Indian Journal of Geo Marine Sciences
Vol. 48 (09), September 2019, pp. 1383-1397

Diurnal variation of phytoplankton community in the coastal waters of South Andaman Island with special emphasis on bloom forming species

Safet Padhan, Karthik R., & G. Padmavati*

Department of Ocean Studies and Marine Biology, Pondicherry University, Brookshabad Campus, Port Blair, Andaman and Nicobar Islands, India.

*[E-mail: padma190@rediffmail.com]

Received 09 September 2017; revised 11 May 2018

Species composition, abundance and distribution of phytoplankton dynamics were studied from the coastal waters of South Andaman Islands during December 2015 to February 2016. Physico-chemical parameters and phytoplankton species composition were observed during the study. Environmental parameters such as surface water temperature - 33ºC (r=0.96; p<0.001), air temperature (r=0.78; p<0.01), salinity 37 psu (r=0.42; p<0.1), pH 7.8 (r=0.34; p<0.1), and dissolved oxygen (6.14mg L^{-1}) were recorded. A total of 82 species under 50 genera of phytoplanktons were recorded belonging to Bacillariophyceae, Dinophyceae, Cyanophyceae and Silicoflagellate groups. Diatoms were represented by 68 species belonging to 40 genera, Dinoflagellates were represented by 12 species belonging to 8 genera, and 1 species belonging to a genera Cyanophyceae and Silicoflagellate were observed. Among the diatoms, *Coscinodiscus centralis, Rhizosolenia alata, R. imbricata, Bacteriastrum furcatum, Leptocylindrus danicus, Odentella sinensis, Pleurosigma* sp., *Skeletonema costatum* and *Thalassionema nitzschioides* and among the dinoflagellates, *Ceratium furca, Prorocentrum micans, P. divergens* and *Pyrophacus* sp. were the most prevalent diatoms and dinoflagellates encountered in the samples. The population density fluctuated between in the range of 53-63034 cells.mL^{-1}. The highest population density was recorded in January at (St.1) Chatham bay due to the blooming of diatom *R. imbricata* (63000 cells.mL^{-1}), were observed. Moreover, increase in water temperature and salinity was also found to be an influencing co-factor that had contributed to the algal bloom.

[Keywords: South Andaman Islands; *Rhizosolenia imbricate;* Population density; Diatom; Phytoplankton.]

Introduction

Phytoplanktons are key organisms in aquatic ecosystems. They initiate the marine food chain by serving as food to primary consumers[1,2]. The effects of environmental factors on plankton dynamics has been investigated by several authors[3,4]. The influence of various factors on the seasonal growth and abundance of phytoplankton differs significantly, with physical (such as temperature and light intensity) and chemical factors (dissolved oxygen, pH, salinity, total hardness, electrical conductivity and nutrient level) as primary limiting factors reported in many regions of the world[5].

Diatoms (Bacillariophyta) are microscopic algae that occur in both freshwater and marine environment as well as in benthic environment. They are characterized by the possession of golden-brown plastids which contain chlorophyll *a, c_1* and *c_2*, as well as accessory pigment fucoxanthin and siliceous frustules or exoskeleton[6]. Similarly, dinoflagellates are distributed in freshwater and marine environment, and are adapted to pelagic and benthic habitats from polar to tropical seas. Many species are planktonic while few species are associated to sediments, corals, macroalgae or to other plants. Dinoflagellates are mostly unicellular and rarely colonial biflagellate cells. Some are relatively large and have complex morphology. The complex plastids contain chlorophyll *a*, *c_1*and *c_2* and fucoxanthin or peridinin as accessory pigments[6]. Among~5000 species of marine phytoplankton, 300 species which include diatoms, dinoflagellate, raphidophytes, prymnesio phytes, cyanophytes and silicoflagellates can at times cause algal blooms[7]. Though there are considerable works carried out on various distribution patterns of phytoplankton of Indian Ocean and Bay of Bengal in general, studies pertaining to Andaman waters are very few[8-15].

However, such information of phytoplankton from South Andaman is very much limited. In this island, there is an influx of fresh water during the rainy season into the coastal waters and tides also play a major role. For this reason, the present study was planned to bridge this hiatus information on total

variation in phytoplankton population in relation to various environmental parameters, monitored for three months from both east and west coast of South Andaman.

The study area

The Andaman and Nicobar Islands have a warm and moist tropical climate[16,17]. These islands experience both north-east and the Southwest monsoons. North east monsoon is experienced from September to December[18]. Non-rainy season from January to April and South west monsoon from May–August[16,17]. The sampling site was selected based on its ecosystem importance such as enormous biological diversity, easy to accesses and conveyance. Meanwhile, limited research was carried out on the proposed research theme in these study sites.

A total of two stations were identified. First was Chatham (St.1) (11° 41' 11.50" N and 92°43' 20.70" E), the major port where shipping activities take place and polluted with oil slicks, and discharged waste from shipping activity. Second station was Carbyn's Cove (St.2) (11° 38' 27.70" N and 92° 44' 59.80 E), an open estuarine system (Carbyn's creek) which brings waters with variable salinity by high tidal influx with irregular arrangement of mangrove forest as per the elevation, tidal stream periods and fresh water in flow. This Carbyn's creek is influenced by discharge of sewage water from anthropogenic activities of small fisher man community in near shore area and two fresh water perennial stream influxes. Carbyn's Creek is a mangrove area and relatively less polluted.

Materials and Methods

Phytoplankton study was conducted during December 2015 to February 2016 in two distinct areas (1) Areas with more anthropogenic activity (i.e. cargo harbor, fishing harbor, fish landing centre and fishing community nearby areas (St. 1); and lower (2) Areas levels of anthropogenic activity, mangroves ecosystem and beach tourism activities (St. 2) present in Carby's coves (Fig. 1). Surface water temperature was measured (ºC) using a standard mercury centigrade thermometer. Salinity (psu) was estimated with the help of a hand-held refractometer (*ATAGO-Smill-E*, Japan) and was expressed in psu. pH was measured by using a portable digital pH meter (*Eutech pH Scan 1* with accuracy + 0.1 pH) which was calibrated with standard buffers prior to the field sampling. DO estimated by the modified Winkler's method[19] and values expressed as (mg. l^{-1}).

Sample collection and preservation

Phytoplankton samples for quantitative and qualitative analyses were collected by filtering 50 L of water by using a phytoplankton net of bolting silk (20 µm) in 1 liter labeled plastic container. The plankton samples were fixed in 4% formaldehyde, 5% magnesium chloride ($MgCl_2$), and then 10 ml of Lugol's solution was immediately added and stored in the polythene bottles.

Enumeration of phytoplankton species

Phytoplankton samples were kept in 1 ml in the Sedgewick-Rafter counting slide. Species identification was done employing (Nikon Eclipse, TS100, and 20 X/0.40) by using standard inverted microscope. Species identification of the phytoplankton samples was done by using the identification keys[20-27]. Quantitative estimation of phytoplankton was found out by employing Sedgewick-Rafter counting cell. Phytoplankton cell counts were performed on Sedgewick-Rafter counting slide[28].

Statistical analysis

Biodiversity indices were calculated following the standard formulae: species diversity:

H' = -ΣPi log Pi; I = 1; richness: D = 1-C; C = Σ Pi2; Pi = ni/N and evenness: J' = H'/log2S[29-31]. Cluster analysis was done to find species similarities, month-wise. SIMPER analysis (analysis of similarity percentages) was then performed to identify the species which contributed to the clustering[32-33] software. Non-metric multi-dimensional scaling (nMDS) represent the sample as point in low dimensional space usually (2-D) such that the relative distance of all points are in the same rank order as the dissimilarities (or distances). nMDS based on Bray-Curtis similarities of species abundance data were produced to provide a visual representation in a two-dimensional plot of the relative similarities in phytoplankton community composition and abundance[34].

Result

Physico-chemical parameters

The present study was conducted from December 2015 to February 2016, with samples collected every month. During the study period, water temperature varied from 26-33ºC. Maximum water temperature (33ºC) was recorded at St.2 during January and minimum (26ºC) was recorded at St.1 during January. Air temperature ranged from 24-29ºC. Higher values (29ºC) was recorded during January at St.1 and lower

value (24ºC) was recorded during January at St.1. Salinity were found to be significantly higher during the bloom period. Salinity fluctuated between 27 and 37 psu. Maximum salinity (37 psu) was recorded St.1 during at February and minimum salinity was recorded at St.1 during February. Dissolved oxygen levels in the study area were found to range from 3.23 to 6.14mg.l^{-1}. Maximum value (6.14mg.l^{-1}) was recorded during January at St.2 and minimum value (3.23mg.l^{-1}) was recorded during January at St.1. At St.1, day sample

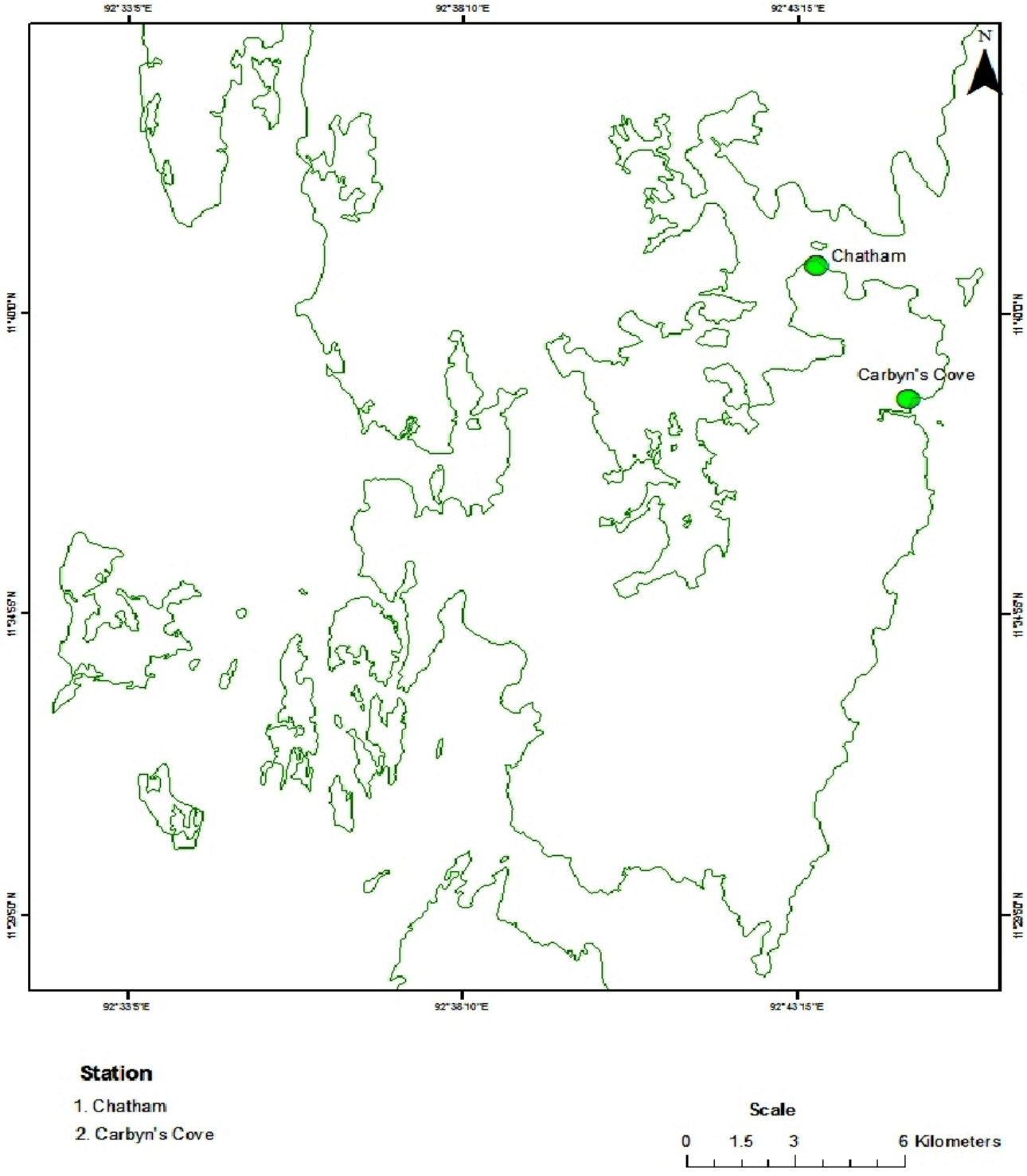

Fig. 1 ─ The study area showing the sampling location from the Port Blair South Andaman.

showing strong positive correlation was found between water temperature (r=0.96), air temperature (r=0.78), and salinity (r=0.42). Weak positive correlation was found between water temperature, air temperature and salinity at St.1 during night time. At St.2, during day and night, a weak and negative correlation was found between air temperature, salinity and pH. Strong positive correlation was found at St.2 dissolved oxygen (r=0.70) (Table 1a & b).

Species composition

Phytoplankton identified at all stations (Dec-2015 to Feb-2016) comprised a total of 82 species belonging to 50 genera. Diatoms comprised 68 species and 40 genera (Centric diatom 37 species and 17 genera and Pennate diatom 31 species and 23 genera), dinoflagellates comprised 12 species and 8 genera. One cyanophyceae and silicoflagellates were the most important taxonomic groups observed during the study period. Phytoplankton population, at almost all the stations diatoms taxa were dominant, especially St.1. During January 2016, green color patches were observed in the study area. The bloom-forming species *R. imbricata* was found to dominate 73-76% in the Sedgewick-Rafter counting slide, with a density of 63,000 cells.ml^{-1} (Fig. 2). Dinoflagellates generally contributed 4-15% of the population. Silicoflagellate and cynophyceae occurred in very low abundances and contributed <2% to the total population. No fish mortality was encountered during the bloom. However, the event led to the exclusion of other phytoplankton species. Nevertheless, some phytoplankton species still persisted in small numbers, regardless of bloom intensity. During the study period, diatoms were the most dominated group. Among the centrales, four families, such as Coscinodiscaceae, Leptocylindraceae, Chaetocerotaceae and Rhizosoleniaceae were found floristically richer than the others, while in the case of pennales, four families, such as Pleurosigmataceae, Licmophoraceae, Naviculaceae and Fragilariaceae dominated the diatom community. Among the diatoms, species of *Coscinodiscus centralis, Pleurosigma* sp., *Leptocylindrus danicus, Bacteriastrum furcatum, Rhizosolenia alata, R. imbricata, Guinardia steriata, G. flaccid, Chaetoceros decipiens, Meuniera membranacea, Thalassionema frauenfedii, Thalassionema nitzschioides* were found to be dominant. Similarly, the dinoflagellate community was

Table 1a ─ Spearman rank correlation coefficient (r) between variations environmental parameters at (St.1) Chatham.

St. 1-Day	Water Temperature (ºC)	Air Temperature (ºC)	Salinity (psu)	pH	Dissolved oxygen (mg.l^{-1})
Water Temperature (ºC)	1				
Air Temperature (ºC)	0.92	1			
Salinity (psu)	0.16	-0.24	1		
pH	0.07	-0.32	1.00	1	
Dissolved oxygen (mg.l-1)	0.96	0.78	0.42	0.34	1
St. 1-Night	Water Temperature (ºC)	Air Temperature (ºC)	Salinity (psu)	pH	Dissolved oxygen (mg.l^{-1})
Water Temperature (ºC)	1				
Air Temperature (ºC)	0.97	1			
Salinity (psu)	0.98	0.91	1		
pH	0.92	0.80	0.98	1	
Dissolved oxygen (mg.l-1)	-0.33	-0.54	-0.14	0.08	1

Table 1b ─ Spearman rank correlation coefficient (r) between variations environmental parameters at (St.2) Carbyn's Cove.

St. 2-Day	Water Temperature (ºC)	Air Temperature (ºC)	Salinity (psu)	pH	Dissolved oxygen (mg.l^{-1})
Water Temperature (ºC)	1				
Air Temperature (ºC)	-1	1			
Salinity (psu)	-0.79	0.79	1		
pH	-0.63	0.63	0.98	1	
Dissolved oxygen (mg.l-1)	1.00	-1.00	-0.79	-0.64	1
St. 2-Night	Water Temperature (ºC)	Air Temperature (ºC)	Salinity (psu)	pH	Dissolved oxygen (mg.l^{-1})
Water Temperature (ºC)	1				
Air Temperature (ºC)	-1	1			
Salinity (psu)	-0.87	0.87	1		
pH	-0.98	0.98	0.94	1	
Dissolved oxygen (mg.l-1)	0.70	-0.70	-0.96	-0.82	1

dominated by *Ceratium furca, Ceratium fusus, Dinophysis caudata, Prorocentrum micans*, *Protoperidinium divergens,* and *Pyrocystis* sp. (Table. 2).

Bloom forming species and Population density

During the monsoon month of January 2016, green color patches were observed in the study area. Monitoring of the algal bloom of *R. imbricata* was observed in Chatham Bay region of Port Blair in South Andaman island. *R. imbricata* dominated 73-76% of the total phytoplankton biomass during the bloom (Fig. 3a-c). Phytoplankton density ranged from 53 to 63034 cells.ml^{-1}. Maximum density 63000 cells.ml^{-1} was recorded during January at St.1 due to the bloom of *R. imbricata*. Minimum density (53 cells.ml^{-1}) was recorded during February at St.1 (Fig. 4).

Species diversity, cluster and non-meric multidimensional scaling

The number of species (S) and the range of diversity indices are given in Table 3. Number of phytoplankton

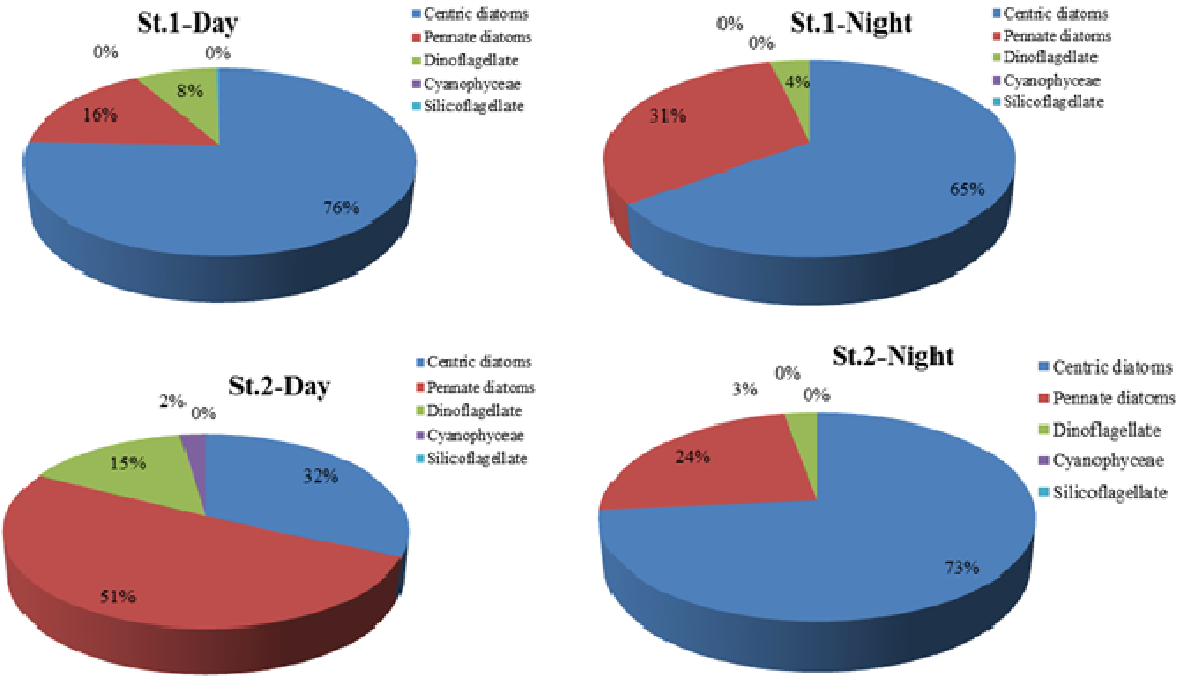

Fig. 2 ─ Percentage composition of phytoplankton from the coastal waters of south Andaman St.1; Chatham and St. 2; Carbyn's Cove.

Table 2 ─ Check list of phytoplankton from the coastal waters of South Andaman Island at St.1 and St.2

List of Phytoplankton	St.1-Day	St.1-Night	St.2-Day	St.2-Night
Class: Cyanophyceae				
Trichodesmium sp. (Ehrenberg) Gomont, 1892.	-	+	+	+
Diatom (Bacillariophyceae)				
Centric diatoms				
Bacteriastrum furcatum (Shadbolt 1854).	+	-	-	-
Bacteriastrum sp. (Shadbolt 1854).	+	-	-	-
Biddulphia sp. (Gray, 1821).	+	+	+	+
Chaetoceros affine (Lauder, 1864).	+	+	-	-
Chaetoceros curvisetus (Cleve, 1889)	+	-	-	-
Chaetoceros danicus (Cleve, 1889).	+	+	-	-
Chaetoceros decipiens (Cleve, 1873).	+	+	-	-
Chaetoceros diversus (Cleve, 1873).	+	+	+	-
Chaetoceros lorenzianus (Grunow, 1863).	+	+	-	-
Chaetoceros messanensis (Castracane, 1875).	+	+	-	-

(*Contd*.)

Table 2 ─ Check list of phytoplankton from the coastal waters of South Andaman Island at St.1 and St.2

List of Phytoplankton	St.1-Day	St.1-Night	St.2-Day	St.2-Night
Chaetoceros peruvianus (Brightwell, 1856).	+	-	+	-
Chaetoceros sp. (Ehrenberg, 1844)	+	+	-	+
Coscinodiscus centralis (Ehrenberg, 1839)	+	+	-	+
Coscinodiscus sp. (Ehrenberg, 1838)	+	+	+	-
Dactyliosolen sp. (Castracane, 1886).	+	+	-	-
Ditylum brightwellii (Grunow, 1885).	+	+	+	-
Guinardia flaccida (Castracane) H.Peragallo, 1892.	+	+	+	-
Gunardia striata (Stolterfoth) Hasle & Syvertsen, 1996.	+	+	-	-
Hemiaulus hauckii (Grunow) Van Heurck, 1882.	+	-	+	-
Hemiaulus sinensis (Greville, 1865).	+	+	+	+
Lauderia annulata (Cleve, 1873).	+	+	-	-
Leptocylindrus danicus (Cleve, 1889).	+	+	+	-
Melosira nummuloides (C.A. Agardh, 1824).	-	-	+	+
Odontella mobiliensis (J.W.Bailey) Grunow, 1884.	+	+	+	-
Odontella sinensis (Greville) Grunow, 1884.	+	+	+	-
Proboscia alata (Brightwell) Sundstrtim, 1986.	+	-	-	-
Rhizosolenia bergonii (H.Peragallo 1892).	+	-	-	-
Rhizosolenia cochlea (Brun, 1891).	+	-	-	-
Rhizosolenia imbricata (Brightwell, 1858).	+	+	+	-
Rhizosolenia setigera (Brightwell, 1858).	+	-	-	-
Rhizosolenia sp. (Silva, 1962).	+	+	-	+
Rhizosolenia robusta (G.Norman) Pritchard, 1861.	-	+	-	-
Rhizosolenia styliformis (T.Brightwell, 1858).	+	+	+	+
Skeletonema costatum (Greville) Cleve, 1873.	+	+	+	-
Triceratium sp. (Ehrenberg, 1841).	-	+	+	-
Thalassiosira sp. (Cleve, 1873).	-	-	+	+
Pennate diatoms				
Asterionella glacialis (Castracane, 1886).	+	-	+	+
Amphora sp. (Ehrenberg, 1840).	+	+	+	+
Bacillaria paradoxa (J.F.Gmelin) Linnaeus, 1791.	+	-	+	-
Campylodiscus sp. (Ehrenberg, 1844).	+	+	+	-
Climacodium sp. (Grunow, 1868).	+	+	-	+
Cocconeis scutellum (Ehrenberg, 1838).	+	-	+	-
Cymbella sp. (C.Agardh, 1830).	-	-	-	+
Cylindrotheca closterium (Ehrenberg) Reimann & J.C.Lewin, 1964.	+	+	+	-
Fragilaria sp. (Silva, 1962).	+	+	+	+
Grammatophora sp. (Ehrenberg, 1839).	+	-	-	+
Gyrosigma balticum (Ehrenberg) Rabenhorst, 1853.	-	+	+	+
Helicotheca sp. (Ricard, 1987).	+	-	-	-
Licmophora ehrenbergii (Kützing) Grunow, 1867.	+	+	+	+
Licmophora remulus (Grunow) 1867.	-	+	+	+
Lyrella sp. (Cleve) Karayeva 1978.	-	+	+	+
Mastogloia sp. (Thwaites) Smith, 1856.	+	-	+	+
Meuniera membranacea (Cleve), Syvertsen, 1996.	+	-	+	+
Navicula sp. (Bory, 1824).	-	+	+	+
Nitzschia longissima (Brebisson) Ralfs in Pritchard 1861.	+	-	-	-
Nitzschia sigma (Kützing) W.Smith, 1853.	+	+	+	+
Nitzschia sp. (Hassall, 1845).	+	+	+	+
Pleurosigma sp. (Smith, 1861).	+	+	+	+
Pleurosigma strigosum (W.Smith, 1852).	+	-	-	-
Pseudo-nitzschia australis (Frenguelli 1939).	+	+	+	-

(*Contd.*)

Table 2 ─ Check list of phytoplankton from the coastal waters of South Andaman Island at St.1 and St.2

List of Phytoplankton	St.1-Day	St.1-Night	St.2-Day	St.2-Night
Gyrosigma balticum (Ehrenberg) Rabenhorst, 1853.	-	+	+	+
Helicotheca sp. (Ricard, 1987).	+	-	-	-
Licmophora ehrenbergii (Kützing) Grunow, 1867.	+	+	+	+
Licmophora remulus (Grunow) 1867.	-	+	+	+
Lyrella sp. (Cleve) Karayeva 1978.	-	+	+	+
Mastogloia sp. (Thwaites) Smith, 1856.	+	-	+	+
Meuniera membranacea (Cleve), Syvertsen, 1996.	+	-	+	+
Navicula sp. (Bory, 1824).	-	+	+	+
Nitzschia longissima (Brebisson) Ralfs in Pritchard 1861.	+	-	-	-
Nitzschia sigma (Kützing) W.Smith, 1853.	+	+	+	+
Nitzschia sp. (Hassall, 1845).	+	+	+	+
Pleurosigma sp. (Smith, 1861).	+	+	+	+
Pleurosigma strigosum (W.Smith, 1852).	+	-	-	-
Pseudo-nitzschia australis (Frenguelli 1939).	+	+	+	-
Pseudo-nitzschia delicatissima (Cleve), Heiden & Kolbe, 1928.	-	+	+	-
Pseudo-nitzschia pungens (Grunow ex Cleve), Hasle 1993.	+	+	+	+
Pseudonitzschia sp. (H.Peragallo, 1900).	+	+	-	-
Surirella fastuosa (Ehrenberg) Ehrenberg 1843).	+	+	+	+
Thalassionema frauenfedii (Grunow), Tempère & Peragallo 1910)	+	+	-	-
Thalassiothrix longissima (Cleve & Grunow 1880)	-	+	+	+
Thalassionema nitzschioides (Grunow) Mereschkowsky, 1902).	+	+	+	-
Dinoflagellates (Dinophyceae)				
Ceratium furca (Ehrenberg) Claparède & Lachmann, 1859.	+	+	+	+
Ceratium fusus (Ehrenberg) Dujardin, 1841.	+	-	-	-
Ceratium trichoceros (Ehrenberg) Kofoid, 1881.	+	-	+	-
Dinophysis caudate (Saville-Kent, 1881).	+	+	+	+
Gonyaulax sp. (Diesing, 1866).	+	+	-	+
Ornithocercus sp. (Stein, 1883).	+	-	+	-
Phalacroma sp. (Stein, 1883).	+	-	-	-
Prorocentrum micans (Ehrenberg, 1834).	-	+	-	-
Protoperidinium conicum(Paulsen) Balech, 1973.	-	-	+	-
Protoperidinium sp. (Bergh, 1881).	+	+	+	+
Protoperidinium divergens (Ehrenberg) Balech, 1974.	-	-	+	-
Pyrocystis sp. (Murray) Haeckel, 1890.	-	-	+	-
Silicoflagellate (Dictyochophyceae)				
Dictyocha sp. (Ehrenberg, 1837).	+	-	-	-

Remarks (-) absent and (+) present

Table 3─Biological diversity indices of phytoplankton species from the Port Blair, Andaman at St. 1 and St. 2. Number of species (S), Margalef richness (d), Pielou's evenness (J') and Shannon diversity (H').

St. 1-Day	**No of Species (S)**	**Species richness (D)**	**Evenness (J')**	**Species diversity (H')**
Dec-2015	58	8.16	0.83	3.35
Jan-2016	13	1.09	0.002	0.006
Feb-2016	18	3.30	0.78	2.27
St. 1-Night				
Dec-2015	45	7.46	0.80	3.03
Jan-2016	11	0.93	0.004	0.009
Feb-2016	13	3.02	0.94	2.42
St. 2-Day				
Dec-2015	30	5.63	0.70	2.39
Jan-2016	24	5.09	0.92	2.92
Feb-2016	15	3.24	0.92	2.48
St. 2-Night				
Dec-2015	14	2.88	0.89	2.35
Jan-2016	19	3.95	0.89	2.61
Feb-2016	15	3.39	0.91	2.47

species ranged from 11 to 58. Maximum value (58) was recorded during December at St.1 day. Minimum (11) value was recorded during January at St.1. Species richness ranged between (0.93 and 7.46). Maximum value (d=7.46) was recorded during December at St. 1 day and minimum value (d=0.93) was recorded during January at St.1. Evenness ranged from 0.002 to 0.94. Higher value (J'=0.94) was recorded during February at St.1 and the lowest value (J'=0.002) was recorded during January at St.1. Relatively higher species diversity (H'=3.03) was recorded during December at St.1 and minimum value (H'=0.009) was recorded during January at St.1. The similarity in phytoplankton species composition among the stations and seasons was determinate by Bray-Curtis similarity cluster analysis. At St.1 two separate assemblages of species were observed in the bloom forming species showing 50% similarity in the day sample. The night sample had two separate assemblages of species showing 50% similarity (Figs 5, 6 & 7). At St.2, two separate assemblages of species were observed. During the day and night time, to 50% of phytoplankton similarity was observed. The non-meric multidimensional scaling (nMDS) is done based on square root transformed average abundances and Bray-Curtis similarities by comparing the phytoplankton assemblages among the sampling sites. The nMDS ordination result revealed a low stress level (i.e <0.11) suggesting the configuration is ideally close to actual dissimilarities. The ordination plot spatially grouped the samples relatively well into two distinct regions. Samples overlaid with the dendogram showed 50% similarity. Data points St.1 day and night as an outlier, primarily due to the occurrence of the high per cent cover of periodic bloom forming species (Fig. 8).

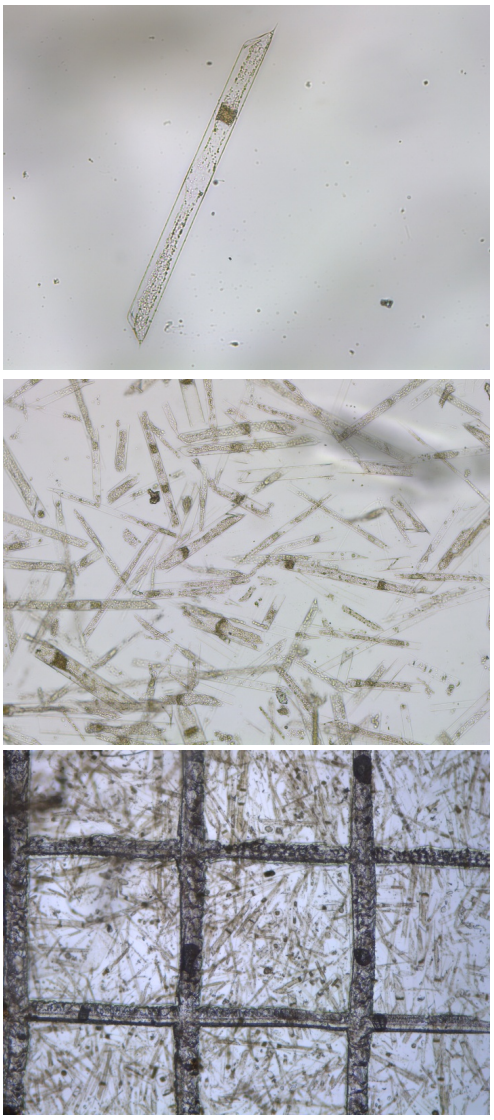

Fig. 3 ─ Microscopic view of the bloom-forming diatom *R. imbricata* (a. 40X, b. 20X & c. 10X) *R. imbricata* in Sedgewick rafter cell.

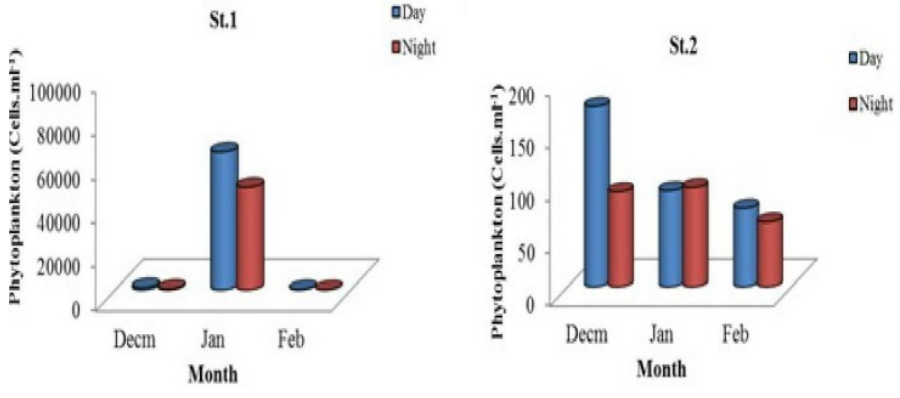

Fig. 4 ─ Monthly variation of Phytoplankton density from the study area at St.1 and St. 2.

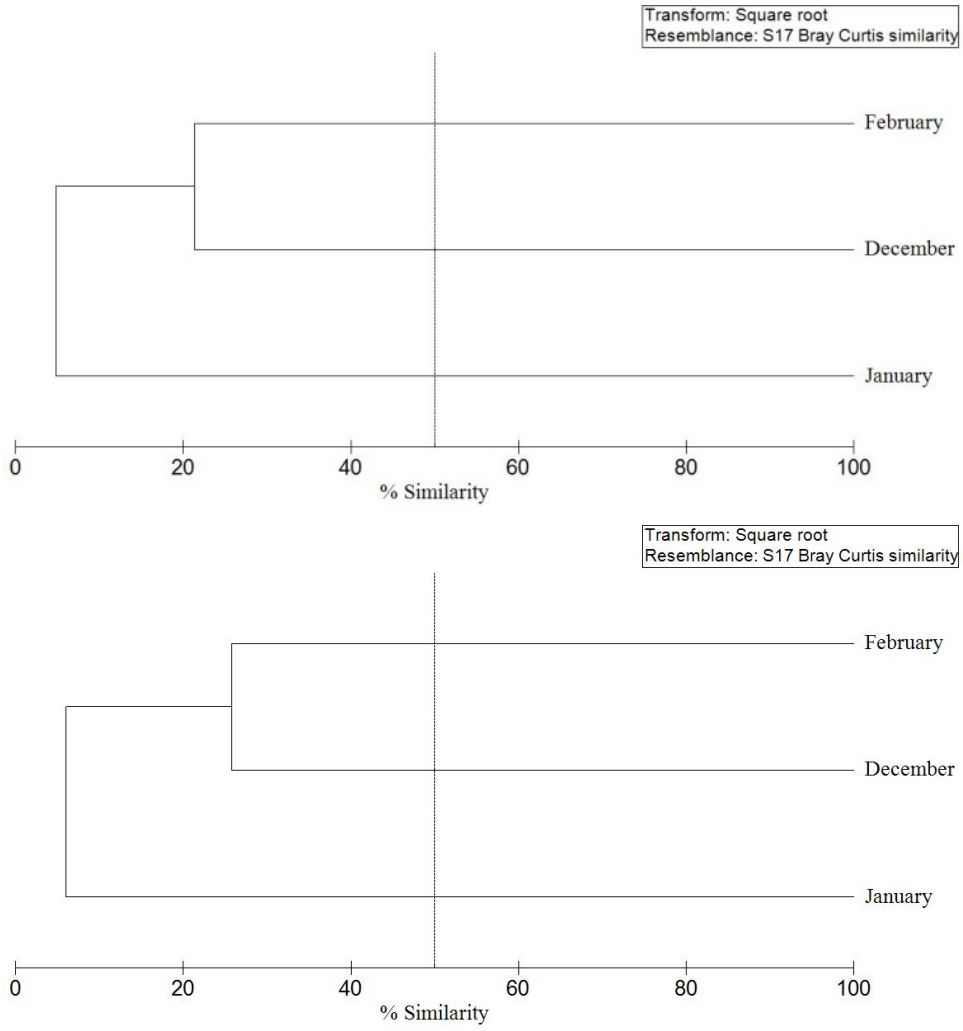

Fig. 5 ─ Bray Curtis similarity showing formation of groups for the month at St. 1 day and night

Discussion

Andaman and Nicobar Islands have a warm and moist tropical climate[16,17]. These islands experience both the north-east and south-west monsoons. North-east monsoon is experienced from October-December[18]. Non rainy season during January-April and South west monsoon from late May to September[16,17]. The average annual rainfall ranges from 3000 to 3500 mm and humidity varies from 66 to 85% (Indian Meteorological Department, Port Blair, India). Cyclones occur during the monsoon accompanied by very strong winds, mainly during May, July and October. The variability in the physico-chemical parameters in this region is mainly due to the monsoon cycle. Phytoplankton species of the present survey were mostly similar to those recorded from the Andaman Sea in November 2004[35] and Myanmar waters in February 2007, but the species number was lower than that in other studies. In the present study, diatoms, cyanophyceae and dinoflagellates were generally dominant. The difference in diversity between these two areas demonstrated that the species composition of the phytoplankton community changes over short time periods, and that the relative abundance of each species might be dependent on particular environmental variables. It has been observed that the species diversity of the phytoplankton community may fluctuate rapidly.

During the study period, water temperature varied from 26 to 33 ºC. Maximum water temperature (33ºC) was recorded at St.2 during January and minimum (26 ºC) was recorded at St.1 during January 2016. Water temperature steadily increased from January to April as observed earlier from this area[8,36,37]. Generally, temperature is influenced by the intensity of the solar radiation, evaporation, fresh water influence and

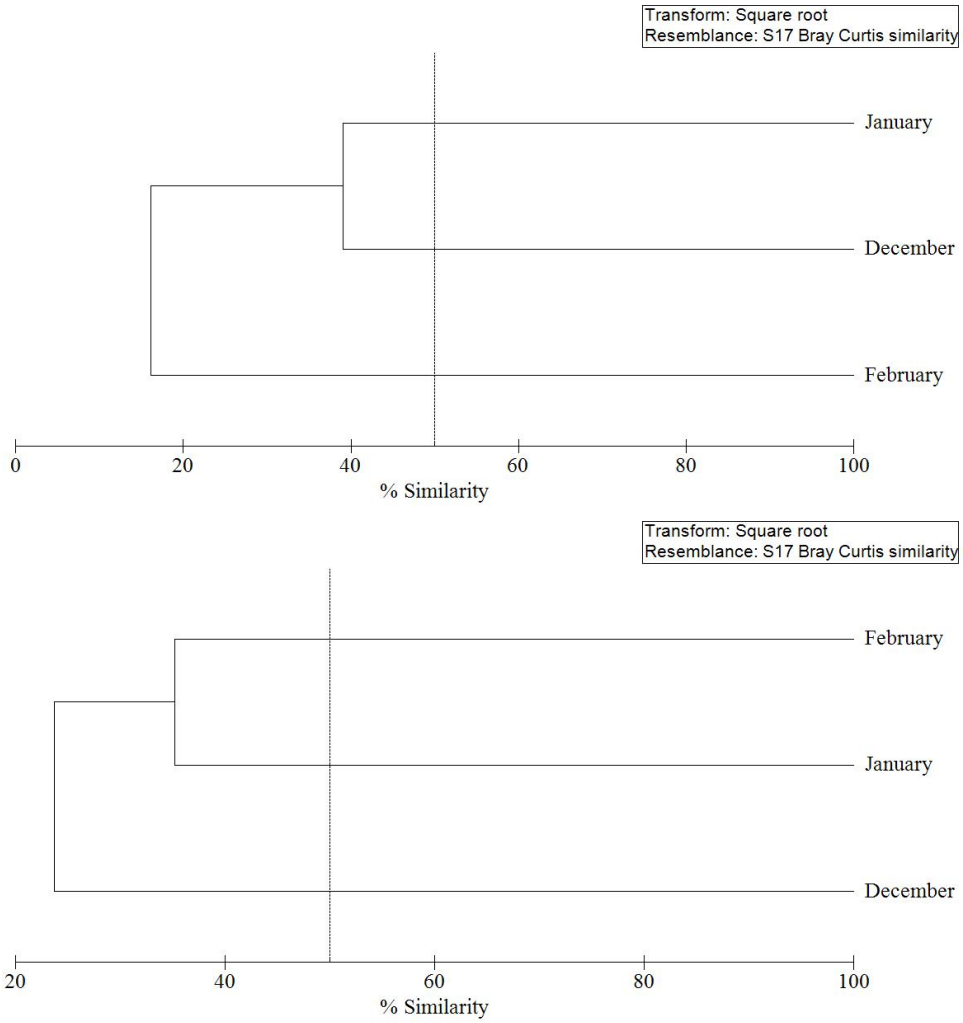

Fig.6 ─ Bray Curtis similarity showing formation of groups for the month at St. 2 day and night

cooling mix up with the adjoining coastal waters[38]. The temperature values for the entire period of observation reflected to a certain extent the climate variation. Surface water of Andaman seems to be warmer at the end of the north-east monsoon as found in this study and similar earlier[39] work from same research sites. Salinity showed wide variation from 27 to 37 psu. Maximum salinity (37 psu) was recorded at St.1. The results revealed that the increase in the salinity and temperature initiated the bloom. The surface salinity distribution was found to follow the seasonally changing current patterns, low salinity flow through north equatorial currents[40].

Dissolved oxygen also showed fluctuating pattern (3.23-6.14mg.l^{-1}). Maximum value (6.14 mg.1^{-1}) was recorded during January at St.2 and minimum value (3.23mg.l^{-1}) was recorded during January at St.1 due to the *R. imbricata* bloom. High primary productivity (phytoplankton bloom observed in this study) led to increased dissolved oxygen in the water column[41]. Decrease in dissolved oxygen concentration in summer might be due to the evaporation of water column which reduced the oxygen saturation as evinced by the negative correlation between dissolved oxygen and temperature revealed in this study. Further, dissolved oxygen concentration increase in the monsoon season could be due to the effect of high wind velocity along with heavy rainfall and result of fresh water mixing and might be due to more productivity[42]. pH ranged from 7.7 to 8.5. Maximum pH was recorded during January at St.2. No significant variation in pH was observed during this study. The extensive buffering capacity of seawater has caused the change in pH within a narrow limit[43].

Phytoplankton density ranged from 53 to 63034 cells.ml^{-1}. Maximum density, 63000 cells.ml^{-1} was

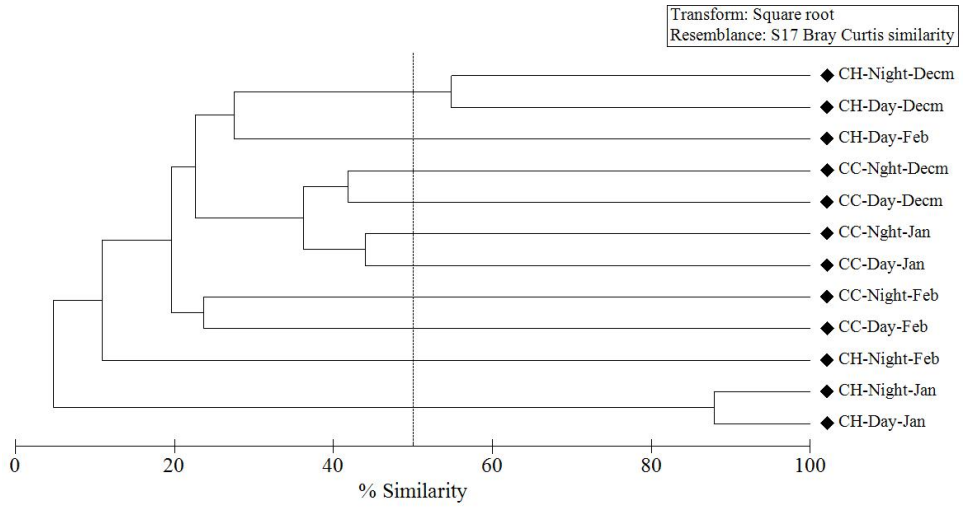

Fig. 7 ─ Bray Curtis similarity showing formation of groups in all the months during day and night

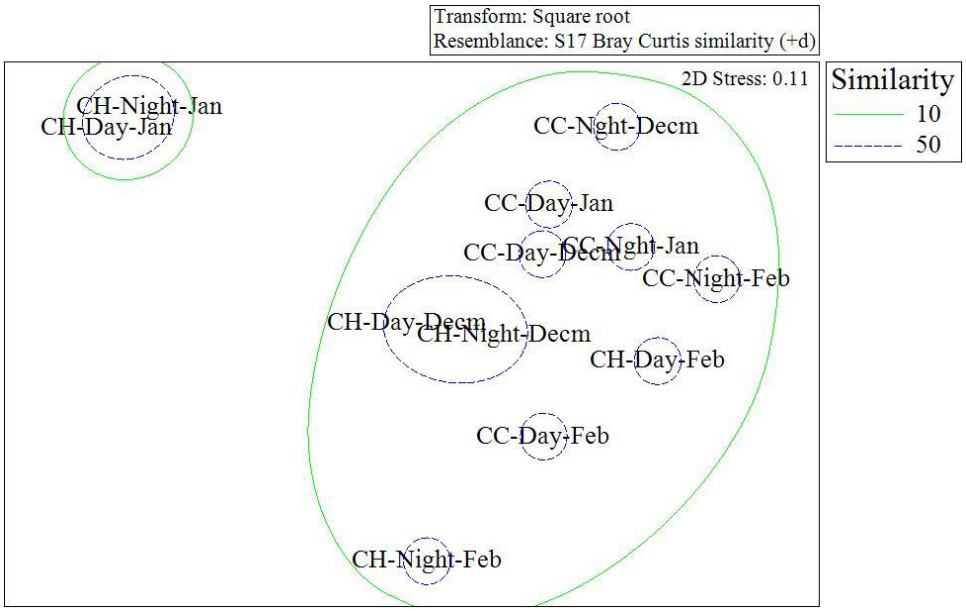

Fig. 8 ─ MDS multi-dimensional scaling showing variation of all the stations

recorded during January at St. 1 due to the bloom of *R. imbricata*. Minimum density (53 cells.ml^{-1}) was observed during February at St. 1. Maximum phytoplankton (97064 cells.ml^{-1}) obtained in this study was quite higher than earlier reports from this area: 12800 nos.l^{-1}[1,14] from coastal waters of Andaman and Nicobar island, 1220 nos.l^{-1}[1,44] from the coastal waters of Treis Island, Nicobar, 2.3x104 cells.l^{-1}[1,10] from the Port Blair bay during the bloom of *Noctiluca scintillans,* and 0.2x10^{5} cells.l^{-1}[1,12] from Minnie bay, Port Blair, also during the bloom of *N. scitillans,* but lower than the reports from other area 244500 cells.l^{-1}[1,45] from the creek waters of Mangrove of Kutch, Gujarat and 321000 cells.l^{-1}[1,46] from Pichavaram waters of south-east coast of India. This could be due to the supply and availability of macro nutrient that influenced the phytoplankton growth and abundance in this region.

Phytoplankton community in this study comprised four different taxa, viz., Diatom, dinoflagellates, cyanophyceae, and silicoflagellates. Diatoms were the major component of phytoplankton (76%) followed by dinoflagellate (8%). Diatoms dominated the phytoplankton population as found in this study was reported earlier from Andaman waters[44,47,14], Port Blair bay[15,36] and other mainland coastal and marine waters of India[46,48,49,50,45,51]. Phytoplankton identified comprised a total of 82 species and 50 genera. Diatoms

comprised 68 species and 40 genera (Centric diatom 37 species and 17 genera and Pennate diatom 31 species and 23 genera), and dinoflagellates comprised 12 species and 8 genera. One cyanophyceae and silicoflagellates were the most important taxonomic groups observed during the study area as per the earlier report from Andaman and Nicobar Island[11]and from east coast of India (249 species & 78 genera)[13]. Diatoms comprised 299 species and 86 genera which is higher than earlier reported from Andaman waters: 41 species and 21 genera[14] 46 species and 18 genera[44], 87 species and 32 genera[47], 65 species and 49 genera[15], 20 species and 15 genera[10], 38 species and 15 genera[49], 57 species and 29 genera[52] and east coast of India 166 species and 46 genera[53], 111 species and 41 genera[13], and 166 species and 57 genera[54].

The diatoms flora comprised 37 species and 17 genera centrales and 31 species and 23 genera pennales (Table 2). Pennate diatoms such as *Asterionella glacialis, Amphora* sp*., Bacillaria paradoxa, Campylodiscus* sp., *Climacodium* sp., *Cocconeis scutellum, Cymbella* sp., *Cylindrotheca closterium, Fragilaria* sp., *Grammatophora* sp., *Gyrosigma balticum, Helicotheca* sp., *Licmophora ehrenbergii, L. remulus, Lyrella* sp*., Mastogloia* sp*., Meuniera membranacea, Navicula* sp*., Nitzschia longissima, N. sigma, Nitzschia* sp*., Pleurosigma* sp*., P. strigosum, Pseudo-nitzschia australis, P. delicatissima, P. pungens, Psudonitzschia* sp*., Surirella fastuosa, Thalassionema frauenfedii, Thalassiothrix longissima* and *Thalassionema nitzschioides* and centric diatoms such as *Bacteriastrum furcatum, Bacteriastrum* sp., *Biddulphia* sp., *Chaetoceros affine, C. curvisetus, C. danicus, C. decipiens, C. diversum, C. lorenzianus, C. messanensis, C. orientalis, C. peruvianus, Chaetoceros* sp., *Coscinodiscus centralis, Coscinodiscus* sp., *Dactyliosolen* sp., *Ditylum brightwellii, Guinardia flaccid, G. striata, Hemiaulus hauckii, H. sinensis, Lauderia annulata, Leptocylindrus danicus, Melosira nummuloides, Odontella mobiliensis, O. sinensis, Proboscia alata, Rhizosolenia bergonii, R. cochlea, R. imbricata, R. setigera, Rhizosolenia* sp., *R. robusta, R. styliformis, Skeletonema costatum, Triceratium* sp. and *Thalassiosira* sp. recorded in this study were not reported earlier from this area[14,10,44,47,15,52,49].

Some species of dinoflagellates such as Ceratium furca, C. fusus, C. trichoceros, Dinophysis caudata, Gonyaulax sp., Ornithocercus sp., Phalacroma sp., Prorocentrum micans, Protoperidinium conicum, Protoperidinium sp., P. divergens and Pyrocystis sp. found in this study were not recorded earlier from east coast of India including Andaman and Nicobar island[13]. Further absence of few diatom species, such as Achnanthes stromii, Amphiplwura gigantia, Amphora decussate, A. lineolata, Asteromphalus whyvellii, Aulacodiscus orbiculatus, Bacteriastrum declinatum, B. elegans, B. pavillardii, B. varians, Biddulphia heteroceros, B. mobiliensis, B. rhombus, Cerataulina bergonii, Chaetoceros denticulatum, C. extensum, C. indicus, C. lascinosus, C. lauderi, C. paradoxum, C. pelagicus, Climacodium moniligera, Cocconeis littoralis, C. sigmoides, Corethron hystrix, C. inerme, Coscinodiscus apiculatus, C. concentricus, C. excentricus, C. gigas, C. jonesia, C. lineatus, C. rothii, C. sublineatus, Ditylum sol, Fragilaria oceanic, Grammatophora undulate, Mastogloia exilis, Melosira sulcata, Navicula clavata, N. forcipta, N. hennadyie, N. longa, Nitzschia forcipata, N. vitrea, Planktoniella sp., Pleurosigma aestuarie, P. carinatum, Pseudonitzschia seriata, Pyxidicula minuta, Rhabdonema magnificum, R. mirificum, Rhaphoneis discoids, Rhizosolenia castracanei, R. crassispina, Thalassionema subtilis, Trachyneis antellarium, T. aspera and Triceratium dublum earlier reported in the coastal waters of east coast of India[13] could be due to ecological distribution type of these flora.

Dinoflagellates were second dominant group of phytoplankton community in the study area. Dinoflagellates ranged from 1 to 64 cells.ml^{-1}. Maximum density (64 cells.ml^{-1}) during December at St.1. Minimum density (1 cell.ml^{-1}) was recorded during December at St.2. They are non-selective feeders that are able to persist at low food abundance and could adapt at low prey abundance by reducing their rate of metabolism[55]. Dinoflagellates comprised 98 species that belonged to 54 genera in this study is higher compared to the earlier studies from this area: 3 species and 1 genera[14], 6 species and 2 genera[47], 6 species and 2 genera[44], species and 6 genera[10], 132 species and 5 genera[52], 7 species and 3 genera[49], and 19 species and 9 genera[15] from this area, but lower than other region e.g. 131 species and 33 genera[13] from east coast of India.

Even dinoflagellates species, such as Ceratium furca, C. fusus, C. trichoceros, Dinophysis caudate, Gonyaulax sp., Phalacroma sp. and Protoperidinium sp. Further absence of some dinoflagellates species, such as Actiniscus pentasterias, A. carteri, A. curcubita, A. klebsei, Amphisolenia bidentata, A. rectangulata, Amphisolenia sp., Blepharocysta compressa, B. splendor-maris, Ceratium belone, C. carriense,

C. buceros, C. bergonii, C. bigelowii, C. concilians, C. contortum, C. declinatum, C. gibberum, C. hexacanthum, C. hircus, C. kofoidinum, C. limulus, C. longirostrum, C. ranipes, C. schroteri, C. symmetricum, Ceratocorys horrid, Diplopsalis lenticula, Diplopsalis sp., Dissodinium lunula, Fragilidium sp., Glenodinium sp., Gonyaulax diacantha, G. diegensis, G. digitalis, G. fragilis, G. monilata, G. polyedra, G. polygramma, Glenodinium sp., Gymnodinium coeruleum, G. falcatum, G. splendens, Gyrodinium falcatum, G. fissum, Histinoneis depressa, Histioneis sp., Kofoidinium pavillardii, Ornithocercus heteroporus, O. quadrates, O. splendidus, O. stenii, O. thumii, Ostreopsis monotis, Oxytoxum elegans, O. gigas, O. milneri, O. periclaudicans, O. tesselatum, Oxytoxum sp., Peridinium abei, O. brochii, P. fatulipes, P. globules, P. longipes, P. nipponicum, P. pallidum, P. pedunculatum, P. polonicum, P. trochoideum, P. tuba, P. venustum, Pronoctiluca acuta, Prorocentrum compressum, P. gracile, P. maximus, P. pyriforme, P. reticultum, Prorocentrum sp., Protoceratuim reticulatum, Protoceratuim sp., Protoceratium. Noctiluca, Pyrocystis pseudonoctiluca, Triadinium acuminatus and T. sphericus which reported earlier in the coastal waters of east coast of India[13] were not recorded in this study, ascertained their oceanic preference.

The blue green algae cyanophyceae having important contributions to the phytoplankton community showed a different trend of distribution. They recorded very low. Maximum density (8 cells.ml^{-1}) was recorded during January at St.2. Cyanophyceae comprised 4 species that belonged to 3 genera which is higher than earlier reported from this area: 1 species and 1 genera[47], 1 species and 1 genera[10] 1 species and 1 genera,[52] 2 species and 2 genera[49], but lower than from east coast of India, 7 species and 5 genera[13]. One species *Oscillatoria formosa* found in this study was not recorded earlier from this region[15]. The occurrence of silicoflagellates was sporadic and poorly represented and formed a minor component of the phytoplankton in this region. Only one species was recorded. Maximum density (2 cells ml^{-1}) was recorded during February at St.1 Chatham. Two species namely, *Ciliophyrs infusionum* and *Dictyocha fibula* recorded earlier[51] from west coast of India was not found in this study, could be due to ecological distribution type of these organisms. The data most basic to understand the community structure are the number of species present and their relative abundance. Three indices, the Shannon Weiner species diversity index (H'), the species richness (d) and species evenness (J') were calculated to evaluate the diversity of phytoplankton in the study area. Various theories involving time (older communities have more number of species), spatial heterogeneity (more heterogeneous physical environment supports more species), competition (leads to narrow niches), predation (reduces competition and allows more prey species), environmental stability (more species in stable environmental) and productivity (greater production results in greater diversity) has been put forward. Three indices, the Shannon wiener index (H') were used to evaluate the species evenness and (J') were used to evaluate the diversity of phytoplankton in the study area.

Number of phytoplankton species ranged from 11 to 58. A maximum value (58) was recorded during December, at St.1 in day time. Species richness ranged between (0.93-7.46. Maximum value (d=7.46) was recorded during December, at St.1 day and minimum value and (d=0.93) was recorded during January at St.1. Evenness ranged from 0.002 to 0.94. Higher value (J'=0.94) was recorded during February at St.1 and lowest value (J'=0.002) was recorded during January at St.1. Relatively higher species diversity (H'=3.03) was recorded during December at St.1 and minimum value (H'=0.009) was recorded during January at St.1. Within the tropical aquatic environment, there is a decreasing gradient in diversity from oceanic to bay habitats as found in this study has been reported earlier[56]. The species richness index (d) ranged between 5.7 and 6.01. Relatively higher 'd' values recorded from open ocean (6.01) compared to eastern (5.7) and bay region (5.1) could be due to their adaptability to utilize the limited resources in open ocean in effective manner and survive in adverse condition[57]. Equitability in phytoplankton population was generally low in bay (mean J'=0.63) compared to eastern (mean J'=0.76) and western (mean J'=0.82) region, which could be due to the presence of few opportunistic bloom forming species that take advantage of frequent change of environmental conditions and rapidly multiply in numbers.

Acknowledgement

Authors are thankful to the Head of the Department, Ocean Studies and Marine Biology, Pondicherry University, Port Blair, for providing facilities.

References

1 Ananthan, G.A., Sampathkumar, P., Soundarapandian, P. & Kannan, L. (2004). Observation on environmental

characteristics of Ariyankuppam estuary and Verampattinam coast of Pondicherry, India. *J. Aqua. Biol.,* 19, pp, 67-72.

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

3 Hassan, F.M., Kathim, F.N., Hussein, H.F. (2004). Effect of chemical and physical properties of river water in shatt al-hilla on phytoplankton communities. E-*J. Chemis.,* 5, pp. 323-330.

4 Nowrouzi, S. & Valavi, H. (2011). Effects of environmental factors on phytoplankton abundance and diversity in Kaftar Lake. *J. Fish. Aquat. Sci.,* 6, pp. 130-140.

5 Reynolds C.S. (1984). Phytoplankton periodicity: The interactions of form, function and environmental variability. *Freshwater Biol.,* 14, pp. 111-142.

6 Reynolds, C.S. (2006). *The ecology of Phytoplankton.* Cambridge University Press, p. 402.

7 Sournia, A., Chretiennot-Dinet, M.J. & Ricard, M. (1991). Marine phytoplankton: how many species in the world ocean? *J. Plankton Res.,* 13, pp. 1093 -1099.

8 Rangarajan, K. & Marichamy, R. (1972). Seasonal change in the temperature salinity and plankton volume at Port Blair. Andamans. *Indian J. Fisheries.,* 19, pp. 60-69.

9 Devassy, V.P. & Bhattathiri, P.M.A. (1981). Distribution of phytoplankton and chlorophyll around little Andaman Islands. *Indian J. Mar. Sci*., 10, pp. 248-252.

10 Eashwar, M., Kuberaraj, K., Nallathambi, T. & Govindarajan, G. (2001). A note on the plankton from Barren Island region, Andamans. *Curr. Sci.,* 81, pp. 25.

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

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

13 Geetha Madhav, V. & Kondalarao, B. (2004). Distribution of phytoplankton in the coastal waters of east coast of India. *Ind. J. Mar. Sci.,* 33, pp. 262-268.

14 Vinithkumar, N. V., Begam, M., Dharani, G., Anushrita Biswas, A.K., Abdul Nazar, R., Venkatesan, R., Kirubagaran, and Kathiroli, S. (2011). Distribution and biodiversity of phytoplankton in the coastal seawaters of Andaman and Nicobar Island, India. *Recent. Advan. Biodiver. India.,* 16, pp. 137-148.

15 Siva Sankar, R. **&** Padmavati, G. (2012). 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, pp. 76-83.

16 Chakravarty, N.V.K., Tripathi, K.P. & Gangwar, B.A. (1987). Comparative study of coastal climate with special reference to Andamans, India- I. Temperature and Rain-fall. *J. Andaman sci. Assoc.,* 3, pp. 119-124.

17 Jayaraj, R.S.C. & Andrews, H.V. (2005). *Andaman and Nicobar Islands Union Territory Biodiversity Strategy and Action Plan.* Government of India – United Nation Development Programme.

18 Sai Elangovan, S., Padmavati, G., Karthik, R., Siva Sankar, R., Damodar Rakesh, O. & Arun Kumar, M. (2017). Comparison between microzooplankton population in polluted and moderately polluted coastal waters of Port Blair, South Andaman. *Environ. Monit. Assess.*, 189:13.

19 Strickland, J.D.H. & Parsons, T.R.A. (1972). *Practical handbook of sea water analysis.* Bulletin no. 167, Fisheries Research Board of Canada, Ottawa. 310pp.

20 Allen, W.E. & Cupp, E.E. (1935). *Plankton diatoms of the Java Sea.* Annales du Jardin Botanique de Buitenzorg., 2, pp. 101-174.

21 Venkataraman, G. (1939). A systematic account of some south Indian diatoms. *Proc. Indian. Acad. Sci.,* 10, pp. 293-368.

22 Desikachary, T.V. (1959). Cyanophyta. Indian Council of Agricultural Research, New Delhi, 686pp.

23 Hendey, N.T. (1974). A revised check list of British marine diatoms. *J. Mar. Biol. Aass.,* 54, pp. 377-384.

24 Subrahmanyan, R. & Sharma, A.H.V. (1960). Studies on the phytoplankton of the west coast of India Part III. Seasonal variations of the phytoplankters and environmental factors. *Indian J. Fish.,* 7, pp. 307-336.

25 Cupp, E.E. (1943). Marine plankton diatoms of the west coast of North America, Vol. 5, No. 1. Berkeley and Los Angeles, *University of California Press.,* 1-238pp.

26 Santhanam, R., Ramanathan, N., Venkataramanujam, K.V. & Jegatheesan, G. (1987). Phytoplankton of the Indian Seas (An aspect of Marine Botany). Daya Publishing House, Delhi- 110 006.

27 Tomas, C.R. (1997). Identifying Marine Phytoplankton. (Academic press, Harcourt Brace and company), 857pp.

28 Guillard, R.R.L. (1978). *Counting slides. In: A. Sournia (ed) Phytoplankton Manual,* UNESCO, Paris. 337pp.

29 Shannon, C.E. & Weaver, W. (1949). *The Mathematical Theory of Communication.* University of Illinois Press, Urbana.

30 Gleason, H.A. (1922). *On the relation between species and area.* Ecology., 3, pp. 158-162.

31 Pielou, E.C. (1966). The measurement of diversity in different types of biological collections. *J. Theoret. Biol.,* 13, pp. 131-144.

32 Clarke, K.R. (1993). Non parametric multivariate analysis of changes in community structure. *Australian Journal of Ecology*., 18, pp. 117-143.

33 Clarke, K.R. & Warwick, R.M. (1994). Change in marine communities: an approach to statistical analysis and interpretation. *2nd edition, PRIMER-E, Plymouth*.

34 Clarke, K.R. & Gorley, R.N. (2006). Primer v6: User Manual/Tutorial, Primer-E., Plymouth, p. 1-190pp.

35 Boonyapiwat, S. (2006). Composition, abundance and distribution of phytoplankton in the Andaman Sea. Preliminary Results on the Large Pelagic Fisheries Resources Survey in the Andaman Sea. TD/RES/99 SEAFDEC.,40-52pp.

36 Karthik, R., Arun Kumar, M., Sai Elangovan, S., Sivasankar, S. & Padmavati, G. (2012). Padmavati, Phytoplankton Abundance and Diversity in the Coastal Waters of Port Blair, South Andaman Island in Relation to Environmental Variables. *J. Mar. Biol. Oceanogr,* 1, pp. 1-6.

37 Karthik, R., Arun Kumar, M. & Padmavati, G. (2014). Silicate as the Probable Causative agent for the Periodic blooms in the coastal waters of South Andaman Island. *Appl. Environ. Res.,* 36, pp. 37-45.

38 Prabu, A.V., Rajkumar, M. & Perumal, P. (2008) Seasonal variations in physicochemical characteristics of Pichavaram mangroves, southeast coast of India. *J. Environ.Biol.* 29, 945-950.

39 Laliolette, (1969). Temperature, salinity and density of the world's seas: Bay of Bengal and Andaman Sea. Naval Oceanography office, Washington DC.

40 Varkey, M.J., Murty, N.S.N. & Suryanarayana, A. (1996) Physical Oceanography of the Bay of Bengal and Andaman Sea. In: Ansell, A.D., R.N. Gibson, M. Barnes, (Eds.), Oceanography and Marine Biology an Annual Review. *University College London Press, London.,* 1-70pp.

41 Subramanian, B. & Mahadevan, A. (1999). Seasonal and diurnal variation of hydrological characters of coastal water of Chennai (Madras), Bay of Bengal. *Indian Journal of Mar. Sci.,* 28, pp. 429-433.

42 Das, J., Das, S.N. & Sahoo, R.K. (1997). Semidiurnal variation of some physiochemical parameters in the Mahanadi estuary, east coast of India. *Indian Journal of Marine Sciences.,* 26, pp. 323-326.

43 Riley, J.P. & Chester, R. (1971) An introduction to Marine chemistry. London. *Academic.*Robertson, J. R. (1983) Predation by estuarine zooplankton on tintinnid ciliates. *Estuar. Coast. Shelf Sci.,* 16, pp. 27-36.

44 Begum, M., Jha, D.K., Vinithkumar, N.V., Das, A.K. & Kirubagaran, R. (2012a). Perliminary study on physico-chemical and biological parameters of coastal water of Treis Island, Little Nicobar, India. *J. Appl. Geochemistry.,* 19-27 pp.

45 Saravanakumar, A., Rajkumar, M., Thivakaran, G.A. & SeshSerebiah, J. (2008). Abundance and seasonal variations of phytoplankton in the creek waters of western mangrove of Kachchh-Gujarat. *J. Environ. Biol.,* 29, pp. 271-274.

46 Rajkumar, M., Perumal, P., Ashok Prabu, V., Vengadesh Perumal, N. & Thillai Rajasekar, K. (2009). Phytoplankton diversity in Pichavaram mangrove waters from south-east coast of India. *J. Environ. Biol.,* 30, pp. 489-498.

47 Begum, M., Vinithkumar, N.V., Mohan, P.M., Dhivya, P. & Kirubagaran, R. (2012b) Spatail distribution pattern of phytoplankton in relation to nutrients availability in the offshore waters of Andaman Sea, India. In: Recent Advances in Biodiversity of Indian subcontinent. (eds) Raghunathan, C., Sivaperuman, C. and Venkataraman, K. *Zoological Survey of India, Kolkata Publication.,*149-168 pp.

48 Smita Achary, (2010). Phytoplankton abundance and diversity in the coastal waters of Kalpakkam, east coast of India in relation to the environmental variables. *The Bioscan.,* 2, pp. 553-568.

49 Sahu, B.K., Begum, M., Kumarasamy, P., Vinithkumar, N.V. & Kirubagaran, R. (2014). Domiance of *Trichodesmium* and associated biological and physicochemical parameters in coastal waters of Port Blair, South Andaman Island. *Indian J. Geo-Mar. Sci..,* 43 pp.

50 Swati, S., Panda, Dhal, N.K. & Panda, C.R. (2012). Phytoplankton diversity in response to abiotic factors along Orissa coast, Bay of Bengal. *Inter. J. Environ. Sci.,* 2, pp. 2012.

51 Karolina, H., Karunasagar, I. & Godhe, A. (2009). Phytoplankton species assemblages and their relationship to hydrographic factors-a study at old pot in Mangalore, coastal Arabian Sea. *Indian J. Mar. Sci..,* 38, pp. 224-234.

52 Begum, M., Sahu, B.K., Das, A.K., Vinithkumar, N.V. & Kirubagaran, R. (2015). Extensive Chaetoceroscurvisetus bloom in relation to water quality in Port Blair Bay, Andaman Islands. *Environ. Monit. Assess.,* 5, pp. 187-226.

53 Kinjarapu, N.M. (2013). Phytoplankton dynamics in relation to physicochemical properties of the central East Indian coast, Bay of Bengal. *Ph.D. Thesis, Andhra University, Visakhapatnam.*

54 Gouri S., Satpathy, K.K., Mohanty, A.K. & Sarkar, S.K. (2012) Variation in community structure of phytoplankton in relation to physicochemical properties of coastal waters, southeast coast of India. *Indian J. Mar. Sci.,* 41, pp. 223-241.

55 Evelyn, B.S. & Sherr, B.F. (2007). Heterotrophic dinoflagellates: a significant component of microzooplankton biomass and major grazers of diatoms in the sea. *Mar. Ecol. Progr. Ser.,* 352, pp. 187-197.

56 Padmavati, G. (1992) Zooplankton ecology of the estuarine, near shore and adjacent coastal waters of Goa. *Ph.D Thesis:* 175pp.

57 Margalef, R. (1978). Life-forms of phytoplankton as survival alternatives in an unstable environment. *Oceanol. Acta.,* 1, pp. 493-509.