

Spatial distribution of dinoflagellates from the tropical coastal waters of the South Andaman, India: implications for coastal pollution monitoring

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Abstract

Dinoflagellate community structure from two semi-enclosed areas along the South Andaman region, India, was investigated to assess the anthropogenic impact on coastal water quality. At the densely inhabited Port Blair Bay, the dominance of mixotrophs in water and Protoperidinoids in sediments was attributed to anthropogenic nutrient enrichment and prey availability. A significant decrease in dinoflagellate abundance from inner to outer bay emphasize the variation in nutrient availability. The dominance of autotrophs and Gonyaulacoid cysts at the North Bay highlight low nutrient conditions with less anthropogenic pressure. The occurrence of oceanic *Ornithocercus steinii* and *Diplopsalis* sp. could evince the oceanic water intrusion into the North Bay. Nine potentially harmful and red-tide-forming species including *Alexandrium tamarense* complex, *A. minutum* were identified in this study. Although there are no harmful algal bloom (HABs) incidences in this region so far, increasing coastal pollution could support their candidature towards the future HABs initiation and development.

Keywords: Dinoflagellates, Cyst, South Andaman region, Anthropogenic impact, Harmful algal bloom species

Coastal Embayments are strategically important for the settlement and sustainability of human civilization as it affords livelihood resources, economic transportations, and trade routes. In recent years, the industrial revolution and urbanization have exerted anthropogenic pressure on the coastal ecosystem. Human activities like domestic and industrial discharge, agricultural fertilizer usage, aquaculture farms, tourism, and marine traffic adversely affect the health of the coastal environment. Anthropogenic effluents distress the ambient coastal water quality, which eventually alters physicochemical and biological characteristics of the coastal ecosystem. Globally anthropogenic nutrient enrichment of coastal waters over time have given rise to issues like eutrophication and harmful algal blooms (HABs) (Anderson et al., 2002). Phytoplankton, as primary producer, responds spontaneously to nutrient composition changes and anthropogenic stress (Korpinen and Bonsdorff, 2015), which eventually alter species composition, biomass, succession and seasonal dynamics (Moncheva et al., 2001). Thus together with the physicochemical parameters, phytoplankton evaluation becomes an integral part of coastal monitoring studies.

Dinoflagellates, one of the major phytoplankton groups, are present in freshwater and marine systems where they often account for substantial amounts of planktonic biomass. They have a varied mode of nutrition and physiological responses to the environmental conditions. About 87 dinoflagellates species are known to be responsible for HABs, causing water discoloration and producing a variety of toxins (Moestrup et al., 2009 onwards; IOC-UNESCO Taxonomic Reference list of harmful microalgae, web: <http://www.marinespecies.org/HAB/dinoflag.php>). Cyst production efficiency of dinoflagellates enables them to withstand against unfavourable conditions for longer durations (Dale, 1983), even up to a century (Miyazono et al., 2012). In certain harmful species, cyst formation regulates bloom initiation as well as termination (Dale, 2001) and eventually the bloom dynamics in the coastal regions (Anderson et al., 2012). These dormant life stages facilitate the species dispersion and spread of HABs in previously unaffected regions (Azanza and Taylor, 2001; Anderson et al., 2012). Cysts preserved in the sediment portray dinoflagellate populations in relation to past environmental conditions (Dale, 1983). In several studies, dinoflagellates and their cysts have been used as indicator species to trace anthropogenic eutrophication processes in coastal regions (Matsuoka, 1999; Dale, 2001; Pospelova et al., 2002; Stoecker et al., 2008; Kim et al., 2009; Wang et al., 2011; Zonneveld et al., 2012; D'Silva et al., 2013; Aydin et al., 2015). Thus, mapping the dinoflagellate species in the water and sediments would improve the understanding of regional anthropogenic pollution and HABs events.

The Andaman and Nicobar Islands, India comprises pristine and diverse terrestrial as well as marine ecosystems. Diverse mangrove and coral reef ecosystem, supports unique marine flora and fauna.

However, increasing human encroachment continuously destructing the mangrove vegetation, coral reefs and seagrass beds along the South Andaman Islets. Anthropogenic pollutants of industrial, domestic and agricultural origin are deteriorating coastal water quality of this previously known pristine island region (Sahu et al., 2013; Jha et al., 2015; Renjith et al., 2015). As a resultant of elevated nutrient concentrations bloom incidences of *Noctiluca scintillans*, *Trichodesmium* spp. and *Chaetoceros curvisetus* are continuously increasing along the densely populated Bay regions (Eashwar et al., 2001; Dharani et al., 2004; Sahu et al., 2014; Begum et al., 2015). This study provides the first detailed analysis of dinoflagellate community in the water column and sediment from the two Bays, Port Blair Bay, and North Bay, which experiences a different level of anthropogenic pressure.

Port Blair Bay, located near the Port Blair town, extends as a narrow stretch in a northeast-southwest direction and opens into the Andaman Sea on the eastern side (Fig. 1). The southern and western margins of the bay comprise of shallow mud flats and are dominated by mangrove vegetation. The Port Blair harbour (Haddo Jetty) is located along the mid-eastern margin of the bay. Port Blair Bay is a hub of anthropogenic activity of the Port Blair town and harbour (Sahu et al., 2013). Sampling in this Bay was carried out at 4 stations, namely Minnie Bay (MB), Junglighat Bay (JB), Phoenix Bay (PB) and Marine Hill (MH) (Fig. 1; Table 1). These stations experience varied natural settings and usages. North Bay is a smaller semi-enclosed, less inhabited area, located on the northern side of the Port Blair Bay entrance (Fig. 1). The mouth of the bay faces to the southeast, towards the open ocean, hence receives high saline open ocean water. The North Bay is one of the reef-dominated areas of the Andaman islets, supporting diverse coral population and associated marine biota. Sampling was carried out at a single station in the North Bay (Fig. 1).

Surface and near bottom water (~1m above the seabed) samples were collected (during 1 December 2010) at each station in duplicate (~5 m apart) for phytoplankton enumerations. At the same stations, surface sediment samples were collected with modified van Veen grab, equipped with flaps on the top side enabling collection of sediment using PVC cores (25 cm long, 2.5 cm inner diameter) in duplicate. For phytoplankton analysis, a known volume of water sample was fixed with Lugol's iodine and further processed using standard methods (Hasle, 1978). For phytoplankton enumeration processed sample was examined under an inverted microscope (Olympus IX 71) equipped with a digital camera (Olympus CAMEDIA C-4040ZOOM) at 100X-1000X magnifications. Identification was carried out to the lowest possible taxonomic level using the identification keys (Taylor, 1976; Tomas, 1997; Okolodkov, 2005; Hoppenrath et al., 2009). For cyst identification, collected sediment cores were sectioned at 2 cm intervals, mixed well and stored in air tight polycarbonate bottles at

4°C in the dark. Surface sediments (0-2 cm) were processed using the sodium polytungstate (SPT) density gradation method (Bolch, 1997) with some modification. For cyst enumeration, an aliquot of the processed sample was observed under an inverted microscope. Dinoflagellate cysts were identified based on published literature (Wall and Dale, 1968; Matsuoka and Fukuyo, 2000; Wang et al., 2004; Satta et al., 2013). Final planktonic dinoflagellate and cyst concentrations are expressed as cells per litre (cells L⁻¹) and cysts g⁻¹ dry sediments (cysts g⁻¹) respectively. The light microscopic photomicrographs of planktonic dinoflagellates and cysts are provided in figure 2 and 3.

Water temperature and depth were recorded at the sampling site. Salinity was measured in the laboratory using a Guideline Autosol 8400B Salinometer. Percentage grain size composition of sediment (sand, silt, and clay) was determined by the standard wet sieving (for sand) and pipette analysis (for silt and clay) method (Buchanan, 1984). Total nitrogen (TN) and total carbon (TC) content measurements of dried, homogenised sediment samples were carried out using an NC soli element analyser (FLASH 2000, Thomas scientific). The total inorganic carbon (TIC) content was measured through CO₂ coulometer (CM-5014) following acidification of the samples. The total organic carbon (TOC) content was calculated as the difference between the total carbon and total inorganic carbon (TOC = TC-TIC). The values of TOC and TN were used to calculate the TOC: TN (C: N) atomic ratio for sediment samples (Table 1). The C: N ratio provides information about the source of organic matter deposited in sediment (Meyers, 1997). Sediment samples with C: N ratios ranging from 6~10 suggest dominant marine algae flux, whereas greater C: N ratios reflect land-plant derived organic material flux (Meyers, 1997).

Dinoflagellate and their cyst abundance were converted into a lower triangular similarity matrix using Bray-Curtis coefficient and subjected to clustering, ordination techniques using PRIMER 6 software. Univariate measures [Species count (S), Shannon-Wiener diversity index (H')] were analysed using PRIMER 6. One-way ANOVA was performed on both planktonic dinoflagellate and cyst abundance to evaluate spatial variation using Statistica 8. Spatial variation in the dinoflagellate community was depicted as SURFER (ver. 8) plots. The percentage contribution of each species for both planktonic dinoflagellates and cyst was calculated for the Port Blair Bay and North Bay (Table 2 and 3).

In this study, a total of 43 dinoflagellate taxa and 26 cyst morphotypes were recorded from the water column and surface sediments respectively. On a regional basis, planktonic and benthic dinoflagellate community was more diverse in the Port Blair Bay than the North Bay (Table 1). Remarkably, a higher abundance of planktonic dinoflagellates was recorded at the Port Blair Bay both in the surface (320-640 cells L⁻¹) and near-bottom waters (480-1880 cells L⁻¹) than at the North

Bay (120 and 160 cells L⁻¹ respectively) (Fig. 4a and c). Similarly, cyst population was abundant in the Port Blair Bay (up to 110 cysts g⁻¹) than the North Bay (8 cysts g⁻¹) (Fig. 5a). This regional heterogeneity in planktonic dinoflagellate and cyst population was highlighted in statistical analysis. Cluster analysis of the planktonic dinoflagellate and cyst community at 40% similarity level grouped sampling stations located in the Port Blair Bay together (Fig. 6a, b and c). Other two stations, MH, and the North Bay were independent. The percentage composition of the planktonic dinoflagellate assemblage revealed the dominance of mixotrophs, *Tripos furca*, *Scrippsiella trochoidea* and *Prorocentrum micans* in the Port Blair Bay (Fig. 4b, d; Table 2). Mixotrophy is an important adaptation in planktonic habitats and increases access to growth limiting nutrients, carbon and other growth factors (Bockstahler and Coats, 1993). These organisms are ‘generalists’ with less efficiency of converting food to energy compared to ‘specialists’ i.e. heterotrophs and autotrophs (Flynn and Mitra, 2009). Mixotrophs can sustain growth under light-limitation by switching to phagotrophy. The capacity of mixotrophic dinoflagellates to utilize dissolved and particulate organic substances efficiently and/or availability of prey organisms could flourish their population in the water column. *T. furca* have a competitive advantage over the other phytoplanktons due to ‘luxury consumption’ (storage of inorganic nutrients), low K_s value, the capability to survive in high N:P conditions (Baek et al., 2008) as well as phagotrophy (Smalley et al., 2003). The ability of *S. trochoidea* to adjust with diverse environmental settings could be the reason for its successes and proliferation in the Port Blair Bay region (Narale, 2016). Additionally, the increase in cyst concentration together with the dominance of *Scrippsiella* in plankton reveals the impacts of enhanced human activities on the Bay ecosystem, as observed in Daya Bay, South China Sea (Wang et al., 2011). The dominance of *P. micans* can be related to the inorganic nutrient enrichment and eutrophication in coastal waters (Sahraoui et al., 2013). In the Port Blair Bay availability of nitrate and phosphate control the abundance of *P. micans* (Narale, 2016). In the present study, we have included less abundant *P. micans*-like species in *P. micans* on the basis of classical taxonomic literature (Table 2). However based on the recent publication of Han et al. (2015) the photomicrographs were reassessed. This examination reveals the presence of *Prorocentrum koreanum* sp. nov. (Han et al., 2015) in this region (Fig. 2n). The coexistence of *P. koreanum* and influence of nutrient enrichment on its abundance needs to be studied further.

Cysts of heterotrophic *Protoperidinium* species (*Protoperidinium* sp. type 2, *P. subinermis* and *P. pentagonum*) and dinoflagellate cyst type 1 dominated cyst assemblage in the Port Blair Bay (Fig. 5b; Table 3). Heterotrophic species are well known for diversified feeding habits ranging from diatom to autotrophic dinoflagellate (Naustvoll, 2000). Their dominance in coastal cyst assemblage

indicates ample prey (mainly diatoms) availability due to nutrient enrichment (Matsuoka, 1999; Godhe and McQuoid, 2003; Kim et al., 2009). Similarly, the dominance of the round, brown coloured cyst of *Protoperidinium* species (*Brigantedinium* spp.) (Table 3) highlights the anthropogenic nutrient enrichment in the coastal region (Zonneveld et al., 2012). Round, brown and smooth walled dinoflagellate cyst type 1 observed in this study shows resemblance with cyst morphotypes reported elsewhere (Satta et al., 2013). These cyst morphotypes are referable to heterotrophic *Protoperidinium*, *Diplopsalis* and related genera (Satta et al., 2013). The dominance of Protoperidinoids in the Port Blair Bay (Fig. 5b) attributed to the anthropogenic nutrient supply and subsequently availability of diatom in abundance.

In the Port Blair Bay, the dominance of mixotrophs and heterotrophs in water and sediments respectively indicate the predatory trophic state of water column supported by nutrient availability. In general, along with the Port Blair Bay planktonic dinoflagellate and cyst abundance significantly decreased from the inner bay to the outer bay region ($p \leq 0.05$). Overall trends of univariate indices, species count and diversity index also resembled those of dinoflagellate and cyst abundance (Table 1). Spatial variation in dinoflagellate population revealed higher abundance at MB than at any other stations (Fig. 4a and c). The dominance of *S. trochoidea* and *P. micans* mainly contribute to the higher dinoflagellate abundance in the surface and near-bottom waters respectively (Table 2). High sedimentary TOC (14.39%) and C: N ratio (1.95) (Table 1) reveals nutrient concentration in the water column and sediment is of terrestrial origin. Ample input of particulate and dissolved, organic and inorganic nutrients through tidal flow and runoff from the mangrove watershed areas (Sahu et al., 2013; Renjith et al., 2015) could support the diversity and abundance (Table 1) of dinoflagellate population. JB receives anthropogenic inputs through untreated municipal discharge and fisheries jetty waste, which alters the natural nutrient concentration (Sahu et al., 2013). Availability of these nutrients supports the growth of mixotrophic and autotrophic (especially *Pyrophacus steinii*) dinoflagellates and in turn high species count, diversity (Table 1) in the water column. PB also receives organic inflow from the boat, ferry discharge, and sewage channel (Sahu et al., 2013). Availability of nutrients (mainly silicate) supports the growth of diatoms (data not presented). The dominance of mixotrophs and *Protoperidinium* species in the water column and sediments respectively (Fig. 4b,d, and 5b), is fuelled by nutrient enrichment and prey availability. Together with natural and anthropogenic influx, increased nutrient residential time due to comparatively less tidal flushing in the inner bay could support the dinoflagellate abundance and diversity. The station MH is located at the outer side of the Port Blair Bay, thus along with the tidal flushing; water movement could also play a significant role in nutrient availability (Sahu et al., 2013). Relatively less

sedimentary TOC (0.98%) observed at MH during this study (Table 1) also suggests low nutrient concentrations. The dominance of autotrophic *Gonyaulax* species in sediments indicate less nutrient availability (Godhe and McQuoid, 2003; Kawamura, 2004) at this station.

The dominance of coral reefs emphasizes the warm, clear, saline and low nutrient water conditions in the North Bay. Restricted human interference could preserve the ambient coastal water quality index in this region (Jha et al., 2015). Comparatively low sedimentary C: N ratio and TOC (Table 1) indicates that sediment is of marine origin and the overlying water with low nutrients. The dominance of *Gonyaulax* species in the planktonic and benthic domain (Table 2; Fig. 5b), signifies the less nutrient availability and high salinity. Furthermore, the occurrence of oceanic heterotrophic dinoflagellates *Ornithocercus steinii* and *Diplopsalis* sp. at this station could evince the intrusion of oceanic water into the North Bay.

Cyst concentration in surface sediments is controlled by cyst formation potential of planktonic dinoflagellate in the water column and cyst deposition in sediments (Dale, 1983; Dale, 2001). Dinoflagellate cyst has a specific gravity similar to silt particle (Dale, 1983), and can be transported by the winnowing action of water currents (Kawamura, 2004). Semi-enclosed areas, where sedimentation prevails over particle transport, can act as “sediment traps” and potential reservoirs of benthic stages (Joyce et al., 2005). The fine sediment also indirectly indicates a stable and favourable sedimentation process. In the study region, highest cyst abundance at the shallow inner Port Blair Bay stations (MB and JB) corresponds to the silty clay sediments (Fig. 5a; Table 1). The low cyst abundance at the North Bay could be a result of coarser-grained sand particles. Also, to cyst deposition, a comparatively higher abundance of cyst-forming dinoflagellates in the water column (Table 2) influence higher cyst abundance in the Port Blair Bay.

Evaluation of dinoflagellates from benthic and pelagic domain provide better information on dinoflagellate species population in a given area (Dale, 1983; Narale et al., 2013; Satta et al., 2013). Nine potentially harmful and red-tide-forming species were encountered in water and sediment samples analysed from the South Andaman coast (Table 2 and 3). We have reported *A. tamarense* complex and *A. minutum* in planktonic forms, whereas cyst of *Alexandrium* spp. also been observed in sediment (Table 2 and 3). Genus *Alexandrium* consists of about 30 species out of which ~16 are considered to be harmful, responsible for paralytic shellfish poisoning (PSP) and other toxic events worldwide (Hoppenrath et al., 2009). Since from this region PSP incidences have not been reported, the potential of *Alexandrium* species to produce toxicity event is unknown and need further study. Potential yessotoxin (YTX) producing *Lingulodinium polyedrum* and *Protoceratium reticulatum* were recorded in sediments, whereas *Gonyaulax spinifera* complex was reported in both cyst and

planktonic forms. Although not all *G. spinifera* complex members produce YTXs, their population was diverse in the region (Table 2 and 3). The increasing dominance of red-tide-forming *S. trochoidea* in planktonic and cyst forms indicates the favourability of environmental conditions for its prevalence. Anoxic red-tide incidences of other bloom-forming species, *T. furca*, *T. fusus*, *P. micans* and *Peridinium quadridentatum* (= *P. quinquecorne*) increased worldwide due to eutrophication (Yu et al., 2007; Garate-Lizarraga et al., 2008; Morton et al., 2011; Sahraoui et al., 2013; Okolodkov et al., 2016). Contemporary, phytoplankton monitoring study in the Port Blair Bay has identified the mixed-dinoflagellate bloom of these species during the March and October 2009 (Narale, 2016). The increasing anthropogenic nutrient loading triggers the growth of the existing resilient dinoflagellate population (Narale, 2016). Considering the increasing incidences of PSP outbreak, red-tides, and HABs spread along the adjacent Southeast Asian regions (Azanza and Taylor, 2001; Fukuyo et al., 2011; Furio et al., 2012; Su-Myat et al., 2013), the Andaman region is potentially at risk. The increasing coastal anthropogenic activities make this ‘pristine region’ susceptible towards the HABs initiation and development.

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Figure legends

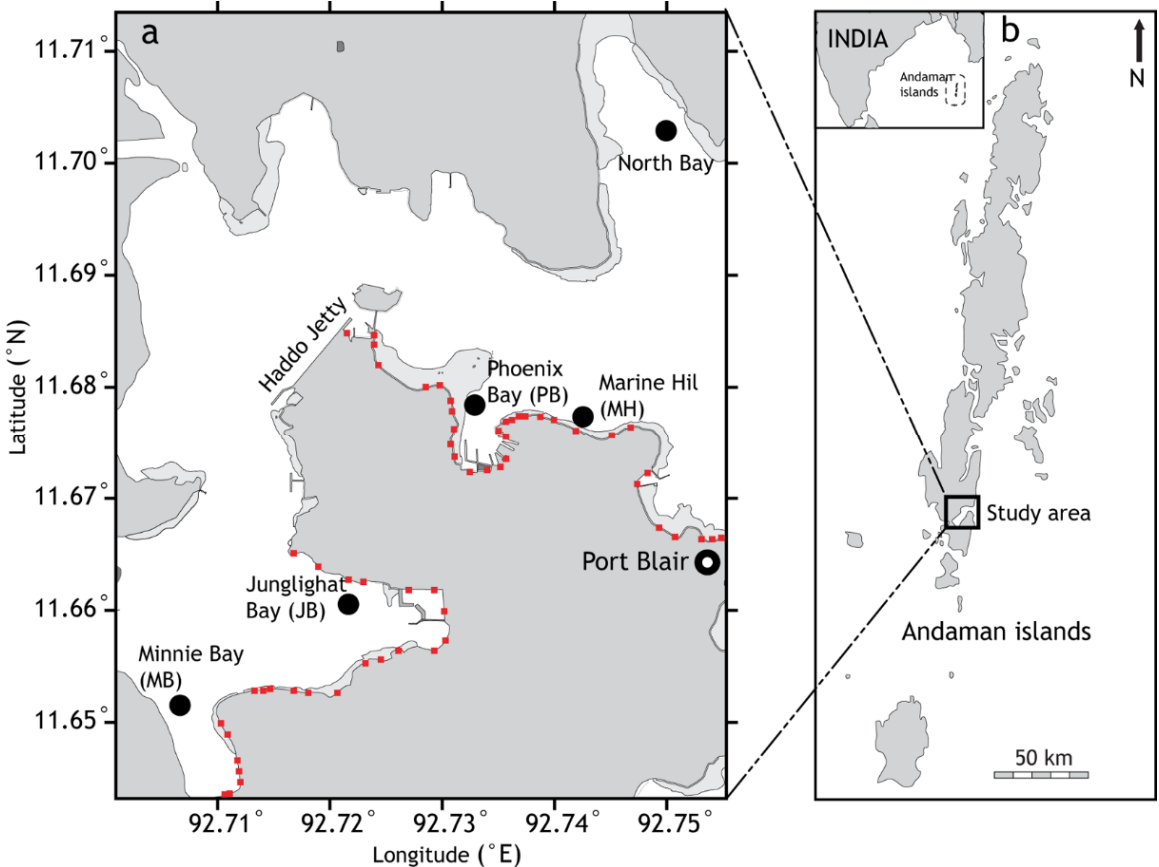


Figure 1. Location of sampling stations along (a and b) the Port Blair, South Andaman, India. Note: red square indicates discharge point locations (inferred from Jha et al., 2015)

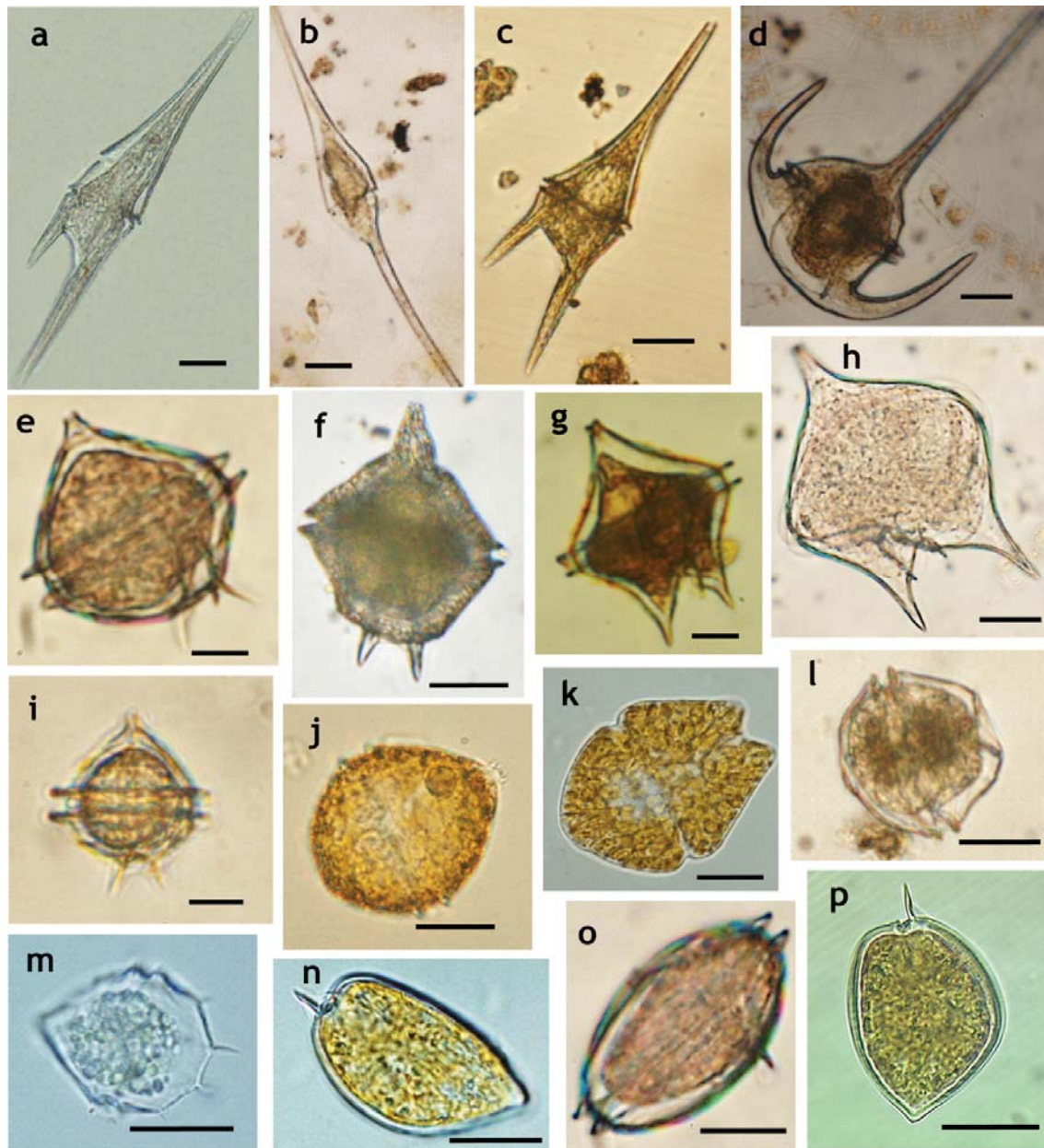


Figure 2. Photomicrographs of planktonic dinoflagellates: (a) *Tripos furca*; (b) *Tripos fusus*; (c) *Tripos hircus*; (d) *Tripos muelleri*; (e) *Protooperidinium pallidum*; (f) *Gonyaulax digitalis*; (g) *Protooperidinium crassipes*; (h) *Protooperidinium oblongum*; (i) *Protooperidinium pellucidum*; (j) *Scrippsiella trochoidea*; (k) *Akashiwo sanguinea*; (l) *Alexandrium tamarense* complex; (m) *Peridinium quadridentatum*; (n) *Prorocentrum koreanum*; (o) *Diplopsalis* sp.; (p) *Prorocentrum micans*. All scale bars 20 μ m

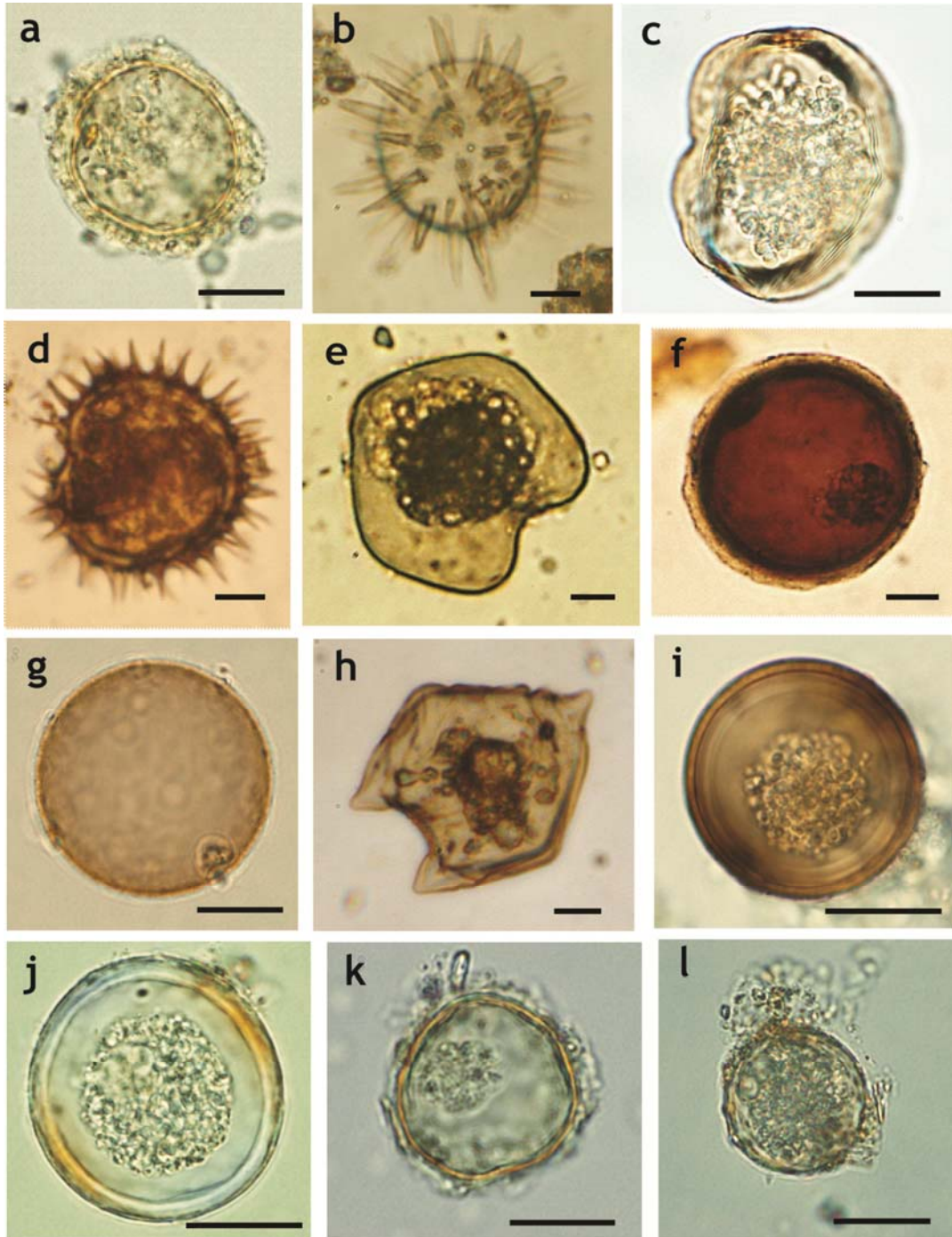


Figure 3. Photomicrographs of some dominant and unidentified dinoflagellates cysts of: (a) *Alexandrium* sp.; (b) *Lingulodinium polyedrum*; (c) *Protoperidinium subinerme*; (d) *Protoperidinium conicum*; (e) *Protoperidinium oblongum*; (f) *Protoperidinium* sp. type 1; (g) *Protoperidinium* sp. type 2; (h) *Protoperidinium* sp. type 3; (i) Dinoflagellate cyst type 1; (j) Dinoflagellate cyst type 2; (k) Dinoflagellate cyst type 3; (l) Dinoflagellate cyst type 4. All scale bars 20 μ m.

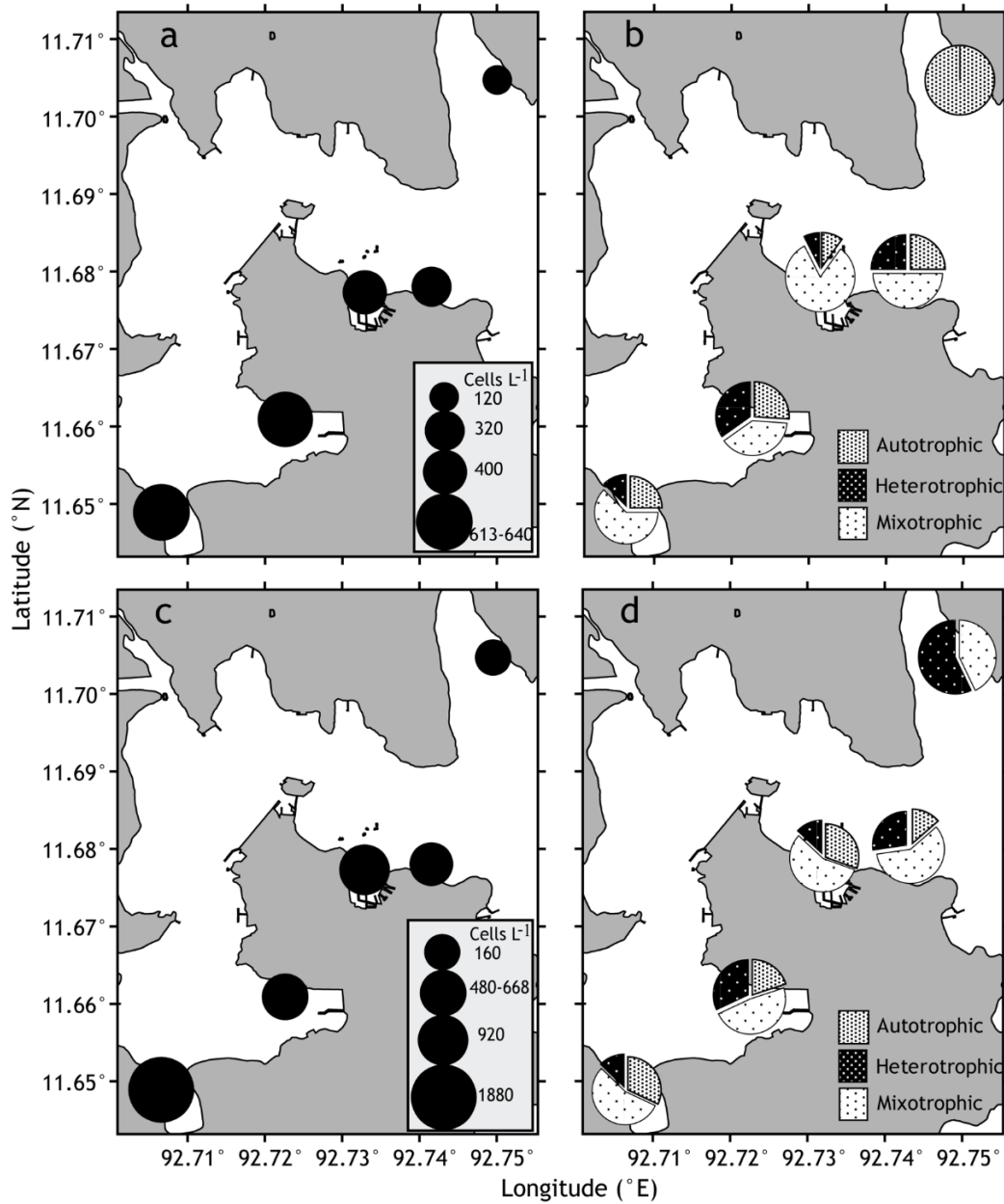


Figure 4. Spatial variation in planktonic dinoflagellate abundance [cells L⁻¹] and percentage contribution of autotrophic, heterotrophic and mixotrophic dinoflagellates in (a and b) surface and (c and d) near bottom waters along the Port Blair Bay and North Bay.

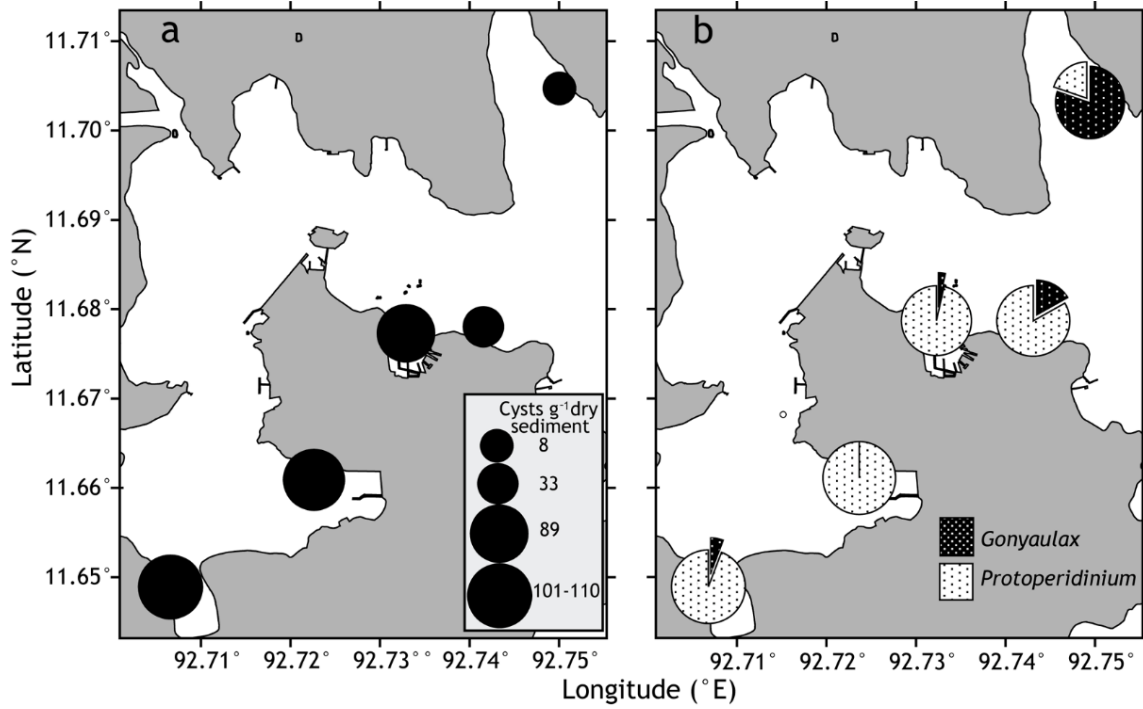


Figure 5. Spatial variation in (a) dinoflagellate cyst abundance [cysts g^{-1}] and (b) percentage composition of cysts of *Gonyaulax* and *Protoperidinium* species along the Port Blair Bay and the North Bay.

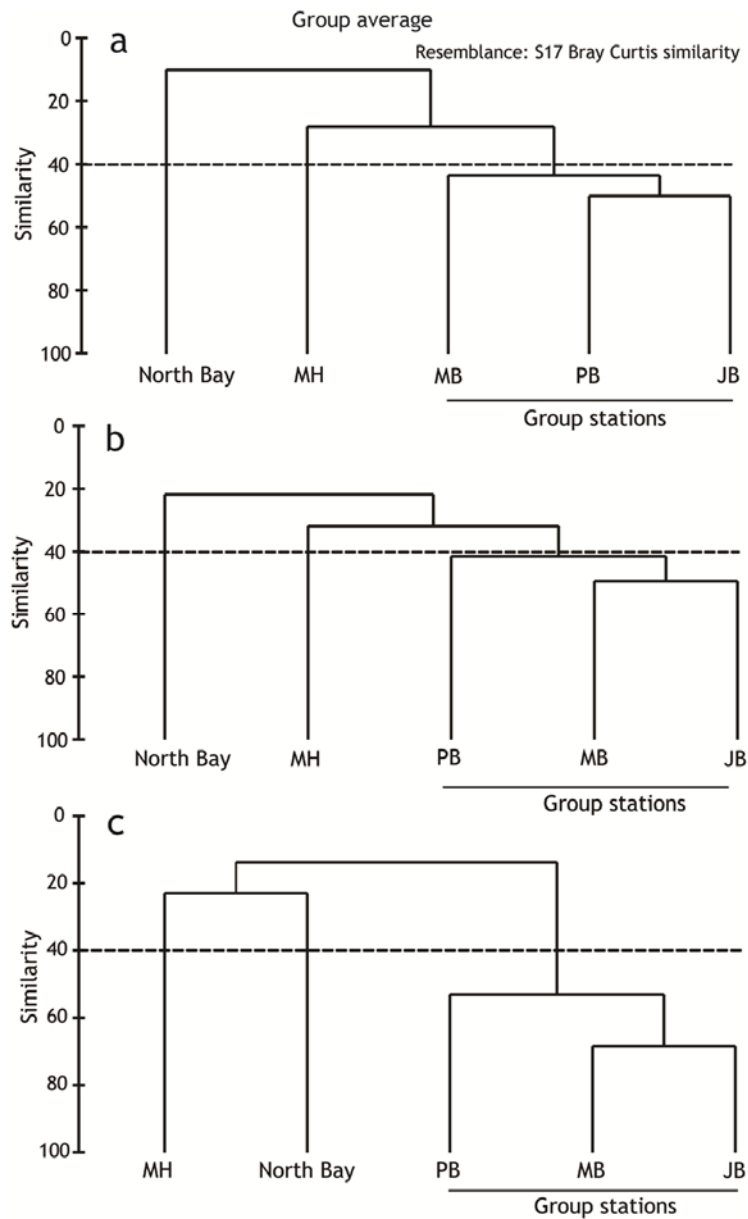


Figure 6. Cluster dendrogram of sampling stations based on similarities in planktonic dinoflagellate assemblage in (a) surface, (b) near bottom waters and (c) cyst assemblage in surface sediments.

Table 1. Location of sampling stations along with water and sedimentary parameters and univariate measures of dinoflagellates.

Sampling stations	Station code	Latitude [°N]	Longitude [°E]	Sediment samples analyzed	Water parameters			Sedimentary parameters				Univariate measures					
					Depth [m]	Temperature [°C] (±SD)	Salinity [‰] (±SD)	TOC [%]	TN [%]	C:N ratio	Sediment type	Planktonic dinoflagellates				Dinoflagellate cysts	
											Ssur	H'sur	Snb	H'nb	S	H'	
Minnie Bay	MB	11.649	92.708	6	6	27.5 (±0.7)	27.2 (±0.4)	1.95	0.16	14.39	silty clay	11	2.19	14	2.32	15	2.46
Junglighat Bay	JB	11.661	92.721	6	8	27.2 (±0.4)	27.4 (±0.3)	1.91	0.19	11.52	silty clay	17	2.77	17	2.72	16	2.61
Phoenix Bay	PB	11.677	92.733	6	7	27.5 (±0.7)	29.5 (±0.7)	1.30	0.13	11.87	sandy silt	11	1.75	11	2.25	14	2.33
Marine Hill	MH	11.679	92.740	4	9	27.5 (±1.3)	30.5 (±0.7)	0.98	0.12	9.32	sandy silt	6	1.73	12	2.15	8	2.03
North Bay	-	11.706	92.749	6	5	26.7 (±0.4)	32.2 (±0.4)	0.63	0.09	8.40	sandy	3	1.10	10	2.25	4	1.28

S, species count; H', Shannon-Wiener diversity index; sur, surface water; nb, near bottom water

Note: In case of salinity and temperature, values outside and inside parenthesis indicate average and standard deviation (SD) between surface and bottom water respectively.

Inner Port Blair Stations highlighted in grey colour.

Table 2. Planktonic dinoflagellates assemblage and their percentage composition recorded in surface and near bottom water at the Port Blair Bay and the North Bay, South Andaman, India. (*, potentially harmful species; †, red-tide-forming; ^, cyst forming species)

Planktonic dinoflagellate	Surface water					Near bottom water								
	Port Blair Bay				Composition [%]	North Bay	Composition [%]	Port Blair Bay				Composition [%]	North Bay	Composition [%]
	MB	JB	PB	MH				MB	JB	PB	MH			
Autotrophic														
<i>Alexandrium tamarense</i> complex*^ (Whedon & Kofoid) Balech									◐			1.0		
<i>Alexandrium minutum</i> †^ Halim	◐	○			5.4			◐	◐	◐	○	2.9		
<i>Alexandrium</i> sp.			○	◐	2.5									
<i>Amphidinium flexum</i> Herdman		○			1.4									
<i>Amphidinium</i> sp.	◐	○			4.1			●	○			8.8		
<i>Blepharocysta</i> sp.		○	○	◐	3.9	◐	33	◐	○		○	5.2		
<i>Gonyaulax digitalis</i> ^ (Pouchet) Kofoid	○				1.4	◐	33				◐	1.0		
<i>Gonyaulax spinifera</i> *^ (Claparède & Lachmann) Diesing			○		0.5	◐	33			◐		1.0		
<i>Gonyaulax</i> sp.											○	0.5		
<i>Akashiwo sanguinea</i> (Hirasaka) G.Hansen & Moestrup			○		0.5									
<i>Goniodoma polyedricum</i> (Pouchet) Jørgensen											○	0.5		
<i>Pyrophacus steinii</i> ^ (Schiller) Wall & Dale		◐			2.7			◐	○			1.7		
Mixotrophic														
<i>Tripos extensus</i> (Gourret) F.Gomez								◐				1.0		
<i>Tripos furca</i> † (Ehrenberg) F.Gomez		◐			2.7			●	○	◐	○	12.3		
<i>Tripos fusus</i> † (Ehrenberg) F.Gomez									○	◐		1.7		
<i>Tripos horridus</i> (Cleve) F.Gomez		◐			2.7			◐	○			4.7		
<i>Tripos hircus</i> (Ehrenberg) F.Gomez										◐		1.0		
<i>Tripos longirostris</i> (Gourret) F.Gomez	○				1.4									
<i>Tripos teres</i> (Kofoid) F.Gomez			○		0.5									
<i>Tripos muelleri</i> † Bory											○	0.5		
<i>Tripos vultur</i> (Cleve) F.Gomez	○				1.4									
<i>Dinophysis parva</i> Schiller													○	6.25

<i>Prorocentrum compressum</i> (Bailey) Abe ex Dodge									○	6.25				
<i>Prorocentrum gracile</i> Schutt		○	◐		4.4			○	◐	2.2		○		
<i>Prorocentrum micans</i> [†] Ehrenberg	◐	◐	◐	◐	17.7		●	◐	◐	○	14.0			
<i>Prorocentrum koreanum</i> Han, Cho & Wang														
<i>Scrippsiella trochoidea</i> ^{†^} (Stein) Balech ex Loeblich III	●	◐	●	◐	21.1		◐	◐	◐	◐	15.9		○	12.5
<i>Scrippsiella</i> sp.	◐				5.4			◐			1.3		○	12.5
Heterotrophic														
<i>Amphidinium sphenoides</i> Wulff		◐			2.7		◐	○	◐		4.7		○	12.5
<i>Ornithocercus steinii</i> Schutt													○	6.25
<i>Protoperdinium brochii</i> [^] (Kofoid & Swezy) Balech		○			1.4			○			0.7			
<i>Protoperdinium crassipes</i> (Kofoid) Balech		○			1.4									
<i>Protoperdinium depressum</i> (Bailey) Balech	○				1.4									
<i>Protoperdinium elegans</i> (Cleve) Balech			○		0.5					◐	1.5			
<i>Protoperdinium leonis</i> [^] (Pavillard) Balech	○			◐	3.4		◐	○		○	3.2		○	12.5
<i>Protoperdinium mediterraneum</i> (Kofoid) Balech		○	○		1.9		◐	◐			2.4			
<i>Protoperdinium oblongum</i> [^] (Aurivillius) Parke & Dodge									◐		1.0			
<i>Protoperdinium pallidum</i> (Ostenfeld) Balech		○			1.4		◐				2.0			
<i>Protoperdinium pellucidum</i> Bergh ex Loeblich Jr. & Loeblich III								○	◐		2.7			
<i>Protoperdinium pentagonum</i> [^] (Gran) Balech				◐	2.0						2.0			
<i>Peridinium quadridentatum</i> ^{†^} (Stein) Hansen									◐		2.0			
<i>Zygabikodinium lenticulatum</i> [^] Loeblich Jr. & Loeblich III		○			1.4		◐	◐			2.4			
Minute thecate dinoflagellate (MTD)													○	12.5

Planktonic dinoflagellate abundance [cells⁻¹ L]: ○, 10-30; ◐, 40-60; ◑, 80-120; ◒, 130-200; ●, 320

Table 3. Cyst assemblage of dinoflagellates and their percentage contribution recorded in surface sediments at the Port Blair Bay and the North Bay, South Andaman, India. (*, potentially harmful species; †, red-tide-forming)

Cyst of dinoflagellate (planktonic name)	Paleontological name	Port Blair Bay				Composition [%]	North Bay	Composition [%]
		MB	JB	PB	MH			
Autotrophic								
<i>Alexandrium</i> sp.	-	○				0.5		
<i>Gonyaulax digitalis</i> (Pouchet) Kofoid	<i>Spiniferites bentorii</i>				○	1.0	○	14.3
<i>Gonyaulax spinifera</i> * (Claparede et Lachmann) Diesing	<i>Spiniferites membranaceus</i>	○		○		1.9	○	42.9
Complex	<i>Spiniferites miribilis</i>							
<i>Gymnodinium impudicum</i> (Fraga & Bravo)	-	○	○		○	2.3		
G. Hansen & Moestrup								
<i>Lingulodinium polyedrum</i> * (Stein) Dodge	<i>Lingulodinium machaerophorum</i>		◐	◐		2.9		
<i>Protoceratium reticulatum</i> * (Claparede & Lachmann) Bütschli	<i>Operculodinium centrocarpum</i>		○			0.7		
Mixotrophic								
<i>Scrippsiella lachrymosa</i> J. Lewis	-			○		0.4		
<i>Scrippsiella trochoidea</i> † (Stein) Balech ex Loeblich III	-	○	○	◐	○	4.3	○	28.6
Heterotrophic								
<i>Protoperidinium avellana</i> (Meunier) Balech	<i>Brigantedinium cariacense</i>	◐				3.2		
<i>Protoperidinium compressum</i> (Abe) Balech	<i>Stelladinium stellatum</i>	○	○	○		2.5		
<i>Protoperidinium conicum</i> (Gran) Balech	<i>Selenopemphix quanta</i>				◐	2.0		
<i>Protoperidinium latissimum</i> (Kofoid) Balech	-	◐	○			2.6		
<i>Protoperidinium leonis</i> (Pavillard) Balech	<i>Quinquecuspis concreta</i>	◐	◐		○	4.6	○	14.3
<i>Protoperidinium oblongum</i> (Aurivillius) Parke &	<i>Votadinium calvum</i>	◐	◐			4.9		
<i>Protoperidinium pentagonum</i> (Gran) Balech	<i>Trinovantedinium applanatum</i>	◐	◐	◐		10.8		
<i>Protoperidinium subinermis</i> (Paulsen) Loeblich III	<i>Selenopemphix nephroides</i>	◐	◐	◐	○	11.5		
<i>Protoperidinium</i> sp.	<i>Stelladinium robustum</i>	◐	○			1.8		
<i>Protoperidinium</i> sp.	<i>Stelladinium reidii</i>	○				0.8		
<i>Protoperidinium</i> sp. type 1	<i>Brigantedinium</i> sp. 1	○	◐	◐		4.1		
<i>Protoperidinium</i> sp. type 2	<i>Brigantedinium</i> sp. 2	◐	●	○		12.2		
<i>Protoperidinium</i> sp. type 3	<i>Quinquecuspis</i> sp.				○	1.0		
Dinoflagellate cyst type 1	-	●	●	●	◐	21.6		
Dinoflagellate cyst type 2	-		○			0.5		
Dinoflagellate cyst type 3	-			○		0.4		
Dinoflagellate cyst type 4	-			◐		1.6		

Dinoflagellate cysts abundance [cysts g⁻¹]: ○, 1-5; ◐, 5-7; ◑, 8-11; ◒, 13-17; ●, 20-22.