Environ Monit Assess (2017) 189: 614
https://doi.org/10.1007/s10661-017-6335-2

Diversity and distribution of heterotrophic dinoflagellates from the coastal waters of Port Blair, South Andaman

S. Sai Elangovan · G. Padmavati

Received: 3 April 2017 / Accepted: 26 October 2017 / Published online: 6 November 2017

Abstract The interaction between the environment and heterotrophic dinoflagellates inhabiting coastal waters of South Andaman was studied based on year round collections made during September 2012–August 2013 in the bay, eastern, and western region of South Andaman. The distribution pattern of microzooplankton in South Andaman showed high abundance in eutrophic waters (bay region) and gradually decreased towards the off shore region. Microzooplankton community comprised of six different taxa, viz. tintinnids, heterotrophic dinoflagellates, non-loricate ciliates, Foraminifera, Rotifera, and Copepoda (nauplii). Tintinnids were the major component of the microzooplankton (43.8 ± 7%) followed by heterotrophic dinoflagellates (34 ± 12%) and copepod nauplii (18.8 ± 4.0%). This study focused on heterotrophic dinoflagellates which ranked next to tintinnids in overall abundance and contributed 38–42% in the bay, 22–37% in the eastern, and 15–29% in the western region to the microzooplankton community. Dinoflagellates showed a positive correlation with salinity and a negative correlation with dissolved oxygen and chlorophyll *a* ($r = -0.3$). Abundance of heterotrophic dinoflagellates in this area may be due to their diverse and advantageous mode of nutrition. A total of 35 species belonging to 8 genera of heterotrophic dinoflagellates were recorded during the study period. Heterotrophic dinoflagellates showed a great potential to thrive in low oxygenated and low productive area ($p < 0.001$, Mann-Whitney test). Relatively higher diversity (H′) in the dinoflagellates population was found in the bay region (avg. H′ = 3.46).

Keywords Heterotrophic dinoflagellates · Distribution · Diversity · Coastal waters · South Andaman

Introduction

Microzooplankton are heterotrophic organisms (20–200 μm in size) and comprise of protozoans (e.g., ciliates, heterotrophic dinoflagellates, radiolarians, and foraminifera) and metazoans (e.g., copepod nauplii, copepodites, and rotifers). They play a significant role in energy transfer through classical and microbial food webs in the marine ecosystems (Berggreen et al. 1988; Turner and Roff 1993). Heterotrophic dinoflagellates are ubiquitous protists in marine environment (Lessard 1991; Hansen 1991; Strom and Buskey 1991; Verity et al. 1993). Dinogflagellates are usually categorized as autotrops and heterotrops according to the presence or absence of chloroplast pigments (Ehrenberg 1854; Ismael Amany 2003). Half of the dinoflagellates species in marine plankton lack chloroplast and consume other plankton cells (Lessard and Swift 1985). The non-photosynthetic nature of many dinoflagellates has been noted since the early studies (Kofoid and Swezy 1921;

S. Sai Elangovan · G. Padmavati (✉)
Department of Ocean Studies and Marine Biology, Pondicherry University, Port Blair, Andaman 744112, India
e-mail: padma190@rediffmail.com

S. Sai Elangovan
National Institute of Oceanography, Dona Paula, Goa 403004, India

Lessard and Swift 1985). The feeding mechanism of dinoflagellates revealed that they are phagotrophic (Gaines and Taylor 1984; Jacobson and Anderson 1986; Hansen 1991). Heterotrophic dinoflagellates have diverse nutrition pattern like autotrophic, mixotrophic, and heterotrophic (Jeong et al. 2010). Documentation made on dinoflagellates feeding on prey size spectrum from bacteria (Lessard and Swift 1985) to large diatoms (Hansen and Larsen 1992), copepod eggs, and early nauplii (Sekiguchi and Kato 1976). Klein Bretler (1980) found better growth of marine copepods when their algal diet was supplemented with heterotrophic dinoflagellates.

In the present study, an attempt has been made to understand the interaction between the environment and heterotrophic dinoflagellates inhabiting three diversified regions (Bay, Eastern, and Western part) of south Andaman. This study represents the first detailed account on distribution and diversity of heterotrophic dinoflagellates from this coastal ecosystem. Prior to this study, no research on heterotrophic dinoflagellates from this area had been undertaken. The present study thus addresses the gap in our knowledge on the taxonomic and ecological approach of heterotrophic dinoflagellates in this little studied ecosystem.

Methods

Study area

Present study was carried out during September 2012 to August 2013 in three distinct coastal regions of South Andaman Island (Bay, Eastern, and Western region). A total of 10 stations (11° 29′ N–92° 36′ E; Fig. 1) were selected, viz. I. Bay region: including Junglighat Bay (St.2); Sippighat (St.7), and Chouldhary (St.8); II. Eastern region: including Chatham (St.1), Burmanallah (St.3), and Carbyn's Cove (St.4); and III. Western region including Chidiyatapu (St.5), Pongibalu (St.6), Manjery (St.9), and (St.10) Wandoor (Fig. 1).

Sampling procedure

Water samples were collected for the determination of physicochemical parameters such as water temperature, salinity, dissolved oxygen, and pH and phytoplankton biomass (chlorophyll *a*). Microzooplankton (heterotrophic dinoflagellates) samples were collected by filtering 10 L of subsurface seawater through plankton net of

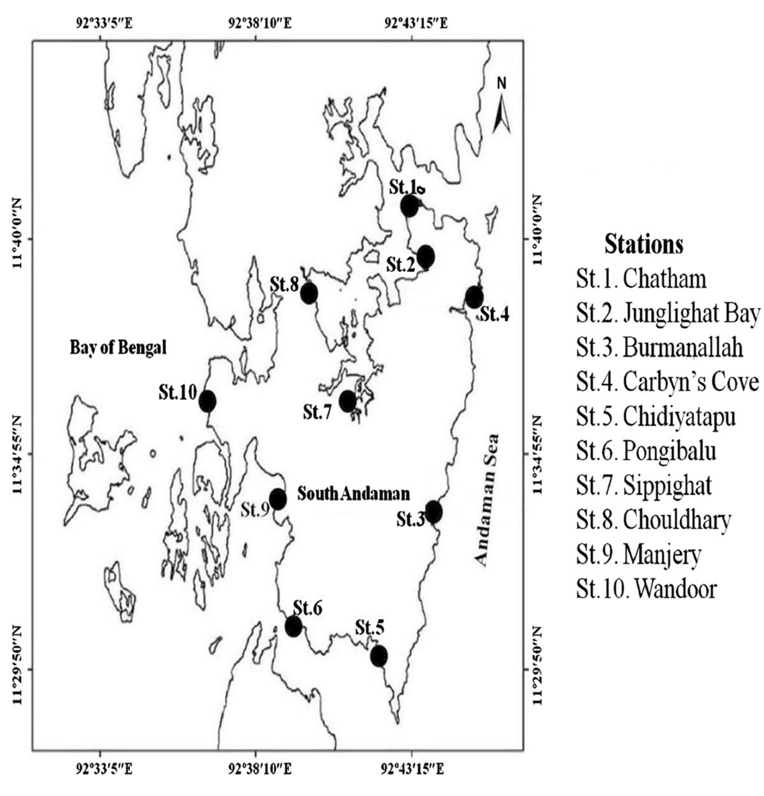


Fig. 1 Map of the study area showing the sampling stations of three different regions in South Andaman Island. Bay stations are St.2, St.7, and St.8; eastern stations are St.1, St.3 and St.4; and western stations are St.5, St.6, St.9, and St.10

200 μm and then slowly passing the filtrate through a 20-μm net.

Physicochemical parameters

Surface seawater temperature was recorded by using standard mercury centigrade thermometer and salinity was estimated with the help of a hand held Refractometer (ATAGO). pH was measured by using a portable digital pH meter (*Eutech pH Scan1* with accuracy + 0.1 pH) and calibrated with standard buffer solution prior to the field sampling. Dissolved oxygen (DO) was estimated by the modified Winkler's method (Strickland and Parson 1972).

Biological parameters

Phytoplankton biomass was estimated as chlorophyll *a* (μg L^{-1}) by 90% acetone extraction method (Strickland and Parson 1972). The following equation was used to calculate the chlorophyll *a* concentration.

$$Chlorophyll\ \ a\left(\mu g\ L^{-1}\right) = \frac{26.7(OD647\text{-}OD665)XV_1}{V_2XL}$$

where

26.7 is derived from AXK (A = Absorption coefficient of chlorophyll *a*; K = factor to equate the reduction in absorbency to initial)
V1 volume of acetone (10 ml)
V2 volume of water (1 L)
L path length (1 cm) of cuvette

Microzooplankton (qualitative and quantitative study)

For microzooplankton (heterotrophic dinoflagellates) taxonomy and quantitative studies, 10 L of subsurface seawater was filtered through 200-μm plankton net and collected in a bucket. Further, this filtered water was then slowly passed through a 20-μm net. The residue samples from the net was collected and transferred in to 1 l of filtered seawater and preserved with 1% acid Lugol's solution. The samples were left to settle for 24 h and concentrated to 10 ml by siphoning out the supernatant (Gauns et al. 1996). For heterotrophic dinoflagellates taxonomy studies, 1-ml sample was taken from concentrated 10-ml sample to Sedgwick-Rafter counting chamber and examined under the plankton inverted microscope (Nikon Eclipse TS 100) and converted to cells per liter.

Statistical analyses

Statistical analysis was performed by using statistical software Primer (Ver.6.1). Biodiversity indices for the heterotrophic dinoflagellates population such as species richness (d), Shannon-Weiner diversity (H′), and evenness (J) were calculated. Bray-Curtis similarity was applied on square-root-transformed abundance data to discern species similarities between different sampling stations. Correlation between the various environmental parameters and dinoflagellates were assessed by using Spearman rank correlation analysis (Microsoft Excel, Window 2007).

Results

Bay region

Sea surface water temperature in the bay region ranged from 25 to 35 °C. Maximum temperature (34 °C) was recorded at St.7 during April 2013 and minimum (25 °C) was recorded at all the three bay stations (St.2, St.7, and St.8) during February 2013. Salinity ranged from 7 to 35 psu. Maximum salinity (35 psu) was recorded at St.7 and St.8 during March 2013 and lower values of salinity was recorded at St.7 during September 2012 (8 psu) and June 2013–July 2013 (7 and 11 psu). pH ranged from 7.4 to 8.4. Higher values (8.3–8.4) were recorded at St.2 and St.8 during July 2013–August 2013 and slightly lower values (7.5–7.7) was recorded in all the three stations in the bay region during October 2012–January 2013. Dissolved oxygen ranged from 2.01 to 6.03 mg L^{-1}. Lower values (2.0 mg L^{-1}) were recorded at almost all the three stations during April 2013–June 2013 and generally higher DO was recorded in this region during September 2012–July 2013. Chlorophyll *a* concentration varied from 0.01 to 0.24 μg L^{-1}. Due to the occurrence of periodic blooms of diatoms and dinoflagellates, higher value of chlorophyll *a* was recorded in the bay stations during September 2012–May 2013 (Elangovan and Padmavati 2017).

Heterotrophic dinoflagellates ranked next to tintinnids in overall abundance from this area. Maximum density of heterotrophic dinoflagellates (125 cells L^{-1}) was recorded during April 2013 at St.7

when both temperature and salinity were recorded high. Minimum density (4–16 cells L^{-1}) was recorded during September 2012 and October 2012 at almost all the bay stations when salinity was low. They showed a positive correlation with salinity and temperature and a negative correlation with chlorophyll *a* and dissolved oxygen (Fig. 2 and Table 1).

Heterotrophic dinoflagellates comprising of 26 species belonged to eight genera in bay and represented by *Dinophysis apicata*, *D. caudate*, *D. miles*, *Dinophysis* sp., *Gymnodinium* sp., *Noctiluca scintillan*, *Ornithocercus magnificus*, *O. thumii*, *Podolampas bipes*, *Porocentrum micans*, *Protoperidinium breve*, *P. conicum*, *P. crassipes*, *P. curtips*, *P. depressum*, *P. divergens*, *P. globules*, *P. granii*, *P. latistriatum*, *P. longicollum*, *P. oceanicum*, *P. ovatum*, *P. pellucidum*, *P. pentagonum*, *P. stenii*, and *Pyrophacus* sp. Among these, six species of heterotrophic dinoflagellates such as *Dinophysis caudata* (70 cells L^{-1}), *Protoperidinium divergens* (38 cells L^{-1}), *P. depressum* (32 cells L^{-1}), *P. granii* (23 cells L^{-1}), *P. stenii* (22 cells L^{-1}), and *Dinophysis* sp. (22 cells L^{-1}) were abundant in the bay region (Plates 1 and 2, Table 4).

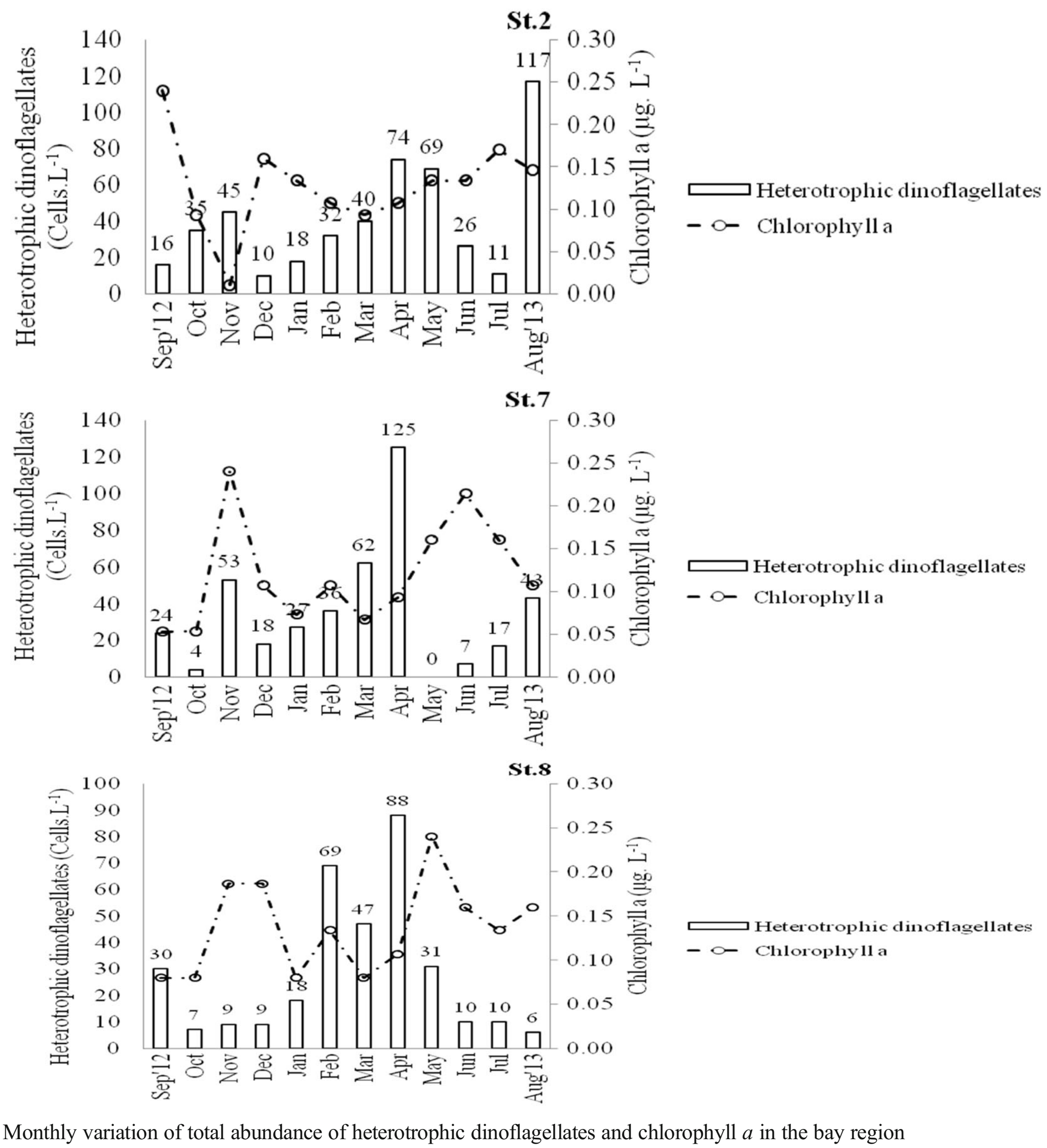


Fig. 2 Monthly variation of total abundance of heterotrophic dinoflagellates and chlorophyll *a* in the bay region

Table 1 Spearman rank correlation coefficients (r) between various environmental parameters and heterotrophic dinoflagellates in the bay region

	Temperature	Salinity	Chl *a*	DO	pH	H. dinoflagellates
St.2						
Temperature	1.00					
Salinity	0.24	1.00				
Chl *a*	− 0.09	− 0.45	1.00			
DO	− 0.65	− 0.48	0.44	1.00		
pH	0.01	0.69	− 0.36	− 0.40	1.00	
H. dinoflagellates	0.45	0.64	− 0.23	− 0.35	0.36	1
St.7						
Temperature	1					
Salinity	0.21	1				
Chl *a*	0.16	− 0.31	1			
DO	− 0.16	− 0.28	− 0.32	1		
pH	− 0.20	0.20	− 0.39	− 0.03	1	
H. dinoflagellates	0.39	0.45	− 0.14	− 0.41	0.37	1
St.8						
Temperature	1					
Salinity	0.03	1				
Chl *a*	0.55	0.11	1			
DO	− 0.24	− 0.27	0.18	1		
pH	− 0.20	0.34	− 0.22	0.00	1	
H. dinoflagellates	− 0.35	0.29	− 0.24	− 0.70	0.09	1

Eastern region

Sea surface water temperature ranged from 22 to 33 °C in the eastern region. Maximum temperature (33 °C) was recorded during April 2013 at St.3 and lower value of temperature (24–26 °C) was recorded during January 2013–March 2013 at all the three stations (St.1, St.3, and St.4). Salinity ranged from 20 to 36 psu. Maximum salinity (36 psu) recorded during March 2013 and minimum (22 psu) recorded during June 2013 at St.4. Generally, higher salinity (32–36 psu) recorded during January 2013–March 2013 at almost all three stations in the eastern region. Salinity values were low during September 2012–October 2012 (20–29 psu) at St.1. pH ranged from 7.7 to 8.4. Higher pH (8.0–8.3) was recorded during July 2013–August 2013 at most of the stations and slightly lower values (7.7–7.9) were recorded during September 2012–December 2012. Dissolved oxygen ranged from 2.08 to 4.91 mg L^{-1}. Higher DO values (> 4 mg L^{-1}) was recorded during July–January 2013 at almost all the three stations and generally lower DO was recorded during February 2013–April 2013. Chlorophyll *a* concentration varied from 0.05 to 0.16 μg L^{-1}. Higher values of chlorophyll *a* was recorded during May–August 2013 and low values recorded during October–November 2012 in the eastern stations (Elangovan and Padmavati 2017). Heterotrophic dinoflagellates showed a positive correlation with salinity and temperature and negative correlation with chlorophyll *a* ($r = -0.51$) and dissolved oxygen at the eastern stations (Fig. 3 and Table 2).

Heterotrophic dinoflagellates ranked next to tintinnids in overall abundance from this region. Maximum density of heterotrophic dinoflagellates (96 cells L^{-1}) was recorded during April 2013 at St.1 when temperature and salinity were recorded high. Minimum density (4–22 cells L^{-1}) was recorded during September 2012–December 2012 at almost all the eastern stations when salinity was low. Heterotrophic dinoflagellates comprising of 26 species belonged to 8 genera in this region represented by *Dinophysis apicata*, *D. caudata*, *D. rotundata*, *Gymnodinium* sp., *Noctiluca*

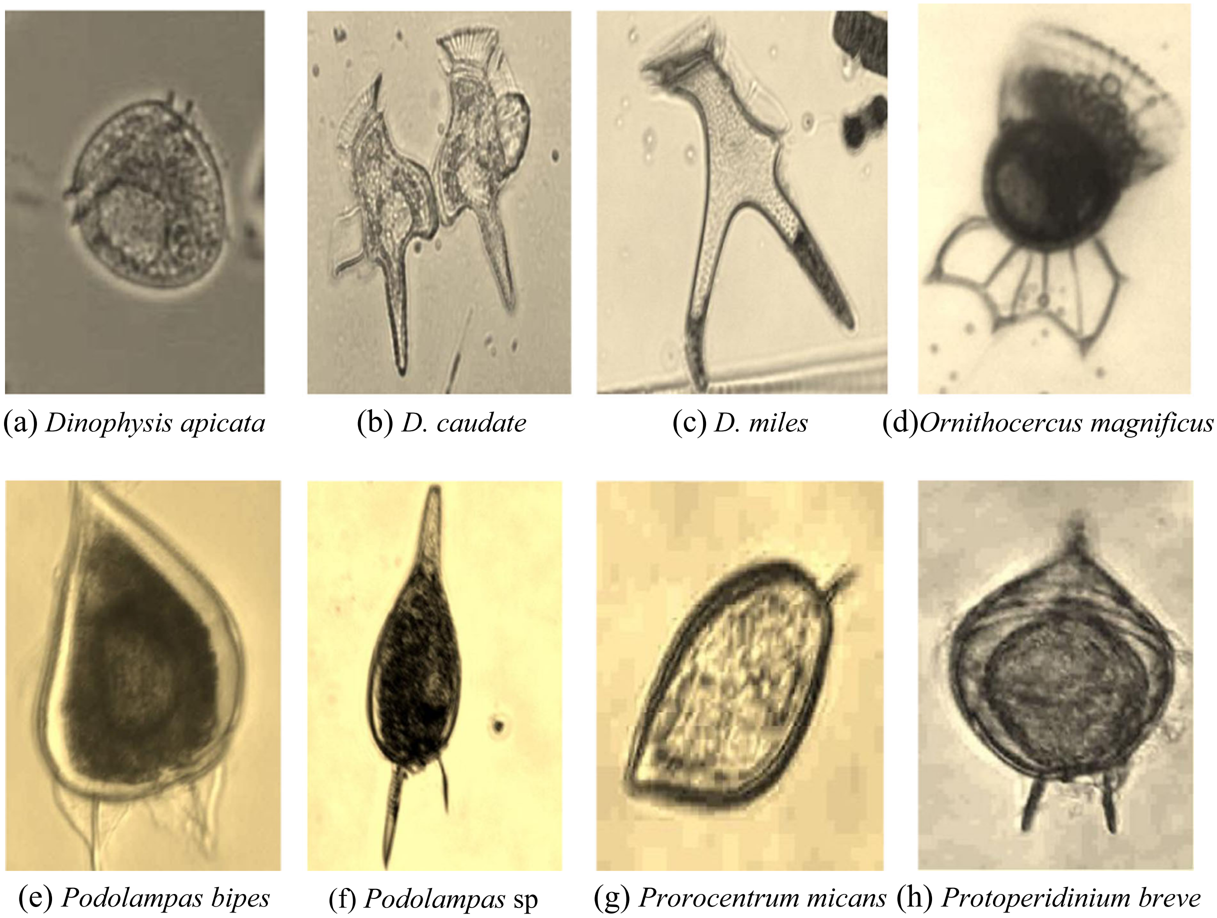
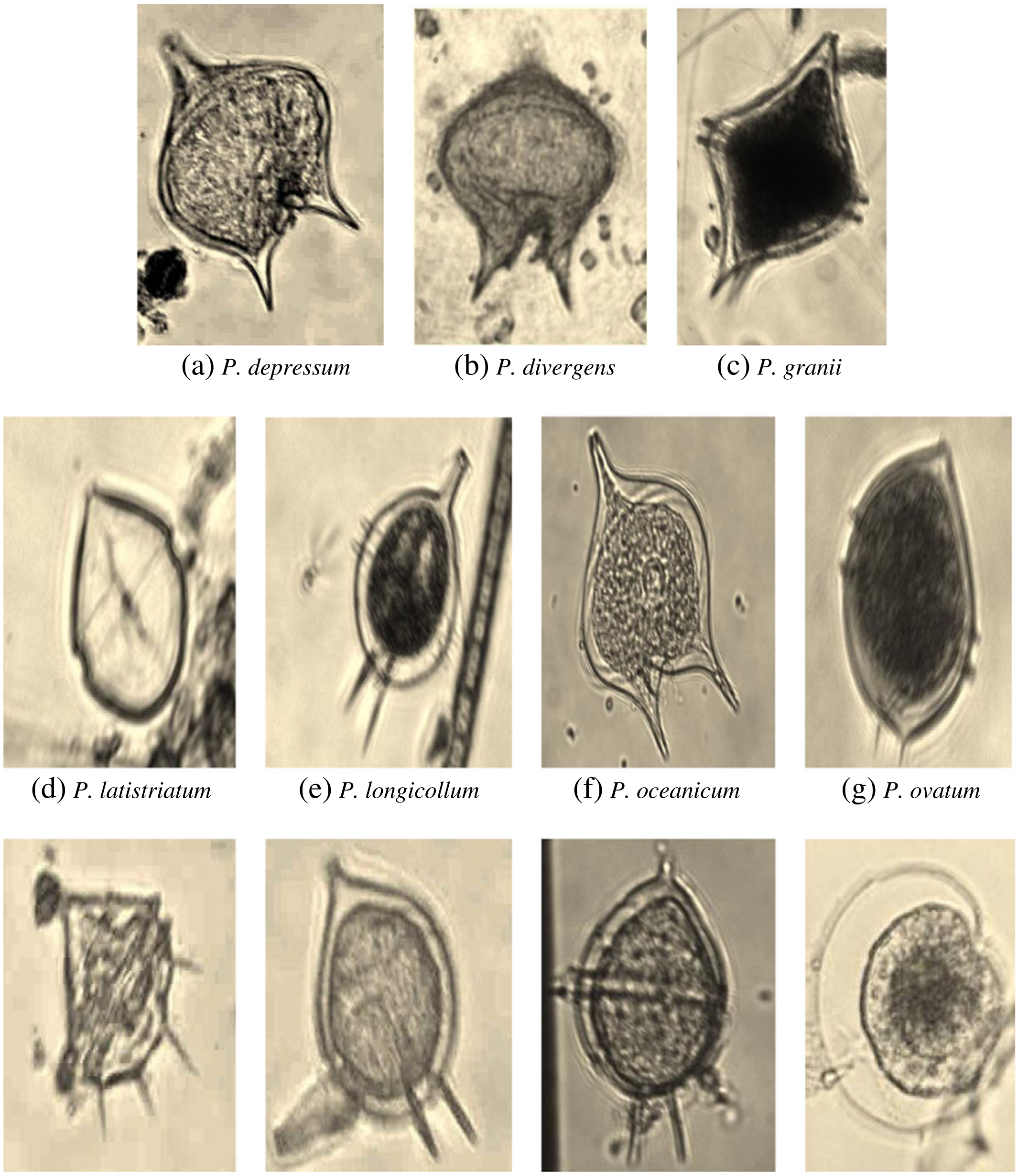


Plate 1 Microphotographs of heterotrophic dinoflagellates (**a**–**h**) identified from coastal waters of South Andaman (× 40 magnification)

scintillans, *Ornithocercus magnificus*, *O. thumii*, *Podolampas bipes*, *Podolampas* sp., *Porocentrum micans*, *Protoperidinium breve*, *P. conicum*, *P. curtips*, *P. depressum*, *P. divergens*, *P. globules*, *P. granii*, *P. latistriatum*, *P. nipponicum*, *P. oceanicum*, *P. ovatum*, *P. pellucidum*, *P. pentagonum*, *P. stenii*, *P. tuba*, and *Pyrophacus* sp. Among these, four species of heterotrophic dinoflagellates such as *Dinophysis caudata* (63 cells L^{-1}), *Protoperidinium depressum* (22 cells $L^{-1)}$, *P. granii* (18 cells L^{-1}), and *P. divergens* (15 cells L^{-1}) were abundant in the eastern region (Plates 1 and 2, Table 4).

Western region

Sea surface water temperature ranged from 23 to 34 °C in the western region. Higher temperature (> 32 °C) was recorded during April 2013 in all the four stations in this region. Maximum temperature (34 °C) was recorded during April 2013 at St.9. Lower values of temperature (23–27 °C) were recorded during January–March 2013 at all the four stations (St.5, St.6, St.9, and St.10). Salinity ranged from 17 to 36 psu. Maximum salinity (36 psu) was recorded during February 2013 at St.6 and minimum (17 psu) was recorded during May 2013 at St.5. Generally, higher values of salinity (31–36 psu) obtained during January 2013–April 2013 at almost all the four western stations. Lower value of salinity was recorded during September–October 2012 (30–31 psu). pH ranged from 7.2 to 8.4. Higher values (8.0–8.3) were recorded during June 2013–August 2013 at most of the sampling stations and slightly lower values (7.7–8.0) were recorded during October 2012–January 2013 in the western region. Dissolved oxygen showed wide range and varied from 0.53 to 5.03 mg L^{-1}. Maximum dissolved oxygen (5.03 mg L^{-1}) was recorded at St.9 during February and August 2013. Lower values (< 3 mg L^{-1}) were recorded during April 2013 and



(a) *P. depressum* (b) *P. divergens* (c) *P. granii*

(d) *P. latistriatum* (e) *P. longicollum* (f) *P. oceanicum* (g) *P. ovatum*

(h) *P. pellucidum* (i) *P. stenii* (j) *P. tuba* (k) *Pyrophacus* sp

Plate 2 Microphotographs of heterotrophic dinoflagellates (**a**–**k**) identified from coastal waters of South Andaman (× 40 magnification)

June 2013 in this region. Chlorophyll *a* concentration varied from 0.01 to 0.19 μg L^{-1}. Higher value of chlorophyll *a* was recorded during November 2012–February 2013 in the western stations (Elangovan and Padmavati 2017).

Heterotrophic dinoflagellates ranked next in the order of abundance in this region. Maximum density of heterotrophic dinoflagellates (42 cells L^{-1}) was recorded during June 2013 at St.10 when both temperature and salinity was recorded high. Minimum density (3–18 cells L−1) was recorded during December 2012 – January 2013 at almost all the western stations when temperature was low. A negative correlation was found between heterotrophic dinoflagellates, chlorophyll *a*, and dissolved oxygen (Fig. 4 and Table 3). Heterotrophic dinoflagellates comprising of 27 species belonged to 8 genera in this region represented by *Dinophysis apicata*, *D. caudata*,

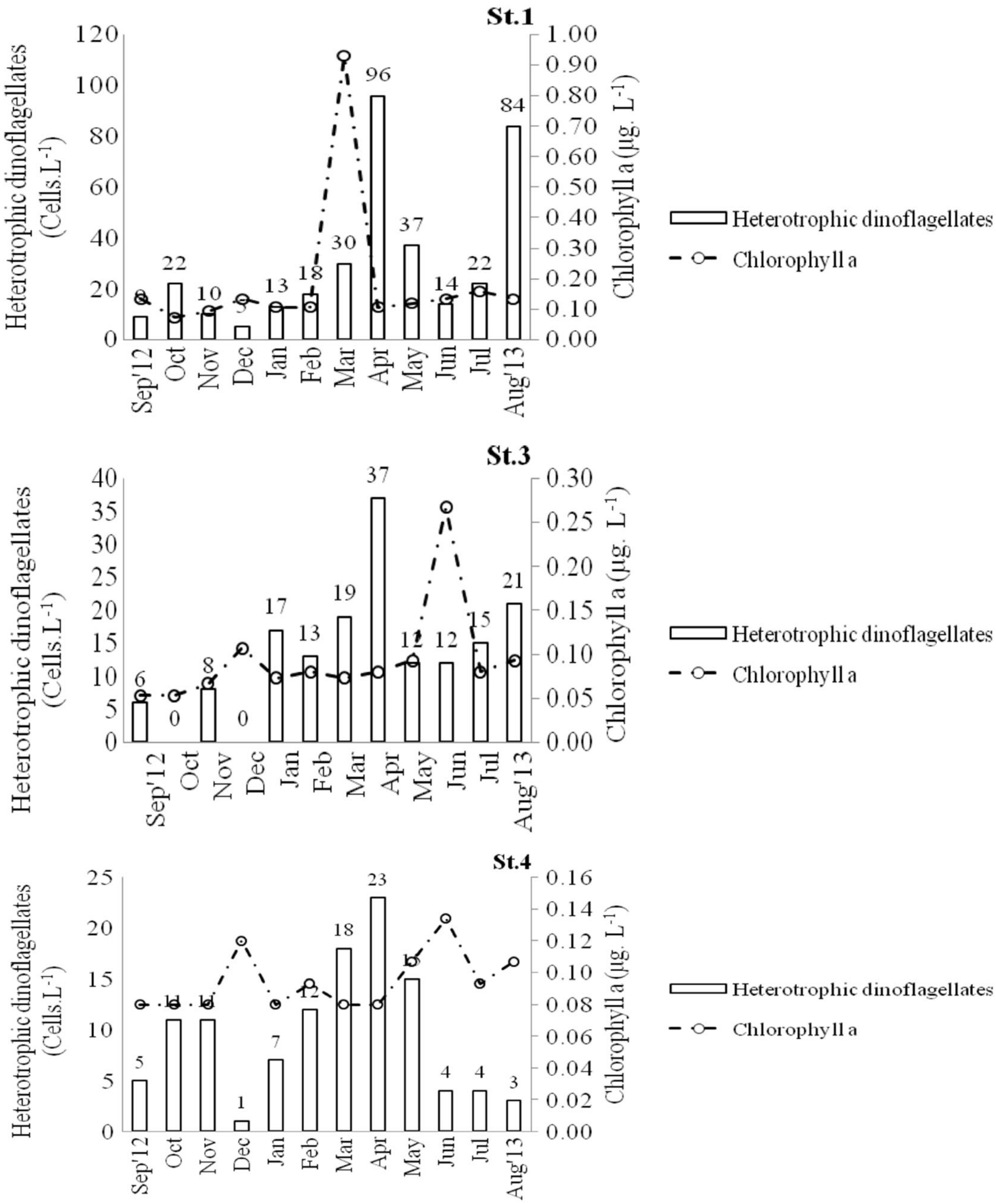


Fig. 3 Monthly variation of heterotrophic dinoflagellates and chlorophyll *a* in the eastern region

D. rotundata, *Gymnodinium abbreviatum*, *Gymnodinium* sp., *Noctiluca scintillans*, *Ornithocercus magnificus*, *O. thumii*, *Podolampas bipes*, *Porocentrum micans*, *Protoperidinium breve*, *P. brevipes*, *P. conicum*, *P. crassipes*, *P. curtips*, *P. depressum*, *P. divergens*, *P. fatulipes*, *P. granii*, *P. latistriatum*, *P. nipponicum*, *P. oblongum*, *P. oceanicum*, *P. ovatum*, *P. pellucidum*, *P. stenii*, and *Pyrophacus* sp. Among these seven of heterotrophic dinoflagellates such as *Protoperidinium granii* (20 cells L^{-1}), *Dinophysis caudata* (15 cells L^{-1}), *Protoperidinium divergens* (15 cells L^{-1}), *P. pellucidum* (12 cells L^{-1}), *P. stenii* (3 cells L^{-1}), *P. depressum* (3 cells L^{-1}), and *Porocentrum micans* (2 cells L^{-1}) were recorded more in the western region (Plates 1 and 2, Table 4).

Table 2 Spearman rank correlation coefficients (*r*) between various environmental parameters and heterotrophic dinoflagellates in the eastern region

	Temperature	Salinity	Chl *a*	DO	pH	H. dinoflagellates
St.1						
Temperature	1					
Salinity	0.197	1				
Chl *a*	− 0.438	0.29	1			
DO	0.054	− 0.53	− 0.28	1		
pH	− 0.175	0.70	0.65	− 0.57	1	
H. dinoflagellates	0.621	0.40	0.00	0.19	0.04	1
St.3						
Temperature	1					
Salinity	− 0.09	1				
Chl *a*	0.11	− 0.25	1			
DO	−0.67	− 0.44	− 0.02	1		
pH	− 0.08	0.45	0.11	− 0.13	1	
H. dinoflagellates	0.38	0.25	0.00	− 0.47	0.25	1
St.4						
Temperature	1					
Salinity	− 0.06	1				
Chl *a*	0.26	− 0.67	1			
DO	− 0.21	− 0.06	− 0.33	1		
pH	0.13	0.30	0.20	− 0.63	1	
H. dinoflagellates	0.10	0.51	− 0.51	− 0.34	0.32	1

Species diversity and association

The mean number of species (S) recorded 12.2 sp. from the bay region, 11.1 sp. from eastern region, and 10.4 sp. from western region. There was a gradual decline in the heterotrophic dinoflagellates species diversity from the bay region to the open ocean. Relatively higher diversity (H′) in the dinoflagellate population was found in the bay region and eastern region (mean H′ = 3.4) compared to western region could be due to the presence of more coastal species (Fig. 5). Higher evenness in the dinoflagellate population was found in the eastern and western region. On the basis of clustering, the different dinoflagellate species from this region formed three major groups over space. Cluster "a" represented a group of exclusively with western species showing 55% similarity, cluster "b" formed of bay species with 50% similarity, and cluster "c" formed with a mixture of eastern and western species showing 30% similarity (Fig. 6).

Discussion

Heterotrophic dinoflagellates (HD) were second dominant group of the microzooplankton community in the study area and contributed 38–42% in the bay, 22–37% in the eastern region, and 15–29% in the western region. The distribution pattern of HD in South Andaman showed high abundance in eutrophic waters (bay region) and gradually decreasing towards the off shore region. The mean abundance of heterotrophic dinoflagellates in bay waters was 35 cells L^{-1}, eastern region, 18 cells L^{-1}, and western region was 10 cells L^{-1}. Maximum density (125 cells L^{-1}) was recorded at St.7 in the bay region during April 2013 when both temperature (34 °C) and salinity (35 psu) was high and dissolved oxygen was quite low (2.6 ml L^{-1}). Heterotrophic dinoflagellates were negatively correlated with dissolved oxygen concentration in the study area showing great potential to thrive at low oxygenated area ($p < 0.001$, Mann-Whitney test) and can survive in adverse conditions as found in this study has also been reported earlier

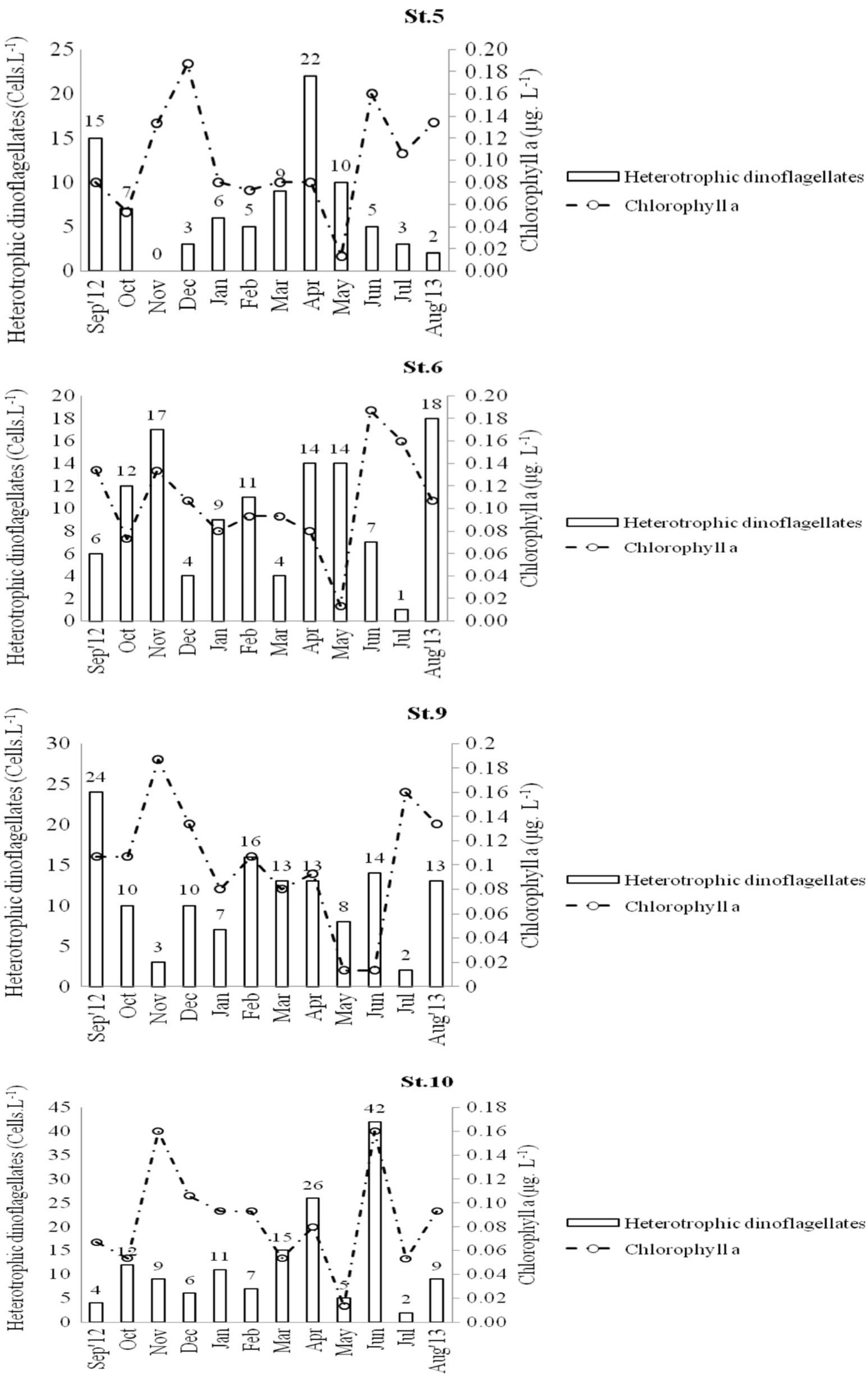


Fig. 4 Monthly variation of total abundance of heterotrophic dinoflagellates and chlorophyll *a* in the western region

Table 3 Spearman rank correlation coefficients (*r*) between various environmental parameters and heterotrophic dinoflagellates in the western region

	Temperature	Salinity	Chl *a*	DO	pH	H. dinoflagellates
St.5						
Temperature	1					
Salinity	0.17	1				
Chl *a*	0.34	0.39	1			
DO	− 0.37	− 0.41	− 0.14	1		
pH	0.40	0.57	0.37	− 0.44	1	
H.dinoflagellates	0.24	− 0.26	− 0.48	− 0.46	0.22	1
St.6						
Temperature	1					
Salinity	− 0.46	1				
Chl *a*	0.21	− 0.20	1			
DO	0.03	0.30	0.35	1		
pH	0.02	0.53	0.07	0.02	1	
H.dinoflagellates	0.10	0.32	− 0.41	− 0.01	0.14	1
St.9						
Temperature	1					
Salinity	0.28	1				
Chl *a*	0.37	0.41	1			
DO	− 0.28	0.41	0.33	1		
pH	0.49	0.77	0.04	0.08	1	
H.dinoflagellates	− 0.19	0.34	− 0.31	0.29	0.33	1
St.10						
Temperature	1					
Salinity	− 0.24	1				
Chl *a*	0.04	0.41	1			
DO	− 0.14	− 0.33	− 0.83	1		
pH	0.21	0.43	0.43	− 0.38	1	
H. dinoflagellates	0.10	0.06	− 0.14	− 0.21	− 0.18	1

(Wenlu Lana et al. 2009). Their abundance was quite low during September 2012–January 2013 when both temperature and salinity was low and dissolved oxygen concentration was quite high. The concentration of chlorophyll *a* and heterotrophic dinoflagellates showed a reverse pattern of distribution in this study ($p < 0.001$, Mann-Whitney test). Low density of heterotrophic dinoflagellates (16 cells L^{-1}) was observed in the bay region where periodic diatom blooms were recorded, viz. at St.2 during September 2012 *Leptocylindrus danicus* bloom (HD, 26 cells L^{-1}); during June 2013 *Protoperidinium pellucidinum* bloom (HD, 26 cells L^{-1}) and during July 2013 *Coscinodiscus centralis* bloom (HD, 11 cells L^{-1}) were noted. Similarly at St.8 during November 2012 *Ceratium furca* bloom (HD, 9 cells L^{-1}) and during May 2013 *Chaetoceros tortissimum* bloom (HD, 31 cells L^{-1}) were noted. The negative correlation of dinoflagaellates abundance and chlorophyll *a* may suggest that a large fraction of the dinoflagellates community is alternatively autotrophic and mixotrophic. The reason for the abundance of heterotrophic dinoflagellates in microzooplankton community in this area could be due to their adapting nature to different modes of feeding (mixotrophic) which compete with other predators for prey and re-package smaller prey into larger plankton cells (Jyothibabu et al. 2003). They are non-selective feeders and able to persist at low food abundance, and can survive on alternate prey, or at low

Table 4 Occurrence list of heterotrophic dinoflagellates species in the coastal waters of Port Blair, South Andaman Island during 2012–2013

Species	Bay region	Eastern region	Western region
Heterotrophic dinoflagellates	–	–	–
Dinophysis apicata	+	+	+
D. caudata	+	+	+
D. miles	+	–	–
D. rotundata	–	+	+
Dinophysis sp.	+	–	–
Gymnodinium abbreviatum	–	–	+
Gymnodinium sp.	+	+	+
Noctiluca scintillans	+	+	+
Ornithocercus magnificus	+	+	+
O. thumii	+	+	+
Podolampas bipes	+	+	+
Podolampas sp.	–	+	–
Prorocentrum micans	+	+	+
Protoperidinium breve	+	+	+
P. brevipes	–	–	+
P. conicum	+	+	+
P. crassipes	+	–	+
P. curtips	+	+	+
P. depressum	+	+	+
P. divergens	+	+	+
P. fatulipes	–	–	+
P. globules	+	+	–
P. granii	+	+	+
P. heteracanthum	+	+	–
P. latistriatum	+	+	+
P. longicollum	+	–	–
P. nipponicum	–	+	+
P. oblongum	–	–	+
P. oceanicum	+	+	+
P. ovatum	+	+	+
P. pellucidum	+	+	+
P. pentagonum	+	+	–
P. stenii	+	+	+
P. tuba	–	+	–
Pyrophacus sp.	+	+	+

prey abundance, during non-bloom conditions (Sarthou et al. 2005). They can also adapt at low prey abundance by reducing their rate of metabolism (Sherr et al. 1986).

In this study, a total of 35 heterotrophic dinoflagellates species belonging to 8 genera were recorded which is quite low compared to an earlier study from oceanic region of Bay of Bengal and the Andaman Sea (76 spp. and 14 genera; Jyothibabu et al. 2003), western Bay of Bengal (57 spp. and 12 genera; Jyothibabu et al. 2008) but higher than the study (25 spp. and 6 genera; Asha Devi et al. 2010) and (28 spp. and 7 genera; Jyothibabu et al. 2008) from the Arabian Sea. Eight species such as

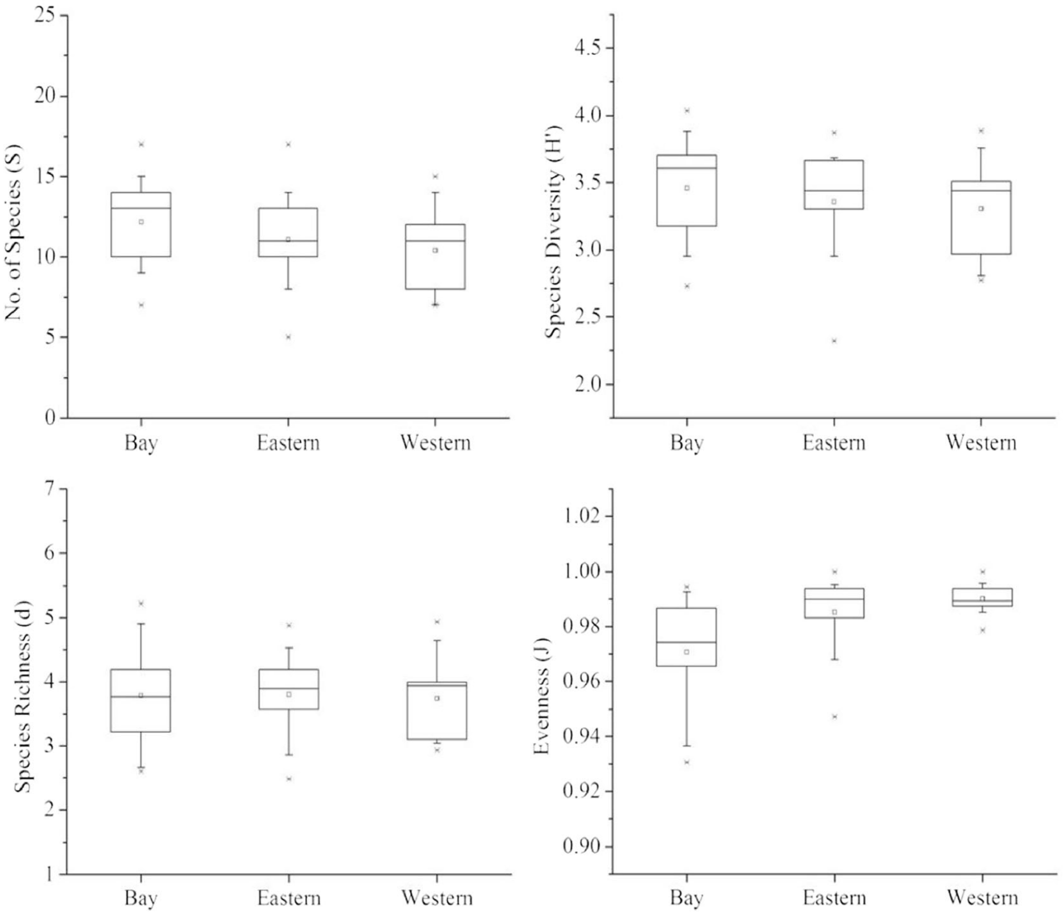


Fig. 5 Diversity indices of heterotrophic dinoflagellates in the study area

Dinophysis hastata, *Ornithocercus quadrates*, *O. steinii*, *Phalacroma rapa*, *P. apicatum*, *P. doryphorum*, *Podolampus spinifera*, and *P. palmipes* recorded from Southeastern Arabian Sea and three species such as *Dinophysis uracantha*, *Prorocentrum compressa*, and *Podolamphas elegans* recorded from the oceanic regions of the Bay of Bengal and the Andaman Sea were not recorded in this study ascertained their oceanic preference (Elangovan et al. 2012). Further absence of two species such as *Protoperidinium brevipes* and *P. fatulips* recorded earlier during 2011 from the bay and eastern stations of this area suggest that the coastal waters of this bay is fast in response to environmental perturbations and the spatio-temporal variation of heterotrophic dinoflagellates species were strongly influenced by environmental variables during the period of investigation.

The mean number of species was higher in the bay and eastern region compared to the open ocean. Relatively higher diversity and species richness in heterotrophic dinoflagellates population was found in the bay and eastern region. Considering diversity as a means of biotope utilization and niche division, the operating species in the bay have "broad" niches and utilizing their adaptability to the fluctuating environmental and extract the maximum within the available food, while the equitability in HD population was relatively high the western region (avg. J = 0.9) compared to both bay and eastern region. The pattern of association of the common dinoflagellates species of coastal waters of south Andaman showed high degree of correlation between species of eastern and western species of open ocean. Cluster analysis clearly showed that the species formed the groups depending on the type of distribution and abundance.

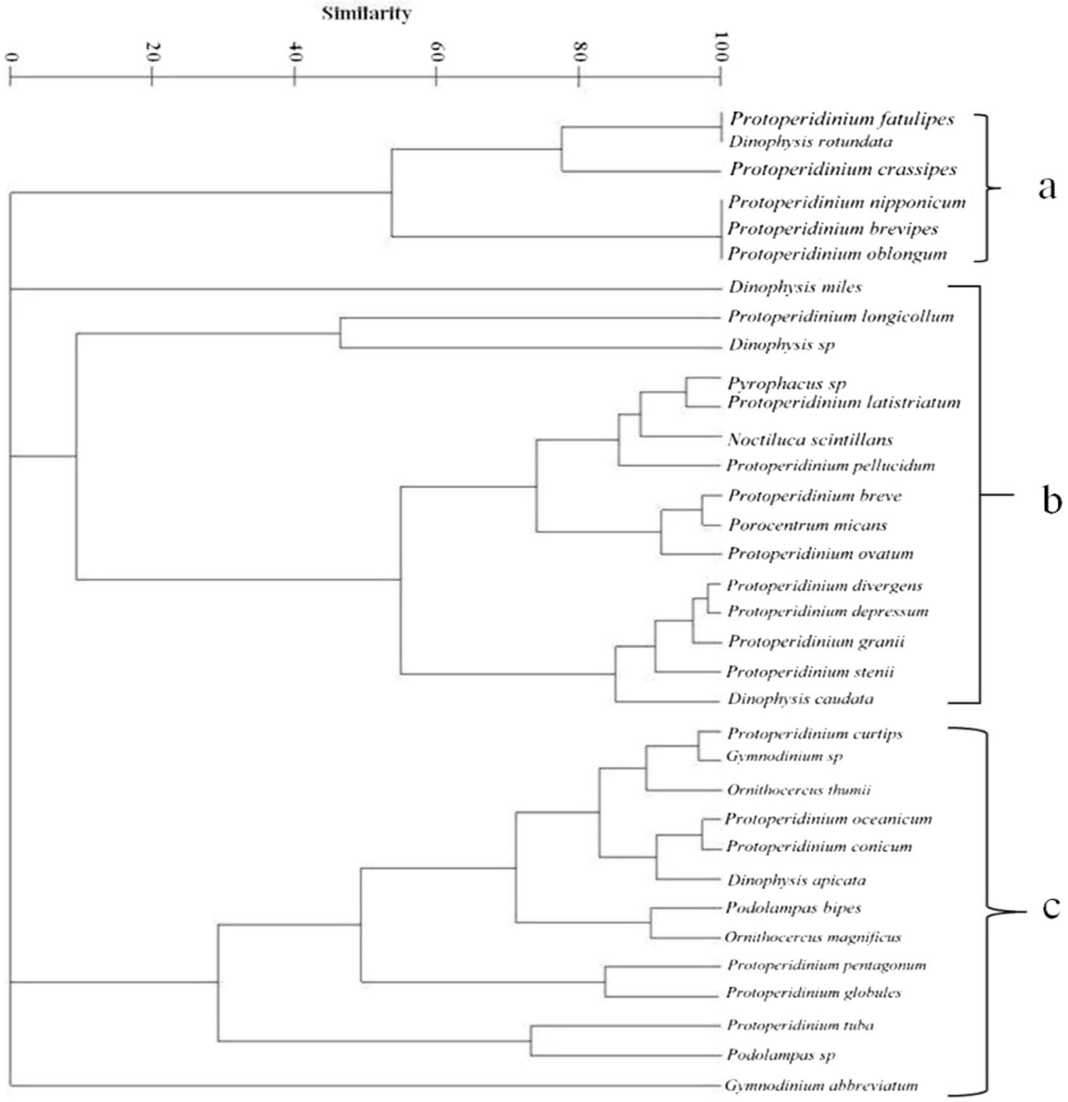


Fig. 6 Cluster analysis showing affinity of heterotrophic dinoflagellates species and formation of groups in the study area

Conclusion

For the first time, this study contributes to the knowledge on abundance, species composition, diversity, and association of heterotrophic dinoflagellates from the coastal waters of South Andaman. The distribution pattern of the heterotrophic dinoflagellates was strongly influenced by the physicochemical processes occurring in this area. Heterotrophic dinoflagellates showed great potential to thrive in low oxygenated and low productivity area ($p < 0.001$, Mann-Whitney test). Abundance of dinoflagellates in the microzooplankton community may be due to the diverse and advantageous modes of nutrition of this group. The successful species of heterotrophic dinoflagellates, viz. *Protoperidinium depressum*, *P divergens*, *P. granii*, *P. stenii*, and *Dinophysis caudata*, exhibited a wide range of tolerance towards salinity and dissolved oxygen in this area. Apart from salinity and dissolved oxygen, strong currents down-stream, turbidity, or non-availability of the "right" food may be rendering low abundance for other species.

There is a continuous need to assess the taxonomic composition, abundance, production of heterotrophic dinoflagellates from the coastal waters of South Andaman where they have been hitherto ignored.

Acknowledgements The authors are thankful to the Department of Ocean studies and Marine Biology, Pondicherry University and National Institute of Oceanography for providing facilities to carry out the research work. First author would like to thank, Dr. Mangesh Gauns, Principal Scientist, CSIR-National Institute of Oceanography, Goa, India, for training in extensive taxonomy of microzooplankton and providing facilities.

Funding Vice-chancellor, Pondicherry University provided financial support to carry out this research work.

References

Asha Devi, C.R., Jyothibabu, R., Sabu, P., Josia, Jacob, Habeeberhman, H., Prabhakaran, M.P., Jayalakshmi, K.J., Achuthankutty, C.T. (2010). Seasonal variations and trophic ecology of microzooplankton in the southeastern Arabian Sea. *Continental Shelf Research 30*, 1070–1084.

Berggreen, U., Hansen, B., & Kiorboe, T. (1988). Food size spectra, ingestion and growth of the copepod *Acartia tonsa* during development: implications for determination of copepod production. *Marine Biology, 99*, 341–352.

Ehrenberg, C. G. (1854). Die systematische Charakteristik der neun mikroskopischen Organismen des tiefen Atlantischen Ozeans. *Monatsberichte der Deutschen Akademie der Wissenschaften Zu Berlin*, 236–250.

Elangovan, S. S., kumar, M. A., Karthik, R., Sankar, R. S., Jayabarathi, R., & Padmavati, G. (2012). Abundance, species composition of microzooplankton from the coastal waters of Port Blair, South Andaman Island. *Aquatic Biosystems, 8*, 1–9.

Elangovan, S. S., & Padmavati, G. (2017). Distribution, diversity and carbon content of the tintinnids from the coastal waters of Port Blair, South Andaman. *Regional Studies in Marine Science, 14*, 132–144.

Gaines, G. F., & Taylor, J. R. (1984). Extracellular feeding in marine dinoflagellates. *Journal of Plankton Research, 6*, 1057–1061.

Gauns, M., Mohanraju, R., & Madhupratap, M. (1996). Studies on the microzooplankton from the central and eastern Arabian Sea. *Current Science, 71*, 874–877.

Hansen, P. J. (1991). Quantitative importance and trophic role of heterotrophic dinoflagellates in a coastal pelagic food web. *Marine Ecology Progress Series, 73*, 253–261.

Hansen, G., Larsen, J. (1992). Dinoglagellater i danske favande. In: Thomsen, H.A., (ed) *Plankton de indre danske favande. Havforskning fra Miljestyrelsen. nr. 11*. The Danish Environmental Protection Agency. Copenhagen. 45–155.

Ismael Amany, A. (2003). Succession of heterotrophic and mixotrophic dinoflagellates as well as autotrophic microplankton in the harbor of Alexandria. *Egyptian Journal of Plankton Research, 25*, 193–202.

Jacobson, D.M., Anderson, D.M. (1986). Thecate heterotrophic dinoflagellates: feeding behavier and mechanics. *Journal of Phycology 22*, 249–258.

Jeong, H., Yoo, Y., Kim, S., Seong, K., Karg, N., Kim, T. (2010). Growth, feeding and ecology role of the mixotrophic and heterotrophic dinoflagellates in marine planktonic foodwebs. *Ocean Science Journal. 45*, 65–91.

Jyothibabu, R., Madhu, N. V., Maheswaran, P. A., Nair, K. K. C., Venugopal, P., & Balasubramanian, T. (2003). Dominance of dinoflagellates in microzooplankton community in the oceanic regions of the Bay of Bengal and the Andaman Sea. *Current Science, 84*, 1247–1253.

Jyothibabu, R., Madhu, N. V., Maheswaran, P. A., Jayalakshmy, K. V., Nair, K. K. C., & Achuthankutty, C. T. (2008). Seasonal variation of microzooplankton (20-200μm) and its possible implication on the vertical carbon flux in the western Bay of Bengal. *Continental Shelf Research, 28*, 737–755.

Klein Bretler, W. C. M. (1980). Continuous breeding of marine pelagic copepods in the presence of heterotrophic dinoflagellates. *Marine Ecology Progress Series, 49*, 141–231.

Kofoid, C. A., & Swezy, O. (1921). The free-living unarmoured dinoflagellata. *Memphis University California, 5*, 1–538.

Lessard, E. J. (1991). The trophic role of heterotrophic dinoflagellates in diverse marine environments. *Marine Microbial Food Webs, 5*, 49–58.

Lessard, E. J., & Swift, E. (1985). Species-specific grazing rates of heterotrophic dinoflagellates in oceanic waters, measured with dual-label radioisotope technique. *Marine Biology, 87*, 289–296.

Sarthou, G.k., Timmermans, R.S., Blain, S., Treguer, P. (2005). Growth physiology and fate of diatoms in the ocean. *Journal of Sea Research 53*, 25–42.

Sekiguchi, H., & Kato, T. (1976). Influence of Noctiluca's predation on the Acartia population of Ise Bay, Central Japan. *Journal of Oceanography, 32*, 195–198.

Sherr, E. B., Sherr, B. F., & Paffenhofer, G. A. (1986). Phagotrophic protozoa as food for metazoans: a 'missing' trophic link in marine pelagic food webs? *Marine Microbial Food Webs, 1*, 61–80.

Stoecker, D. K., Verity, P. G., Michales, A. E., & Davis. (1987). Feeding by larval and post larval ctenophores on microzooplankton. *Journal of Plankton Research, 198*, 67–68.

Strom, S., & Buskey, E. J. (1991). Grazing rates and swimming behaviours of some thecate heterotrophic dinoflagellates. *In Proceedings of the Zooplankton Ecology Symposium*, Appleton, Wisconsin, 24–29.

Strickland J. D. H., & Parson, T. R. (1972). Practical handbook of seawater analysis. University of California. Fish. Res. Board Can.

Turner, J. T., & Roff, J. C. (1993). Trophic levels and trophospecies in marine plankton: lessons from the microbial food web. *Marine Microbial Food Webs., 7*, 225–248.

Verity, P. G., Stoecker, D. K., Sieracki, M. E., Burkill, P. H., Edwards, E. S., & Tronzo, C. R. (1993). Abundance, biomass and distribution of heterotrophic dinoflagellates during the North Atlantic spring bloom. *Deep-Sea Research, 40*, 227–244.

Wenlu Lana., Bangqin Huang., Minhan Dai., Xiuren Ning., Lingfeng Huang., Huasheng Hong. (2009). Dynamics of hetrotrophic dinoflagellates of the Pearl River Estuary. Northern South China Sea. *Estuarine, Coastal and Shelf Science 85*, 422–430.