankton in the coastal seawaters of Andaman and Nicobar Islands, India. In: Recent advances in biodiversity of Indian subcontinent (2009).
Vuorio, K., L. Lepisto and A.L. Holopainen: Intercalibrations of freshwater phytoplankton analyses. *Boreal Env. Res.*, **12**, 561-569 (2007).
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. Marine Syst.*, **59**, 219-237 (2006).
Winkler, L.W.: The determination of dissolved oxygen in water. Berich. Deutschen Chemisch. Gesells. **21**, 28-43 (1888).
Yao, P., Z. Yu, C. Deng, S. Liu and Y. Zhen: Spatial and temporal distribution of phytoplankton pigments in relation to nutrient status in Jiaozhon bay, China. *Estuar. Coast Shelf S.,* **89**, 234-244 (2010).