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DIVERSITY OF MARINE PHYTOPLANKTON COMMUNITIES ON THE ANDAMAN SEA CONTINENTAL SHELF, THAILAND

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ABSTRACT: In November 2012, we conducted an investigation into the taxonomy and vertical distribution of phytoplankton on the Andaman Sea continental shelf. The research yielded the identification of 107 distinct phytoplankton species, encompassing dinoflagellates, diatoms, and cyanobacteria. Diatoms demonstrated a notable degree of diversity, with *Thalassiosira* spp. and *Chaetoceros* spp, representing the most prevalent taxa. Dinoflagellates were dominated by *Tripos* spp. while *Trichodesmium* spp. of cyanobacteria exhibited high abundance in surface waters.

Key words: marine phytoplankton, Andaman Sea, continental shelf

INTRODUCTION

The Andaman Sea, situated on the eastern coast of the Indian Ocean between the Thai-Malay Peninsula and the Andaman-Nicobar Islands, encompasses an area of approximately 6×10^5 km^2 with an average depth of 1100 meters and a maximum depth of 4419 meters (Dutta *et al.* 2007). The region is subject to significant vertical mixing as a consequence of intermittent waves generated by tidal currents as they traverse the rugged topography (Dutta *et al.* 2007). The region is distinguished by a seasonal reversal in the tropical monsoon, with the northeast monsoon prevailing from December to March and the southwest monsoon between June and September (Tomczak and Godfrey 2013). In response to these monsoons, the oceanic flow undergoes a semi-annual change in direction, with a cyclonic flow occurring in spring and early summer and an anticyclonic flow for the remainder of the year (Potemra *et al.* 1991).

Marine phytoplankton, representing approximately one-quarter of all plants globally, play a pivotal role in global carbon fluxes (Berges and Falkowski 1998). The diverse array of taxonomic organisms that comprise oceanic phytoplankton collectively govern total production and interactions across various trophic levels (Buesseler 1998; Hoppenrath *et al.* 2009), as well as the flux of particulate carbon from the euphotic zone (Michaels and Silver 1988).

The phytoplankton communities of the Andaman Sea exhibit considerable variability, exhibiting a strong correlation with seasonal fluctuations in climatic conditions. There is a clear and robust connection between the prevailing physical factors and the biological processes that occur within this ecosystem. Cyanophyta such as *Trichodesmium erythreae*, typically constitute a significant component of the biomass, while diatoms and dinoflagellates exhibit the highest species diversity (Sarojini and Sarma 2001; Nielsen *et al.* 2004; Buranapratheprat *et al.* 2010; Suwannathatsa *et al.* 2012). The diverse physical conditions and elevated temperatures during the southwest monsoon period promote the development of highly diverse phytoplankton communities in the Andaman Sea (Sarojini and Sarma 2001). However, Nielsen *et al.* (2004) found no difference in primary production between the two monsoons, with pico- and nano-phytoplankton sizes dominating the biomass in the Andaman Sea off Phuket.

The present study seeks to elucidate the taxonomy and vertical distribution of the phytoplankton community on the Andaman Sea continental shelf. The study, conducted in November 2012, primarily aimed to characterize the phytoplankton communities in the area.

MATERIALS AND METHODS

Study site

This study was conducted as part of the Thailand-China joint cruises, which were aboard the vessel "Mv. SEAFDEC" in November 2012. The study was conducted as part of the pilot project designated "Monsoon Onset Monitoring and its Social and Ecosystem Impact (MOMSEI)." The MOMSEI project successfully deployed the Bailong buoy system in the Andaman Sea through collaborative efforts between the Phuket Marine Biological Center (PMBC) in Thailand and the First Institute of Oceanography (FIO), the People's Republic of China.

The research was conducted along the Andaman Sea continental shelf, situated along the southwestern coast of Thailand, between latitudes 9°25'90N to 9°25'96N and longitudes 95°43'81E to 97°28'99E (Fig.1). Station 1, situated at the northernmost point, served as the initial reference point, followed by Station 2, which demarcates the transition zone. As the transect proceeded in a southerly direction, Stations 3 to 6 yielded insights into phytoplankton dynamics across a range of coastal regions. Station 7, situated at the southernmost point, marked the conclusion of the transect line. Each station represented a distinct geographic position along the shelf, thereby contributing to a comprehensive understanding of phytoplankton distribution and diversity in the study area. The sampling stations spanned a depth range of 30 to 75 meters across eleven locations along the Andaman Sea continental shelf transect.

Methods

In November 2012, water sampling expeditions were conducted at each of the eleven designated sites labeled A1 to A11. Vertical profiling of various water column properties was accomplished through the use of a rosette of Niskin bottles equipped with a CTD instrument.

In this study, our focus on the phytoplankton community led us to collect samples exclusively from two specific depths at each station: the surface (approximately 4 meters) and the depth corresponding to the Fluorescence Maximum (FM). This approach allowed us to concentrate our investigation on the phytoplankton populations present at these critical levels within the water column.

In order to identify and enumerate phytoplankton, a duplicate of 150 mL of seawater samples was collected and transferred into brown glass bottles with great care. In order to preserve these samples, a 3% formaldehyde solution in seawater was added, resulting in a final concentration suitable for microscopy. Each preserved sample was gently mixed in order to ensure uniform distribution of the formaldehyde solution.

The phytoplankton samples were identified by Taylor (1976), Tomas (1997) and Round *et al.* (2007).

Statistical analysis

The statistical analysis of the data was conducted using a variety of software programs. Microsoft Excel 2013 was employed for the organization and preliminary processing of the data. Data visualization and graphing were conducted using Sigma Plot 13. The PRIMER-E 7 software, a widely utilized tool in multivariate ecological research (Clarke and Warwick 1994; Clarke *et al*. 2014), was employed for cluster analysis on the square root transformation data. The euclidean distance matrix was employed to calculate the dissimilarity between each pair of samples, and the Bray-Curtis similarity index was utilized to transform the clustering. This approach permitted the exploration and visualization of the intricate patterns in phytoplankton abundance.

RESULTS AND DISCUSSION

Phytoplankton community structure and composition

A comprehensive analysis of the phytoplankton community structure and composition on the Andaman Sea continental shelf in November 2012 revealed a total of 107 species, identified through the use of a light microscope. The most abundant group was dinoflagellate species, which constituted over 61

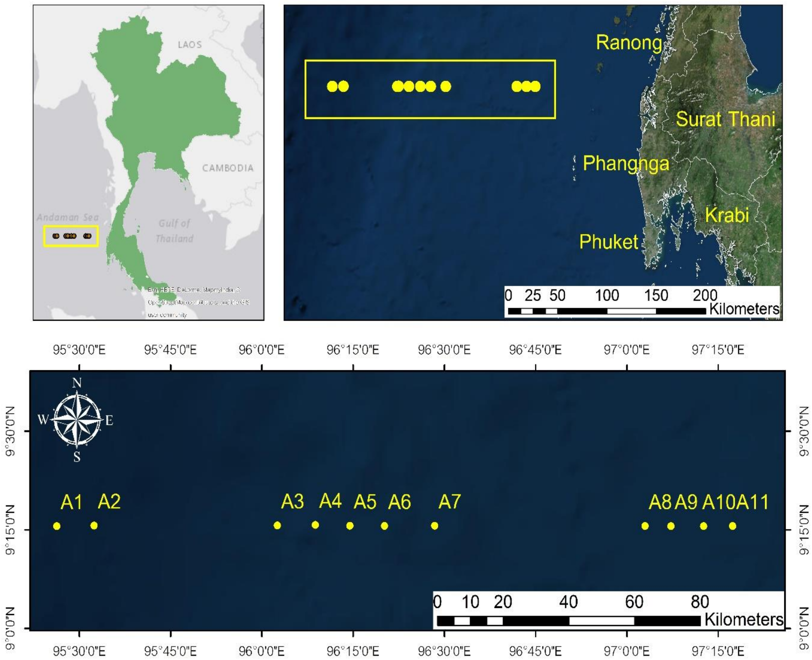

Figure 1. Sampling locations on the Andaman Sea continental shelf transect, Thailand in November 2012.

species, followed by the diatoms (43 species) cyanophyte (1 species), and silicoflagellates (2 species). The dinoflagellate genus *Tripos* exhibited the highest diversity, while the diatom genera *Thalassiosira* and *Chaetoceros* also displayed notable diversity (Table 1).

The density of phytoplankton ranged from 1,270 to 9,940 cells·10 L^{-1}. Among the identified species *Thalassiosira* spp., *Chaetoceros* spp., *Fragilariopsis* doliolus, *Pseudo-nitzschia* spp., and *Bacteriastrum* spp. were the most abundant. These species contributed significantly to the overall phytoplankton biomass during the study period.

Diatoms

Microscopic observation revealed the presence of marine diatoms, with a total of 43 species identified. This study identified the species belonging to 35 genera in 20 families and two orders. Among the diatoms, the Centrales were more prevalent than the Pennales. The most diverse genera were *Thalassiosira*, followed by *Chaetoceros* and *Asteromphalus*. The most frequently occurring marine diatoms included *Thalassionema* spp., *Chaetoceros* spp., and *Rhizosolenia* spp. These dominant diatoms have also been previously reported by Sarojini and Sarma (2001), Paul *et al.* (2008) and Charoenvattanaporn *et al.* (2018). The abundance of diatoms at the surface and the FM depth ranged from 80 to 690 cells 10 L^{-1} and 250–9,500 cells 10 L^{-1}, respectively (Figure 2). The highest mean abundance of diatom species was observed at station A1 at the surface depth. The proportion of diatom abundance at the surface was 2–26% of total phytoplankton density, while the percentage range at the FM depth was 10–96%. The highest proportion of diatoms was observed at the FM depth at station A4, representing 96% of the total phytoplankton density).

Dinoflagellates

A total of at least 61 species belonging to 21 genera in 15 families and six orders of marine dinoflagellates were identified. The most diverse genera were Tripos, followed by Dinophysis and Protoperidinium. The most frequently occurring marine dinoflagellate species were Scrippsiella and Peridinium. The density ranges of dinoflagellates at the surface and the FM depth were found to be 195–500 cells·10 L^{-1} and 150–540 cells·10 L^{-1}, respectively (Fig. 2). The highest mean abundance of dinoflagellate species was observed at 50 m in the FM depth of station A9, where high abundances of *Peridinium* spp. (80 cells·10 L^{-1}) and Gonyaulax spinifera (60 cells·10 L^{-1}) were recorded. The percentage of dinoflagellate abundance at the surface ranged from 4 % to 30%, whereas at the FM depth, it ranged from 3 % to 23%. The highest percentage distribution of dinoflagellates was observed at station A9, at a depth of 50 meters, with a percentage of 30%). The dominant dinoflagellate species identified in the present study were *Peridinium* spp., *Scrippsiella trochoidea*, *Blepharocysta splendor-maris*, *Oxytoxum scolopax*, *Tripos kofoidii*, *Tripos fusus*, *Podolampus palmipes*, *Tripos teres* and *Gonyaulax spinifera*. Furthermore, Charoenvattanaporn *et al.* (2018) and Satapoomin *et al.* (2004) have also observed that this group is present in high density and biomass at the FM depth.

Cyanophytes

The cyanobacterial species *Trichodesmium* spp. was observed at all sampling stations and depths. The abundance of *Trichodesmium* spp. at the surface and the FM depth ranged from 850 to 8,095 filaments·10 L^{-1} and 60–2,000 filaments·10 L^{-1}, respectively. The percentage of *Trichodesmium* spp. abundance at the surface ranged from 65 to 94%, while at the FM depth it ranged from 1 to 76%. The highest percentage distribution of *Trichodesmium* spp. was The cyanobacterial species *Trichodesmium* spp. was observed at all sampling stations and depths. The abundance of *Trichodesmium* spp. at the surface and the FM depth ranged from 850 to 8,095 filaments·10 L^{-1} and 60–2,000 filaments·10 L^{-1}, respectively. The percentage of *Trichodesmium* spp. abundance at the surface ranged from 65 to 94%, while at the FM depth it ranged from 1 to 76%. The highest percentage distribution of *Trichodesmium* spp. was observed at the A2 station (94% at the surface).

The present study reports the results of a microscopic analysis of the phytoplankton community. The cyanophyte was present in greater abundance in surface waters, while the diatoms became the dominant group at the FM depths (Fig. 2). The dominance of *Trichodesmium* spp. is likely attributed to the combination of low salinity and moderate temperatures during the November cruise. A comparable observation of the highest biomass of diatoms in conjunction with dinoflagellates has been previously documented in the Central Bay of the Bay of Bengal (Paul *et al*. 2008; Charoenvattanaporn *et al.* 2018). This study builds upon previous research examining the prevalence of *Trichodesmium* in surface waters (Sarojini and Sarma 2001; Satapoomin *et al*. 2004; Paul *et al.* 2008) and the maximum species diversity observed for diatoms and dinoflagellates (Paul *et al.* 2008).

Phytoplankton taxa analyses

The dominance data of phytoplankton species (filaments·10 L^{-1} or cells·10 L^{-1}), with only *Trichodesmium* spp. presented in filaments·10 L^{-1}, were transformed to the square root prior to illustration via a spectrum shade plot with 50% reduced species set-off. A Bray-Curtis similarity matrix was conducted for each pair of samples and a clustering analysis was performed to represent the similarity associations in the plots.

The distribution of phytoplankton on the Andaman Sea continental shelf transect is represented by a spectrum of colours, with bright red bands indicating high abundance and blues indicating low abundance. Figure 3 presents the spectrum shade plot for the most significant species contributing to *Trichodesmium* spp. and diatom species for the Andaman Sea continental shelf transect samples in November 2012. The results of the cluster analysis of phytoplankton abundance revealed the existence of two major clusters of samples with a similarity level range of approximately 50%. The results demonstrated that *Trichodesmium* spp. exhibited high abundance at the surface, while the diatoms peaked at the FM depth at each station. This finding suggests that cyanophytes were the dominant species at the surface of the Andaman Sea continental shelf transect, a conclusion that is consistent with the observations of Sarojini and Sarma (2001), who studied the vertical distribution of phytoplankton around the Andaman and Nicobar Islands in the Bay of Bengal in 1996.

A distinct pattern emerges when comparing the abundance of diatom species at the FM depth to those at the surface. The most prevalent diatom species, *Thalassiosira* spp., exhibited the highest abundance at the FM depth, followed by *Cheatoceros* spp. along the transect. The centric diatom

Cheatoceros spp. exhibited a markedly high abundance at the A4 station, situated at a depth of 50 meters. In contrast, the surface exhibited a markedly lower abundance of marine diatoms in comparison to the FM depth. Furthermore, several diatom species were observed to be present exclusively at a single station. These included *Cyclotella stylorum*, *Lauderia annulata*, *Asteromphalus hookerii*, *Asteromphalus* spp., *Actinoptychus senarius*, *Dactyliosolen* sp., *Eucampia cornuta*, *Chaetoceros diversus*, *Triceratium favus* and *Grammatophora* sp.

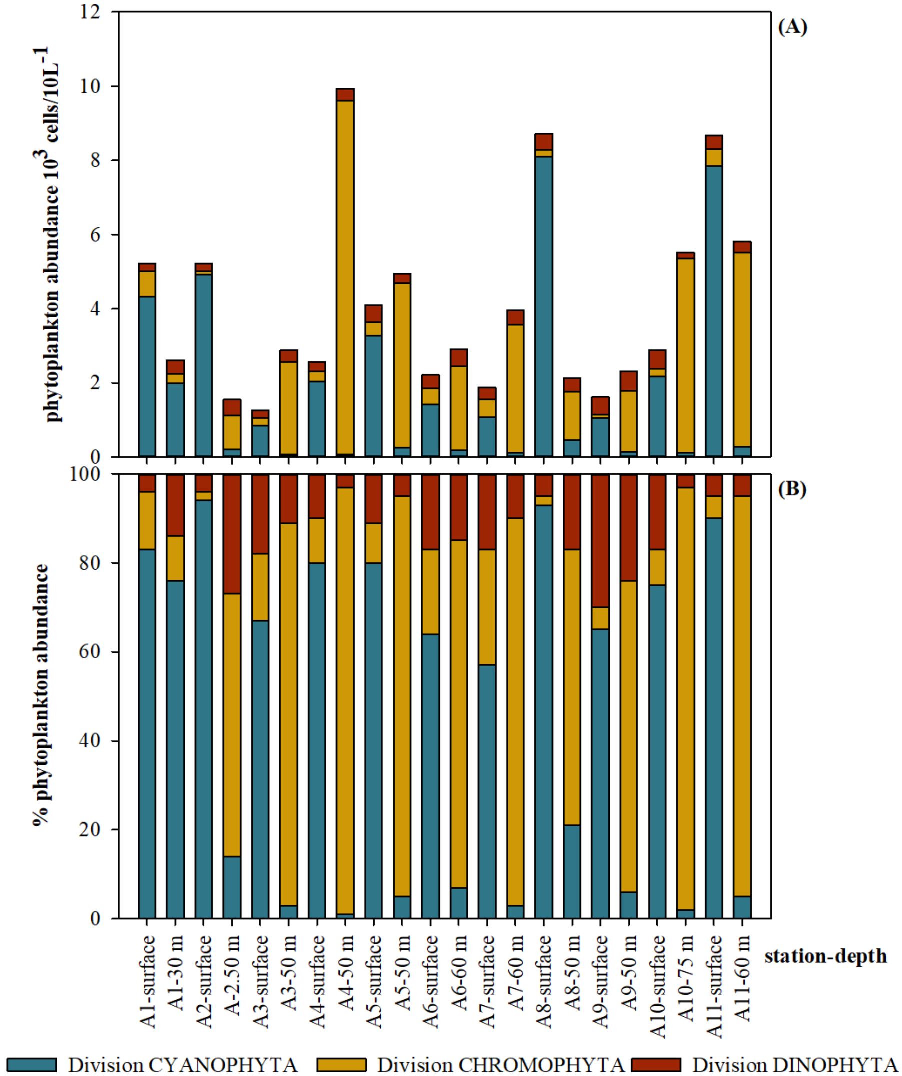

Figure 2: Distributions of abundance and cell count percentage for the primary phytoplankton divisions at the eleven sampling sites on the Andaman Sea continental shelf in November 2012. The density of cyanobacteria is expressed in filaments per ten liters.

Table 1. The taxonomic composition of phytoplankton on the Andaman Sea continental shelf in November 2012.

No.	List	No.	List
	Division CYANOPHYTA	19	*Actinoptychus senarius* (Ehrenberg) Ehrenberg
	Family Oscillatoriaceae		**Suborder Rhizosoleniineae**
1	*Trichodesmium* spp.		**Family Rhizosoleniaceae**
	Division CHROMOPHYTA	20	*Dactyliosolen* sp.
	Class Chrysophyceae	21	*Guinadia* spp.
	Order Dictyochales	22	*Proboscia alata* (Brightwell) Sundström
	Family Dictyochaceae		
2	*Dictyocha fibula* Ehrenberg	23	*Rhizosolenia pungens* Cleve-Euler
3	*Octactis octonaria* (Ehrenberg) Hovasse	24	*Rhizosolenia* spp.
	Class Bacillariophyceae		**Suborder Biddulphiineae**
	Order Biddulphiales		**Family Hemiaulaceae**
	Suborder Coscinodiscineae	25	*Ceratualina pelagica* (Cleve) Hendey
	Family Thalassiosiraceae	26	*Eucampia cornuta* (Cleve) Grunow
4	*Cyclotella stylorum* Brightwell		**Family Biddulphiaceae**
5	*Detonula pumila* (Castracane) Gran	27	*Climacodium flauenfeldianum* Grunow
6	*Lauderia annulata Cleve*	28	*Hemiaulus membranaceus* Cleve
7	*Planktonella sol* (Wallich) Schütt		**Family Chaetoceraceae**
8	*Thalassiosira* spp.	29	*Bacteriastrum* spp.
	Family Melosiraceae	30	*Chaetoceros diversus* Cleve
9	*Paralia sulcata* (Ehrenberg) Cleve	31	*Chaetoceros messanensis* Castracane
	Family Leptocylindraceae	32	*Chaetoceros* spp.
10	*Leptocylindrus* sp.		**Family Lithodesmiaceae**
	Family Coscinodiscaceae	33	*Ditylum sol* Grunow
11	*Coscinodiscus* spp.		**Family Eupodiscaceae**
	Family Hemidiscaceae	34	*Odontella* spp.
12	*Hemidiscus cuneiformis* Wallich	35	*Triceratium favus* Ehrenberg
13	*Pseudoguinardia* sp.		**Order Bacillariales**
	Family Asterolampraceae		**Suborder Fragilariineae**
14	*Asterolampra marylandica* Ehrenberg		**Family Fragilariaceae**
15	*Asteromphalus hookerii* Ehrenberg	36	*Fragilariopsis doliolus* (Wallich) Medlin & Sims
16	*Asteromphalus cleveanus*		
17	*Asteromphalus* spp.		**Family Thalassionemataceae**
	Family Heliopeltaceae	37	*Thalassionema bacillare* (Heiden in Heiden & Kolbe) Kolbe
18	*Actinoptychus grundleri* A. Schmidt		

No.	List	No.	List
38	*Thalassionema nitzschioides* (Grunow) Mereschkowsky	62	*Dinophysis* spp.
		63	*Ornithocercus magnificus* Stein
39	*Thalassionema* sp.	64	*Ornithocercus quadratus* Schütt
40	*Thalassiothrix* spp.	65	*Ornithocercus thumii* (Schmidt) Kofoid & Skogsberg
	Family Striatellaceae		
41	*Grammatophora* sp.	66	*Histioneis* spp.
	Suborder Bacillariineae		**Order Gymnodiniales**
	Family Mastogloiaceae		**Family Gymnodiniaceae**
42	*Mastogloia rostrata* Hustedt	67	*Gymnodinium sanguineum* Hirasaka
	Family Naviculaceae		**Order Noctilucales**
43	*Meuniera membranacea* (Cleve) P.C. Silva		**Family Kofoidiniaceae**
44	*Navicula* spp.	68	*Kofoidinium lebourae* (Pavillard) Taylor
45	*Pleurosigma spp.*		**Order Gonyaulacales**
	Family Nitzschiaceae		**Family Ceratiaceae**
46	*Pseudo-nitzschia* spp.	69	*Tripos azoricum* Cleve
	Division DINOPHYTA	70	*Tripos biceps* Claparède & Lachmann
	Order Prorocentrales	71	*Tripos breve* (Ostenfeld & Schmidt) Schröder
	Family Prorocentraceae		
47	*Prorocentrum micans* Ehrenberg	72	*Tripos carriense* Gourret
48	*Prorocentrum sigmoides* Böhm	73	*Tripos declinatum* (Karsten) Jörgensen
49	*Prorocentrum* spp.	74	*Tripos deflexum* (Kofoid) Jörgensen
	Order Dinophysiales	75	*Tripos dens* Ostenfeld & Schmidt
	Family Amphisoleniaceae	76	*Tripos extensum* (Gourret) Cleve
50	*Amphisolenia bidentata* Schröder	77	*Tripos falcatum* (Kofoid) Jörgensen
	Family Dinophysiaceae	78	*Tripos furca* (Ehrenberg) Claparède & Lachmann
51	*Dinophysis cuneus* (Schütt) Abé		
52	*Dinophysis doryphorum* (Stein) Abé	79	*Tripos fusus* (Ehrenberg) Dujardin
53	*Dinophysis expulsa* Kofoid & Michener	80	*Tripos kofoidii* Jörgensen
54	*Dinophysis favus* (Kofoid & Michener) Balech	81	*Tripos teres* Kofoid
		82	*Tripos trichoceros* (Ehrenberg) Kofoid
55	*Dinophysis infundibulus* Schiller	83	*Tripos tripos* (O.F. Müller) Nitzsch
56	*Dinophysis mitra* (Schütt) Abé	84	*Tripos vultur* Cleve
57	*Dinophysis parvula* (Schütt) Balech		**Family Ceratocoryaceae**
58	*Dinophysis recurva* Kofoid & Skogsberg	85	*Ceratocorys horrida* Stein
			Family Gonyaulacaceae
59	*Dinophysis rotundata* Claparède & Lachmann	86	*Gonyaulax polygramma* Stein
		87	*Gonyaulax spinifera* (Claparède & Lachmann) Diesing
60	*Dinophysis schuettii* Murray & Whitting		
61	*Dinophysis uracantha* Stein		

No.	List	No.	List
88	*Gonyaulax* spp.		**Order Peridiniales**
89	*Lingulodinium polyedrum* (Stein) Dodge		**Family Calciodinellaceae**
	Family Oxytoxaceae	98	*Scripsiella trochoidea* (Stein) Loeblich III
90	*Corythodinium tesselatum* (Stein) Loeblich Jr. & Loeblich III		**Family Podolampadaceae**
91	*Oxytoxum scolopax* Stein	99	*Blepharocysta splendor-maris* (Ehrenberg) Ehrenberg
92	*Oxytoxum subulatum* Kofoid		
	Family Pyrocystaceae	100	*Podolampus bipes* Stein
93	*Dissodinium elegans* (Parvellard) Matzenauer	101	*Podolampus palmipes* Stein
		102	*Podolampus spinifera* Okamura
94	*Dissodinium gerbaultii* (Pavillard) Taylor		**Family Protoperidiniaceae**
		103	Diplopsalis group
95	*Pyrocystis* spp.	104	*Peridinium quinquecorne* Abé
	Family Pyrophacaceae	105	*Peridinium curtipes* (Jörgensen) Balech
96	*Pyrophacus* sp.		
	Family Triadiniaceae	106	*Peridinium elegans* (Cleve) Balech
97	*Goniodoma polyedricum* (Pouchet) Jørgensen	107	*Peridinium* spp.

As illustrated in Figure 2, the highly abundant marine dinoflagellate species, *Peridinium* spp., was the predominant species observed across all stations. A cluster analysis of phytoplankton abundance identified two major clusters of samples with a similarity level of approximately 44% (Fig. 4). Station A9 at the FM depth exhibited a high diversity and abundance of oceanic dinoflagellate species. The species Scripsiella trochoidea was observed to be particularly abundant at the surface, from station A9 to A10. Furthermore, numerous dinoflagellate species were observed at a single station, including *Prorocentrum sigmoides*, *Dinophysis cuneus*, *Dinophysis schuettii*, *Gymnodinium sanguineum*, *Tripos carriense*, *Tripos dens*, *Tripos extensum*, *Dissodinium elegans*, *Dissodinium gerbaultii*, *Podolampus spinifera* and P*eridinium elegans.*

Phytoplankton diversity

The dominance of phytoplankton species (cells·L^{-1}) is illustrated by a shade plot (Fig. 3). To elucidate the similarity associations between each pair of samples, Bray-Curtis similarity was calculated between each pair of samples, with depth, and this matrix was clustered (Fig. 4).

The quantity of phytoplankton is represented by a color gradient, with black bands indicating a high abundance and blue bands indicating a low abundance. Figure 4 depicts a shade plot for the most significant diatom species. A cluster analysis of phytoplankton abundance yielded three primary clusters with a similarity level of approximately 50%. The greatest abundance of diatom species was observed at stations 3, 4, 5, 10 and 11, while the highest concentration of dinoflagellates was recorded at stations 3, 5 and 7. The cluster analysis of phytoplankton abundance yielded two major clusters with a similarity level of 44% (Fig. 4). Station 1 (bottom) had the lowest abundance, as did both sampling depths at station 2. Notably, *Peridinium* spp. was particularly abundant at station 10.

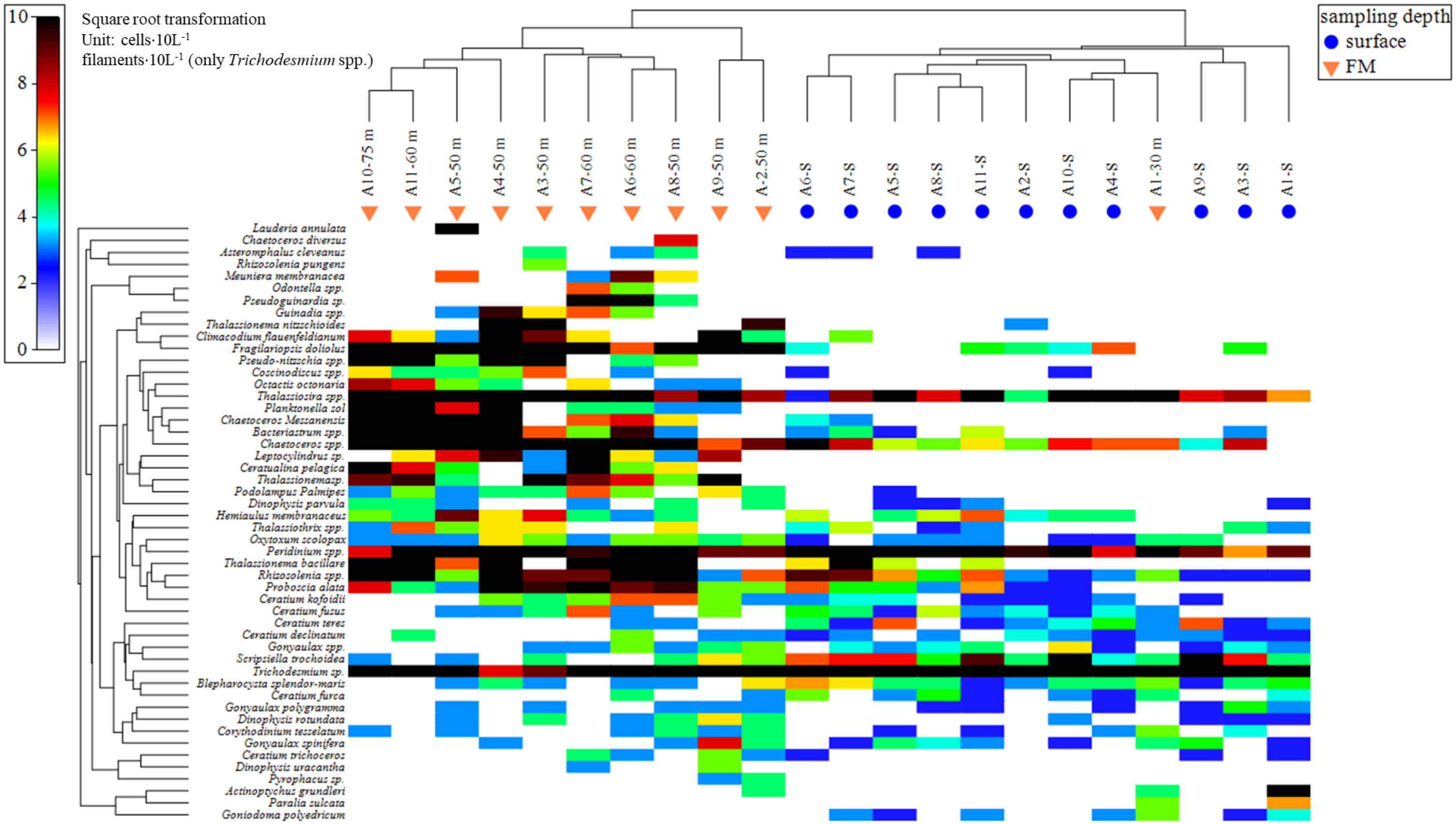

Figure 3. The shade plot of abundance (50% reduced species set-off) with a linear spectrum scale intensity proportional to a square root transformation. Letters and numbers indicate the sample stations and sampling depths

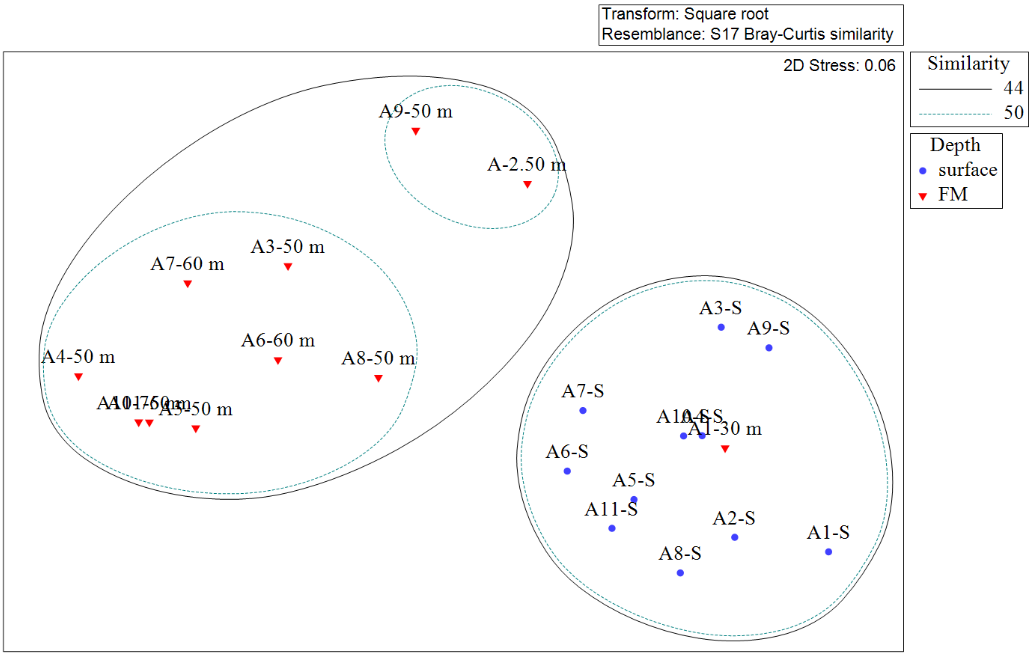

Figure 4. A non-metric multidimensional scaling (NMDS) plot of samples defined by phytoplankton species abundance. The dashed line represents a similarity level of 50%, while the solid line indicates a similarity level of 44%.

CONCLUSIONS

This study provides a comprehensive examination of the phytoplankton community structure and composition on the Andaman Sea continental shelf in November 2012. A total of 107 phytoplankton species were identified, with dinoflagellates representing the most diverse group, followed by diatoms, cyanophytes, and silicoflagellates. Dinoflagellates, particularly *Tripos* spp., exhibited high diversity, while diatoms like *Thalassiosira* spp. and *Chaetoceros* spp. were notably abundant.

Our findings indicate the existence of pronounced vertical stratification in phytoplankton communities, with cyanobacteria such as *Trichodesmium* spp. exhibiting a prevalence at the surface and diatoms demonstrating a dominance at the Fluorescence Maximum (FM) depth. This vertical distribution is subject to influence from environmental factors, including light availability and nutrient concentrations, which exert a shaping effect on community dynamics.

The study also highlights the necessity of incorporating environmental data, including temperature, salinity, and nutrient concentrations, to enhance comprehension of the processes influencing phytoplankton diversity and distribution. Future research should concentrate on the seasonal fluctuations and ecological importance of these phytoplankton shifts, particularly their impact on higher trophic levels and carbon fluxes within the ecosystem.

The findings of this research contribute to our comprehension of phytoplankton ecology in the Andaman Sea, offering crucial baseline data for future monitoring and management initiatives aimed at conserving the biodiversity and productivity of this ecologically significant marine ecosystem.

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