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Original Article

Spatial variability in the phytoplankton community along a transect across the Similan Islands in the Andaman Sea: A case study 2007-2008

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Abstract

The marine phytoplankton community was studied between October 2007 and March 2008 along a transect across the Similan Islands in the Andaman Sea during the southwest and northeast monsoon seasons. Seawater was collected from 11 stations on the transect. At least 146 species belonging to 68 genera in 37 families and 11 orders of marine phytoplankton were identified by microscopic observation. Diatoms were the major group of dominant phytoplankton particularly at depths in the study. Cyanophyta, particularly *Trichodesmium* spp., was the dominant group but the species diversity was maximal for dinophyta and heterokontaphyta from both monsoon sampling periods. The most diverse genera of dinoflagellate were *Ceratium*, *Dinophysis*, and *Protoperidinium*, while a high variety of diatom genera were *Rhizosolenia* and *Chaetoceros*. The relative results between the phytoplankton group and environmental parameters revealed that phytoplankton was strongly affected by salinity and silicate concentration during the southwest monsoon, while the availability of photosynthetically active radiation was significantly correlated with seasonal succession during the northeast monsoon.

Keywords: marine phytoplankton, monsoon, Similan Islands, Andaman Sea

1. Introduction

The Andaman Sea is located in the eastern side of the Indian Ocean between the Thai-Malay Peninsula and the Andaman-Nicobar Island. It covers a region of 6×10^5 km^2 with an average depth of 1100 m and a maximum depth of 4419 m (Dutta *et al.*, 2007). This area has high vertical mixing rates by interval waves generated from tidal currents flowing through rough topography (Dutta *et al.*, 2007). The region is characterized by the seasonally reversing Asian monsoon (Wyrtki, 1973). The northeast monsoon (NE) is active between December and March, whereas the southwest monsoon (SW) is active between June and September (Tomczak & Godfrey, 2013). In response to the monsoons in the Andaman Sea, the oceanic flow changes direction twice a year with a cyclonic flow between March and August and an anticyclonic flow for the rest of the year (Potemra *et al.*, 1991). In this region, it was reported using remote sensing and estimation

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models that the amount of riverine nutrient discharge from the Bengal delta and Myanmar estuaries plays a major role in the high phytoplankton biomass (Suwannathatsa *et al.*, 2012).

The Andaman Sea displays various patterns in the phytoplankton community which are linked to seasonal variations in climatic forcing and a strong coupling between the prevailing physical conditions and the biological processes (Sarojini & Sarma, 2001; Nielsen *et al.*, 2004; Buranapratheprat *et al.*, 2010; Suwannathatsa *et al.*, 2012). The combination of a wide range of physical conditions and warm water temperatures during the SW results in highly diverse phytoplankton communities in the Andaman Sea (Sarojini & Sarma, 2001). The phytoplankton community structure in the Andaman Sea is, therefore, highly dependent upon prevailing environmental conditions. Although cyanophyta (e.g., *Trichodesmium erythreae*) was usually a significant component to the biomass, the diatoms and dinoflagellates represented much of the specie diversity(Sarojini & Sarma, 2001). However, Nielsen *et al.* (2004) found that both monsoon seasons had no difference in primary production, and the pico- and nano-phytoplankton sizes were the dominant biomass in the Andaman Sea off Phuket Island.

The Similan Islands in the Andaman Sea are an island group that is one of the marine national parks under the Royal Thai government. Some research has studied the marine diversity in this area; however, a tropical coral community was recently studied in response to several environmental variations (Schmidt *et al.*, 2012). The study showed that a change of the Similan Islands coral community was related to a rapid change in temperature, pH, and nutrient availability from pulsed upwelling events. Fillinger (2008) studied the impacts of internal waves on the zooplankton community and seston around the islands and found that the internal waves bring cold water from the thermocline to the islands. However, few studies have reported on the phytoplankton community structure around the Similan Islands and the composition and correlation with environmental factors.

The present study attempts to understand the taxonomy and vertical distribution of the phytoplankton community along the Similan Islands transect in the Andaman Sea. This study was carried out during both monsoon seasons of 2007 and 2008. We aim to understand the relationship between phytoplankton community and environmental variables in the study area.

1.1 Study area

This study was conducted during a Thai-German cruise of *Chukratong Tongyai* between October 2007 and March 2008. The Similan Islands in the Andaman Sea, Thailand are located 60 km west of the Thai coast and the nine small islands are aligned from north to south over a distance of 24 km. Two sets of 11 stations are placed in a west-east transect across to the Similan Islands toward the west of the shelf break (Figure 1). The depths ranged from 30 to 340 meters along the stations along the Similan Island transect.

2. Materials and Methods

During the two monsoon seasons water sampling was done at each of the 11 sites (A-K). The vertical profiles of water column properties were measured using initially a rosette of Niskin bottles with a conductivity-temperature-depth (CTD) instrument attached for temperature (ºC), salinity,

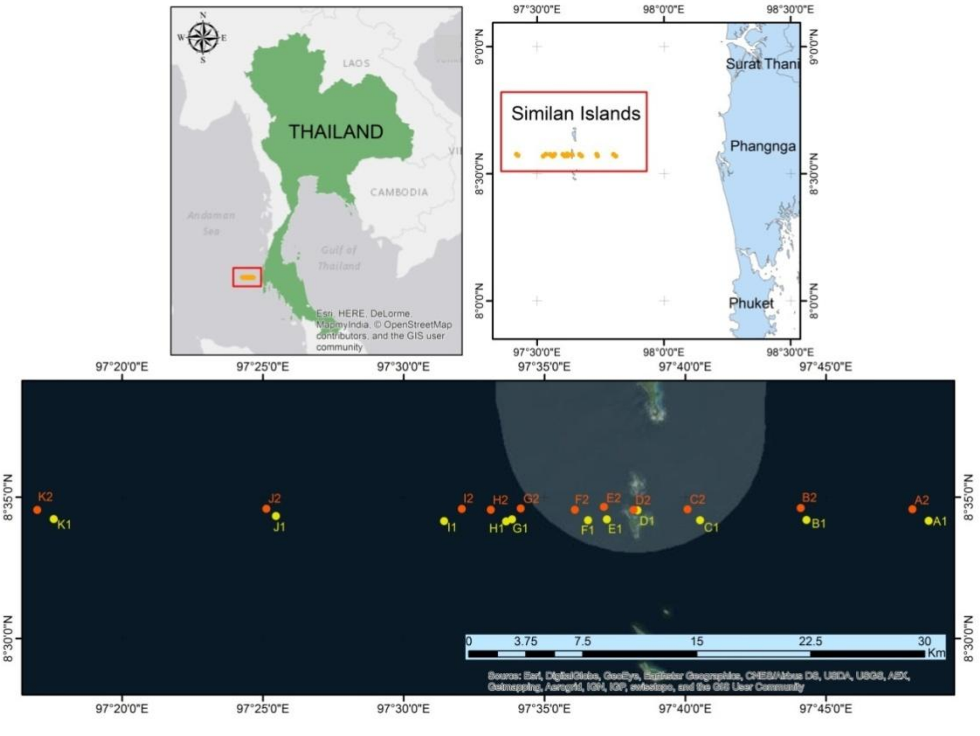


Figure 1. Map of the Andaman Sea showing the eleven sampling sites along the Similan Islands transect.Yellow dots are stations sampled in October 2007 (SW monsoon) and orange dots are stations sampled in March 2008 (NE monsoon).

pH, photosynthetically active radiation (PAR) (µmols m^{-2} s^{-1}), fluorescence (arbitrary unit), dissolved oxygen (mg L^{-1}), and depth (m). The CTD was deployed to provide a vertical profile of the environmental parameters at depths from 1.0 to 10.0 m intervals dependant on the maximum depth at each station along the transect. The probes were rinsed with freshwater after each measurement and the data from the probe were imported into Excel. In the present study, the samples of seawater for biological and physiochemical analysis were collected only at 4 m from the surface and at the depth of fluorescence maximum (FM) at each station.

2.1 Chemical measurements

Total nitrogen (TN), total phosphorus (TP), nitrite, nitrate, phosphate, and silicate data in this report were provided by a team from the oceanography unit, Phuket Marine Biological Center. Freshly collected water samples were filtered through 0.7 µm Whatman GF/F filters into clean polyethylene bottles. Then the filtered water samples were immediately frozen at –20 ºC until subsequent spectrophotometer analysis for nutrients according to Strickland and Parsons (1984).

2.2 Total suspended solids (TSS)

The TSS data were also provided by a team from the oceanography unit as well as all nutrient data. The TSS concentration in the water samples collected from each site was determined by filtering 500-1000 ml of water through pre-weighed and dried 47 mm Whatman GF/C filters in duplicate. The filtered samples were dried overnight at 80 °C and then re-weighed in unit mg l^{-1}.

2.3 Phytoplankton sampling survey, cell count, and identification

Duplicate 150 ml water samples for phytoplankton identification and enumeration were placed in brown glass bottles and at 3% formalin solution in seawater until analysis. Each preserved sample was gently mixed and then a 1 ml subsample was transferred to a Sedgewick-Rafter counting chamber using a 1 ml automatic pipette. The chamber was covered with a glass plate and left to settle for at least 1 h before placing on a light microscope to allow cells to be counted and identified at a magnification of 200×. The sample was counted in duplicate. A filament count was only done for the cyanobacteria group. Tomas (1997) and Round *et al.* (2007) were used for identification of marine phytoplankton.

2.4 Statistical method

The data analysis was undertaken using Excel 2010, Sigma Plot 13, PRIMER-E 7 (Plymouth Routines In Multivariate Ecological Research), and CANOCO 4.5 software (CANOCO, Microcomputer Power, Ithaca, NY, USA). Excel was used to organise, display, and complete simple data analysis tasks. Sigma Plot was applied to create graphs, including bars of environmental variables and stack plots of phytoplankton data. PRIMER-E 7 was used for cluster analysis and matrix display by shade plot to resolve the complexity of the phytoplankton abundance (Clarke & Warwick, 1994; Clarke *et al.*, 2014). CANOCO software was used in this study to analyse the effect of selected environmental parameters on the phytoplankton abundance. A redundancy analysis (RDA) was carried out using the CANOCO 4.5 software package (Ter Braak & Šmilauer, 2002) to assess the interactions between the environmental parameters and phytoplankton groups. This analysis determined the environmental variables that best explained the distribution of the main selected taxonomic groups by selecting the linear combination of environmental variables that yielded the smallest total residual sum of squares in the taxonomic data (Peterson *et al.*, 2007).

3. Results and Discussion

3.1 Environmental parameters

The distributions of physical components at the surface and the FM depth from both monsoons are shown in Figures 2 and 3. In general, the salinity at the surface was slightly less than the FM depth during both monsoon samplings. In October 2007, the means of salinity at the surface and the FM depth were 31.0±0.1 and 32.5±0.5 (n=11, Figure 2A), respectively, whereas the values in March 2008 were 31.0±1.4 and 32.4±0.2 (n=11), respectively (Figure 2B). The salinity at surface depth was slightly less than the FM depth during both monsoon periods probably due to the rainy season; however, the range of salinity were similar with other studies near this area (Sarojini & Sarma, 2001; Nielsen *et al.*, 2004; Fillinger, 2008; Schmidt *et al.*, 2012). The water temperature was generally high at the 4 m surface at all stations in both monsoon seasons (Figures 2C and 2D). The PAR showed the highest value at the surface of the K2 station during the NE in 2008 (Figure 2F).

In the present study, the fluorescence maximum covered the depth strata from 20 to 50 m. During the NE monsoon, the highest fluorescence values were observed between 20 and 50 m, while the highest fluorescence during SW monsoon was located deeper in some stations, according to the mixing by wind and storms during the rainy season (Figure 3A) as reported by Satapoomin *et al.* (2004) during the 1996-1997 cruises. Dissolved oxygen decreased form the surface to the FM depth in October 2007 (Figure 3C), whereas the concentrations in March 2008 varied which depended on the sampling stations (Figure 3D). TSS concentrations in the SW samples were generally higher than the NE samples (Figures 3E and 3F).

3.2 Nutrients

In general all nutrient concentrations in the October 2007 samples were higher than the March 2008 samples (Figures 4 and 5. TN concentrations of the October 2007 samples varied between 1.9 and 24.0 µg at-N l^{-1} at the surface, while at the FM depth TN concentrations ranged from 3.2 to 89.3 µg at-N l^{-1} (Figure 4A). The NE samples ranged from 0.8 to 4.1 µg at-N l^{-1} of TN at the surface, whereas the concentrations at the FM depth varied between 1.0 and 11.3 µg at-N l^{-1} (Figure 4B). The nitrite concentrations had no clear pattern from either monsoon season; however, the highest concentration was measured at the FM depth at the K1 station during the SW sampling (Figures 4C and 4D). The nitrate concentrations in the October 2007 samples showed the same pattern (Figure

4E) but did not present in the March 2008 samples (Figure 4F). At the FM depth of the J1 station the highest concentration of ammonia reached 32.9 µg at-N l^{-1} (Figure 4G). However, the ammonia concentration was generally lower than 1.0 µg at-N L^{-1} from the samples of both monsoon seasons.

The TP concentrations were high at the FM depth during the SW sampling period (Figure 5A), whereas the concentration was lower (0.4 µg at-P l^{-1}) in March 2008 (Figure 5B). Phosphate concentration was either undetected or present at some stations in October 2007. The highest concentrations of phosphate and ammonia were present at the FM depth of the J1 station. The phosphate concentration reached 3.7 µg at-P l^{-1} (Figure 5C). High concentrations of ammonia and phosphate measured at the J1 FM depth were probably due to the mixing process of thermocline water and surface water or internal waves that transported thermocline water to this site during the SW monsoon. Otherwise, the phosphate concentrations in the NE samples were generally detected below 0.15 µg at-P l^{-1} (Figure 5D). Silicate concentration increased at the FM depth from the samples of both monsoon seasons. At only two stations (G1 and H1) in October 2007 and one station (G2) in March 2008 did the silicate concentration increase rapidly from the surface to the FM depth (Figures 5E and 5F).

In this study, higher amounts of nutrient concentrations and the FM depth were observed to be conducive for the growth of heterotrophic dinoflagellates as observed by Satapoomin *et al.* (2004). Furthermore, the surface water was depleted in nitrogen (Nielsen *et al.*, 2004) in this region. Thus, in particular at the FM depth, ideal high nutrient concentrations and light conditions appear to be beneficial for the growth of diatom and dinoflagellate species.

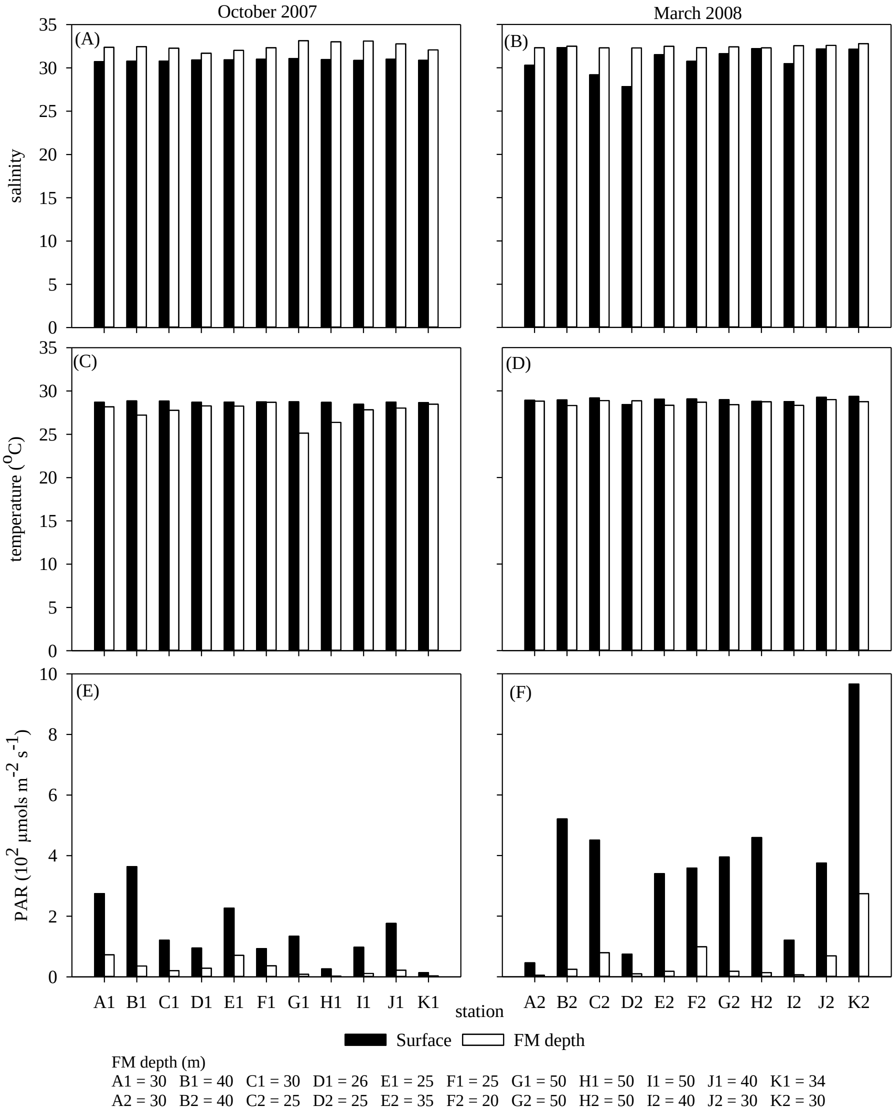


Figure 2. Environmental parameters (salinity, temperature, and PAR) along the Similan Islands transect, Andaman Sea in October 2007 and March 2008, (A-B) salinity, (C-D) temperature, and (E-F) PAR. Symbols apply to all panels.

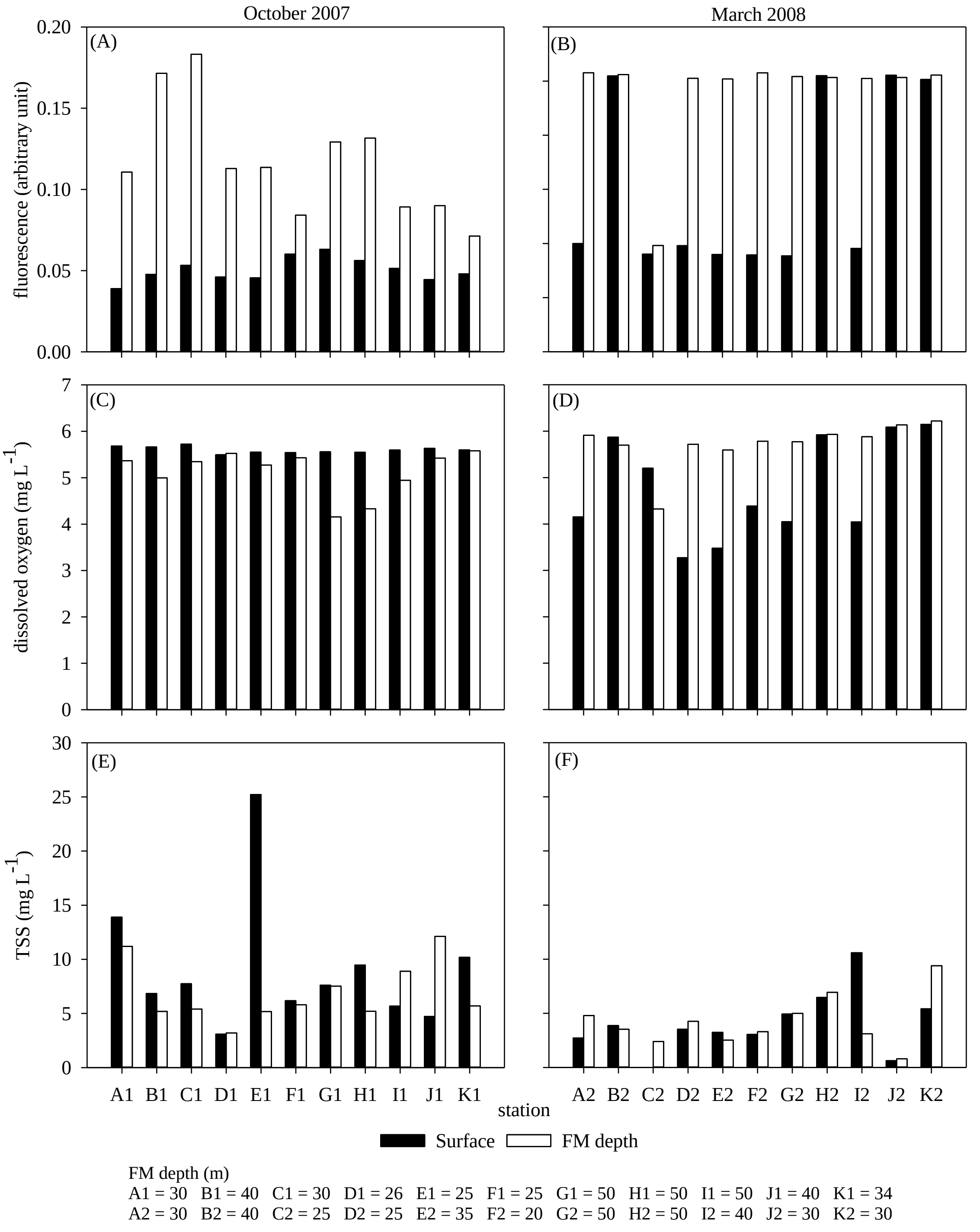


Figure 3. Environmental parameters (fluorescence, dissolved oxygen, and TSS) along the Similan Islands transect, Andaman Sea in October 2007 and March 2008, (A-B) fluorescence, (C-D) dissolved oxygen, and (E-F) TSS. Symbols apply to all panels.

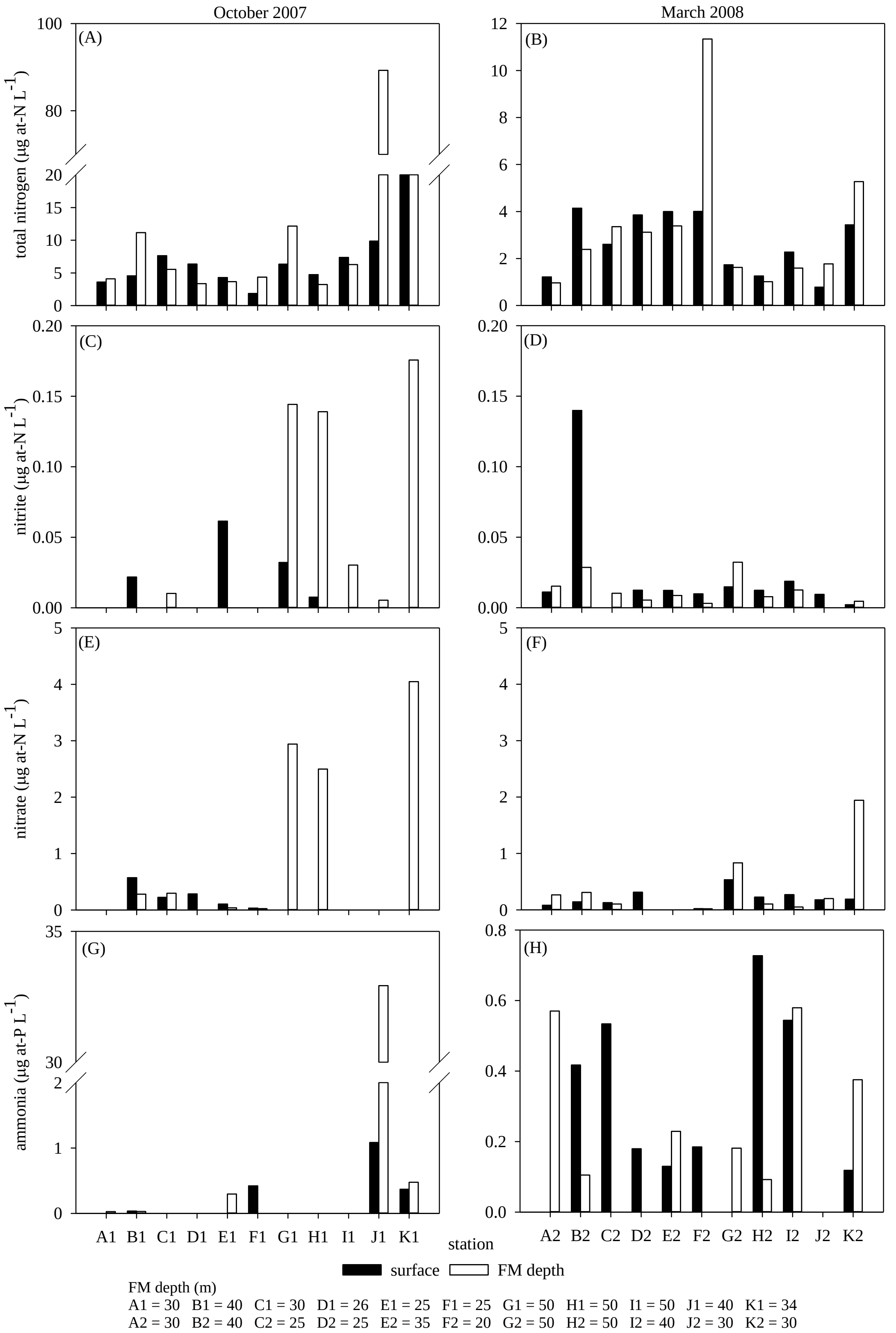
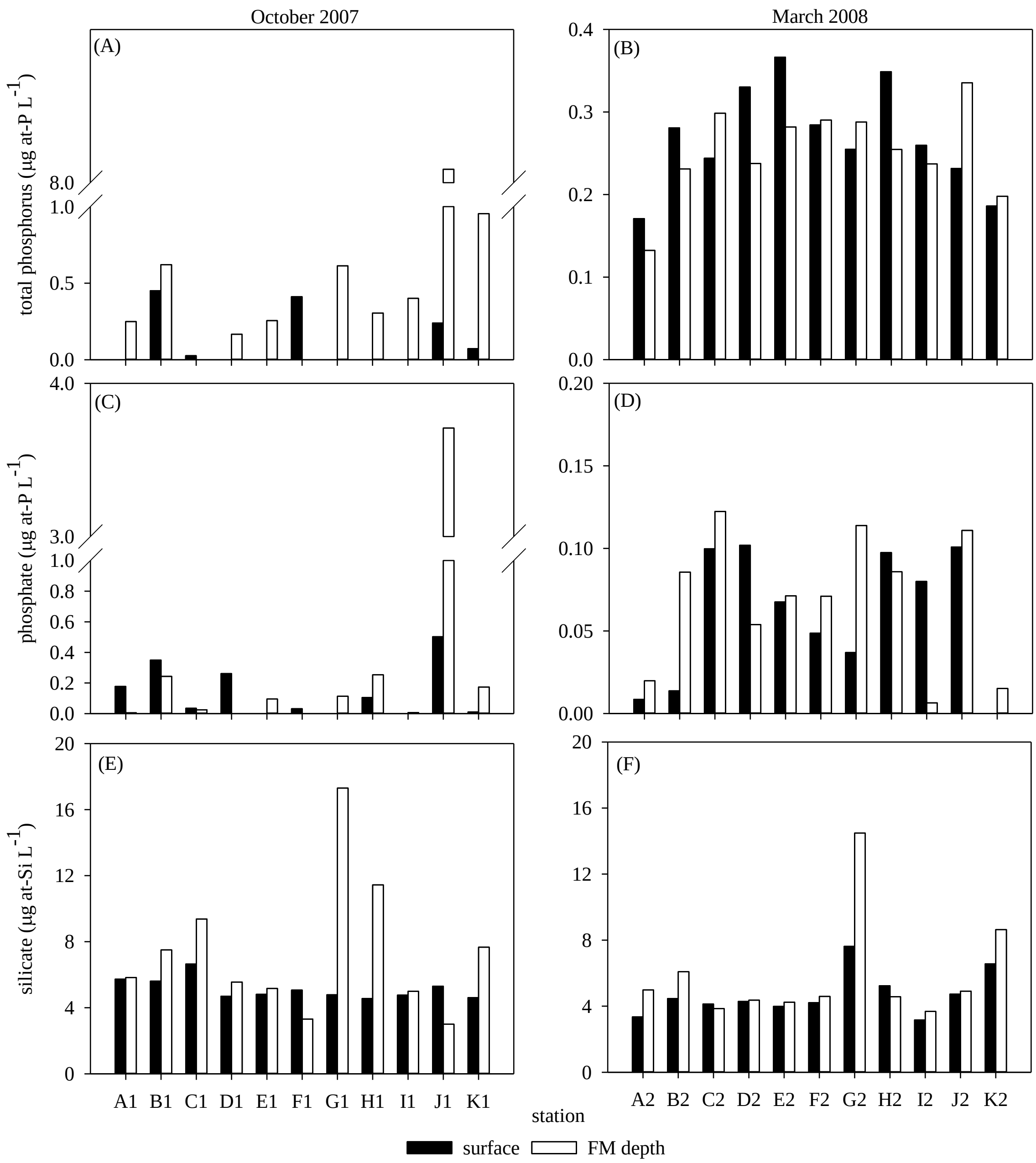


Figure 4. Nutrient concentrations (µg at l^{-1}) along the Similan Islands transect, Andaman Sea in October 2007 and March 2008, (A-B) total nitrogen, (C-D) nitrite, (E-F) nitrate, and (G-H) ammonium. Symbols apply to all panels.



FM depth (m)
A1 = 30 B1 = 40 C1 = 30 D1 = 26 E1 = 25 F1 = 25 G1 = 50 H1 = 50 I1 = 50 J1 = 40 K1 = 34
A2 = 30 B2 = 40 C2 = 25 D2 = 25 E2 = 35 F2 = 20 G2 = 50 H2 = 50 I2 = 40 J2 = 30 K2 = 30

Figure 5. Nutrient concentrations (µg at l^{-1}) along the Similan Islands transect, Andaman Sea in October 2007 and March 2008, (A-B) total phosphorus, (C-D) phosphate, and (E-F) silicate. Symbols apply to all panels.

3.3 Phytoplankton community

3.3.1 Diatoms

Microscopic observation revealed the presence of marine diatoms during the SW and the NE with species counts of 44 and 54, respectively. This study found 56 diatom species from both monsoon seasons belonging to 38 genera in 17 families and 2 orders of marine diatoms. There was a lack of diversity (44 species) of diatoms in the SW compared with the NE season (54 species). Among the diatom composition, the centrales (44 species) were more than the pennales (12 species). The most diverse genera were *Rhizosolenia* followed by *Chaetoceros.* The most frequent occurrence of the marine diatoms species consisted of *Thalassiosira* spp., *Chaetoceros* spp., *Thalassiothrix* spp., *Thalassionema nitzschioides*, *Asteromphalus* spp., *Pseudo-nitzschia* spp., *Fragilariopsis doliolus*, and *Nitzschia longissima*. These dominant diatoms were also previously reported by Sarojini and Sarma (2001) and Paul *et al.* (2008). The abundances of diatoms at the surface and the FM depth ranged from 6 to 39 cells l^{-1} and 16 to 804 cells l^{-1} in the SW season, whereas in the NE season the counts were from 23 to 2,727 cells l^{-1} and 37 to 3,354 cells l^{-1}, respectively (Figure 6). The highest mean abundance of diatom species occurred at the A2 station at the FM depth (3,354 cells l^{-1}, 30 m). The percentages of diatom abundance at the surface were 1 to 12% in the SW samples and 4 to 94% in the NE samples. At the FM depth from both monsoon seasonsthe percentages ranged from 2 to 96% (SW) and from 5 to 97% (NE). The highest distribution of diatom percentage occurred at the G1 station (96%, 50 m) during the SW, whereas during the NE the highest distribution was 97% at the FM depth of station B2.

3.3.2 Dinoflagellates

At least 89 species belonging to 29 genera in 19 families and 8 orders of marine dinoflagellates were identified. The diversity of the dinoflagellates in the SW (73 species) was almost the same as in the NE (72 species). The most diverse genera were *Ceratium* followed by *Dinophysis* and *Protoperidinium*. The most frequent marine dinoflagellate species were *Scrippsiella* and *Protoperidinium.* The density ranges of dinoflagellates at the surface and the FM depth were from 19 to 62 cells l^{-1} and 11 to 1,495 cells l^{-1} in the SW and the densities were from 36 to 116 cells l^{-1} and 41 to 79 cells l^{-1} in the NE (Figure 6). The highest mean abundance of dinoflagellate species occurred at 34 m in the FM depth of the K1 station in October 2007 with a high abundance of *Protoperidinium* spp. (503 cells l^{-1}) followed by *Scrippsiella* spp. (267 cells l^{-1}). The percentages of dinoflagellate abun-dance at the surface was from 5 to 14% in the SW samples and from 3 to 15% in the NE samples. The percentage ranges at the FM depth from both monsoon seasons were from 2 to 48% (SW) and 2 to 16% (NE). The highest distribution of dinoflagellate percentage occurred at the F1 station (48%, 25 m) during the SW, while the highest percentage during the NE was 16% at the FM depth of station J2. The dominant dinoflagellate species in the present study consisted of *Protoperidinium* spp., *Scrippsiella* spp., *Dinophysis dorypho-rum*, *Ornithocercus magnificus*, *Alexandrium* sp., *Peridinium quinquecorne*, *Gonyaulax polygramma*, *Blephalocysta splen-dor-maris*, and *Gonyaulaxspinifera*. Satapoomin *et al.* (2004) also observed that this group presented in high amounts of biomass at the FM depth.

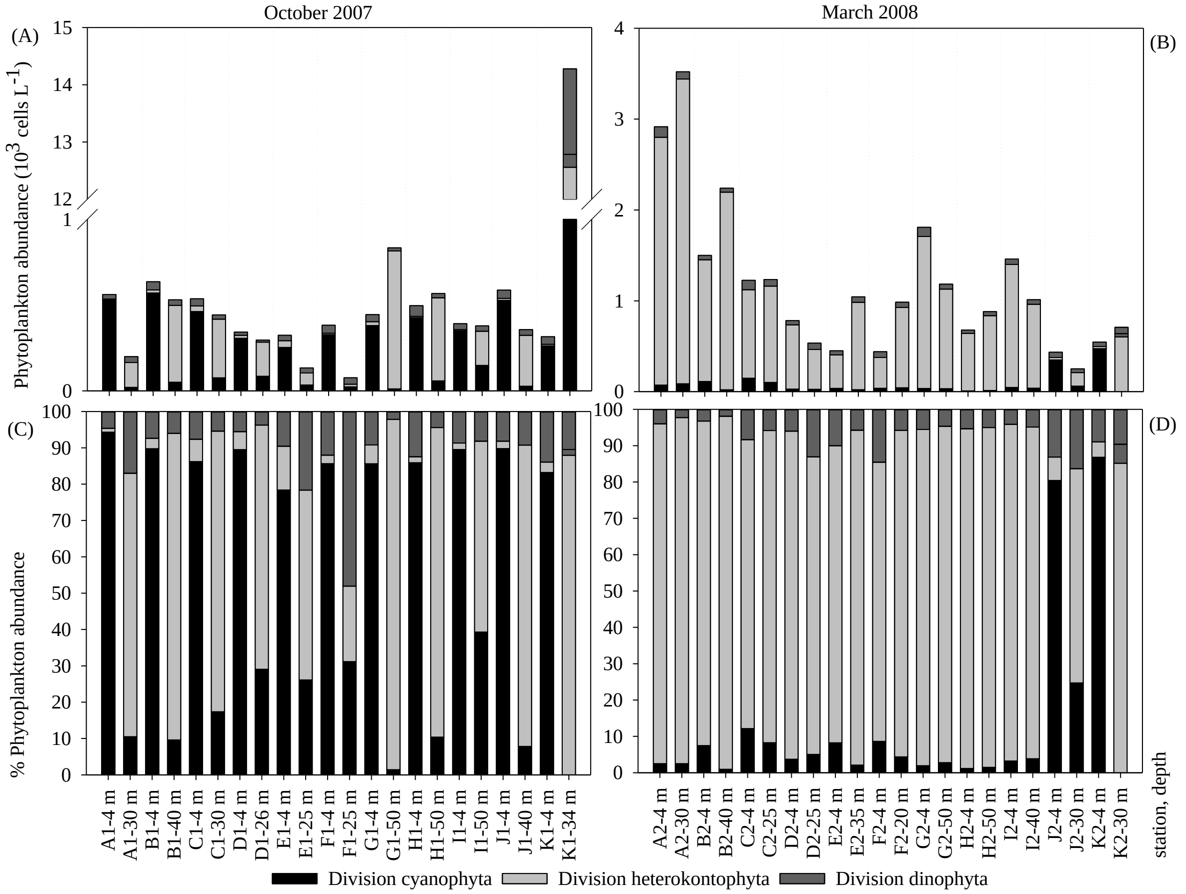


Figure 6. Distributions of abundance and cell count percentage for main phytoplankton divisions of the eleven sampling sites along the Similan Island transect, Andaman Sea during both monsoon seasons. Cyanophyta density unit is filaments l^{-1}.

3.3.3 Cyanobacteria

The cyano-phytoplankton species, *Trichodesmium* spp., was present at all stations at both sampling depths. The abundances of *Trichodesmium* spp. at the surface and at the FM depth ranged from 254 to 571 filaments l^{-1} and from 12 to 12,560 filaments l^{-1} in the SW, whereas in the NE they ranged from 8 to 474 filaments l^{-1} and from 13 to 603 filaments l^{-1}, respectively. The percentages of *Trichodesmium* spp. abundance at the surface was from 78 to 94% in the SW samples and from 1 to 87% in the NE samples. The percentages at the FM depth from both monsoon seasons ranged from 1 to 88% (SW) and from 1 to 85% (NE). The highest percentage distribution of *Trichodesmium* spp. occurred at the K1 station (88%, 34 m) during the SW, while during the NE it was 87% at the FM depth of station K2.

In the present study, the phytoplankton community was based on a microscopic analysis. Cyanophytes were present in higher abundance in the surface waters during the SW, while the diatoms became the dominant group in both seasons and at both depths (Figure 6). The dominance of *Trichodesmium* spp. was probably caused by low salinity and moderate temperature during the October cruise. Similar observations of the highest biomass of diatoms along with dinoflagellates was previously recorded in the Central Bay of the Bay of Bengal (Paul *et al.*, 2008). This study complements previous reports addressing the dominance of *Trichodesmium* spp. in the surface water (Sarojini & Sarma, 2001; Satapoomin *et al.*, 2004; Paul *et al.*, 2008) and the species diversity was maximum for diatoms and dinoflagellates (Paul *et al.*, 2008).

3.4 Phytoplankton taxa analyses

The dominance of phytoplankton species data (filaments or cells l^{-1}) were transformed to the fourth root before illustrating by spectrum shade plot with 50% reduce species set off. Bray-Curtis similarity was performed between each pair of samples and clustering of this matrix to represent the similarity association in the plots.

3.4.1 Southwest monsoon

The amount of phytoplankton along the Similan Islands transect are represented by a color spectrum where bright red bands indicate high abundance and the blue bands show low abundance. Figure 7 gives the spectrum shade plot for the most important species contributing to *Trichodesmium* spp. and diatom species for the Similan Islands transect samples in October 2007. Cluster analysis of phytoplankton abundance from the Similan Islands samples during the SW demonstrated five major clusters of samples (A-E) with a similarity level range of about 49%. *Trichodesmium* spp. had high abundance at the surface, while the diatoms peaked at the FM depth at each station during the SW. These results suggested that the cyanophytes were the dominant species at the surface along the Similan Islands transect in the SW which was also observed by Sarojini and Sarma (2001) who previously studied the vertical distribution of phytoplankton around the Andaman and Nicobar Islands in the Bay of Bengal during the SW in 1996. The diatom species at the FM depth showed a clear pattern of larger abundance followed by the surface. The highly dominant diatom species, *Cheatoceros* spp., gave the most weight at the FM depth followed by *Thalassiosira* spp. along the transect. The centric diatom, *Cheatoceros* spp., was highly abundant at the G1 station at 50 m. There were sixteen marine diatoms that were absent during this sampling comparing with the NE samples that included *Lauderia annulata*, *Skeletonema costatum*, *Leptocylindrus danicus*, *Hemidiscus* sp., *Dactyliosolen fragilissimus*, *Guinadia flaccida*, *G. striata*, *Rhizosolenia robusta*, *R. setigera*, *R. styliformis*, *Eucampia cornuta*, *Hemiaulus sinensis*, *Helicotheca* sp, *Odontella aurita*, *O. sinensis*, *Bellerochea* sp., and *Diatoma hyaline*.

In general the highly marine dinoflagellate species, *Protoperidinium* spp., were most abundant at all stations during the SW season (Figure 7). Cluster analysis of phytoplankton abundance from the samples during the NE demonstrated three major clusters of samples (A-C) with a similarity level range of about 55%. K1 station at the FM depth presented a high number and abundance of oceanic dinoflagellate species. *Lingulodinium polyedrum* and *Corythodinium tesselatum* were highly distinguished at the E1 to F1 stations at both depths. Several marine dinoflagellates species were found only at the K1 station, for example, *Dinophysis rapa*, *Histioneis* sp., *Ceratium horridum*, *C. inflatum*, *Ceratocorys horrida*, and *Alexandrium* sp. There are also several dinoflagellates species that presented only at one station, including *Ornithocercus stenii*, *Gymnodinium* sp., *Protoperidinium asymmetrica*, and *Dinothrix paradoxa*.

3.4.2 Northeast monsoon

The diatom species during the NE 2008 gave a higher weight than during the SW sampling (Figure 8). Cluster analysis of phytoplankton abundance demonstrated three major clusters of samples (A-C) with a similarity level range of about 55%. The centric diatom, *Chaetoceros* spp. was also the dominant species but it presented more abundance in the SW samples. *Thalassionema nitzschioides*, *Bacteriastrum* spp., and *Pseudo-nitzschia* spp. The J2 and K2 stations showed a low weight of marine diatom abundance compared with the other stations. There are seven marine diatoms that were absent from this sampling compared with the SW samples that included *Palmeria hardmaniana*, *Asterolampra marylandica*, *Actinoptychus senarius*, *Dactyliosolen phuketensis*, *Rhizosolenia* sp., *Chaetoceros aequatorialis*, and *C. peruvianum*.

The shade plot indicates abundance of the dinoflagellate species during the NE sampling (Figure 8). In general, the *Protoperidinium* spp. also had the most weight at all stations as presented during the SW sampling. There are seventeen dinoflagellate species that were absent from the study sampling that included *Prorocentrum pyriforme*, *Dinophysis hastate*, *Histioneis* sp., *Ornithocercus stenii*, *Gymnodinium sanguineum*, *Gymnodinium* sp., *Ceratium contortum*, *C. horridum*, *C. limulus*, *C. macroceros*, *C. platycorne*, *C. vulture*, *Gonyaulax digitale*, *G. monacantha*, *Protoperidinium claudicans*, and *Dinothrix paradoxa*.

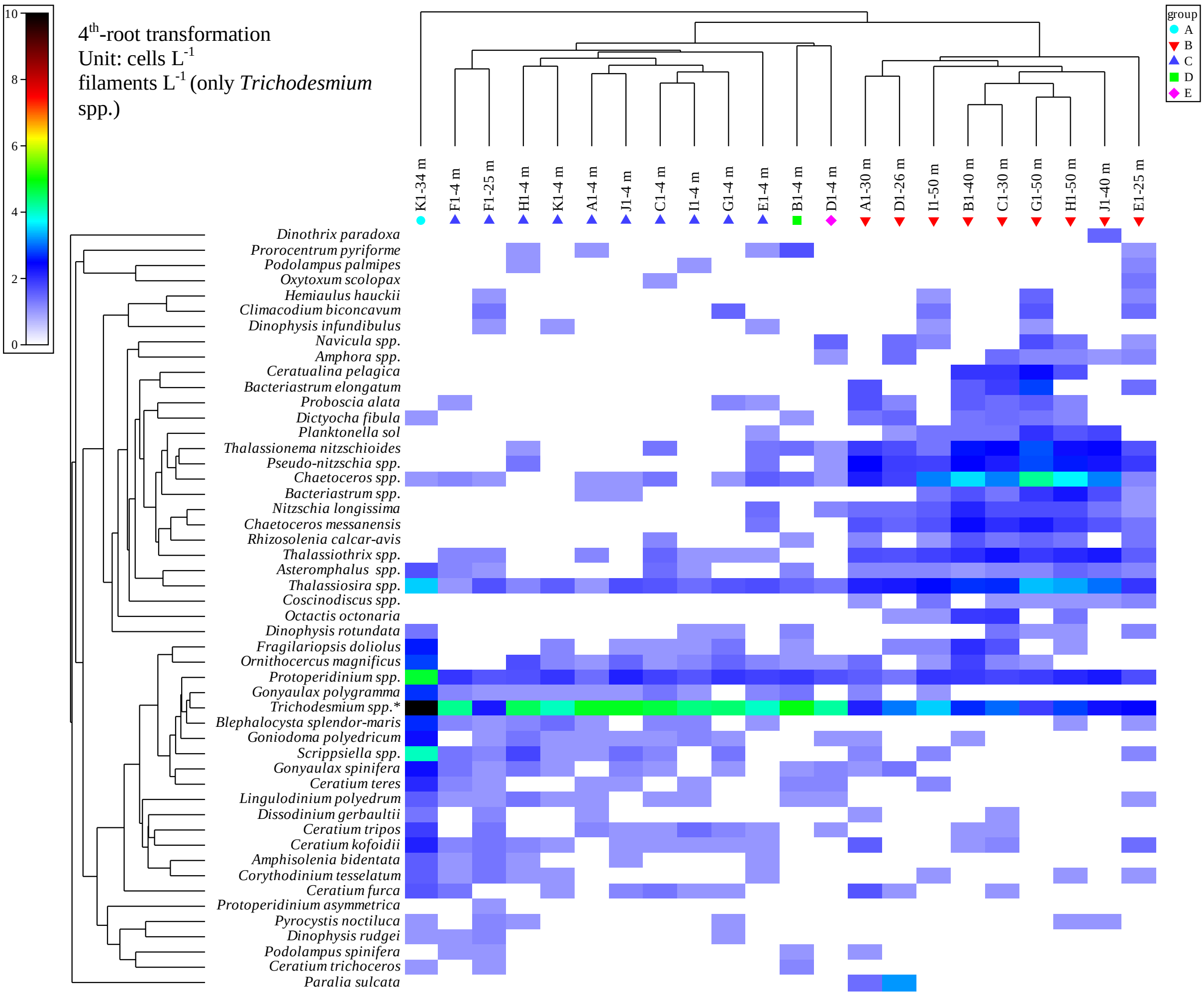


Figure 7. Shade plot of abundance (50% reduce species set off) for the southwest monsoon samples with linear spectrum scale intensity proportional to 4th-root transformed. Letters and numbers indicate the sample stations and sampling depths.

3.5 Correlation between phytoplankton and environments

Environmental variables that explained the variance in the abundance of phytoplankton taxa were investigated using RDA. The ordination diagram in Figure 9 revealed associations between each taxon and the explanatory variables. Proximity of taxa to the environmental variables (arrows) in the same or opposite direction suggests negative or positive correlations, whereas no proximity suggests a weak or no correlation and a longer arrow represent a stronger correlation.

3.5.1 Southwest monsoon

The associations in the ordination diagram (Figure 8A) show that the abundance of marine diatoms (heterokontophyta) was correlated positively with environmental factors (salinity and fluorescence) and chemical concentrations (TN, TP, ammonia, phosphate, nitrite, nitrate, and silicate) and high abundance occurred at the FM depth. Dinophyta and cyanophyta groups dominated in water where PAR values were high. Moreover, these groups were found in relatively warmer waters and several high environmental factors (oxygen saturation, dissolved oxygen, pH, and TSS). The diatom group was negatively correlated with water temperature. Water temperature was inversely correlated with all nutrient concentrations which indicated that the maxima concentrations were related to depth as this would have supported it from being concentrated.

The x axis of the analysis explained most of the variance (eigenvalue=85.3%, cumulative percentage variance between abundance and environmental parameters=88.1%), whereas all canonical axes explained 99.2% of the variance. This means a) the arrows displayed closer to the x axis explained most of the variability in the data and b) the environmental variables explained almost 100% of the variation of the taxa, when all four axes were analysed together.

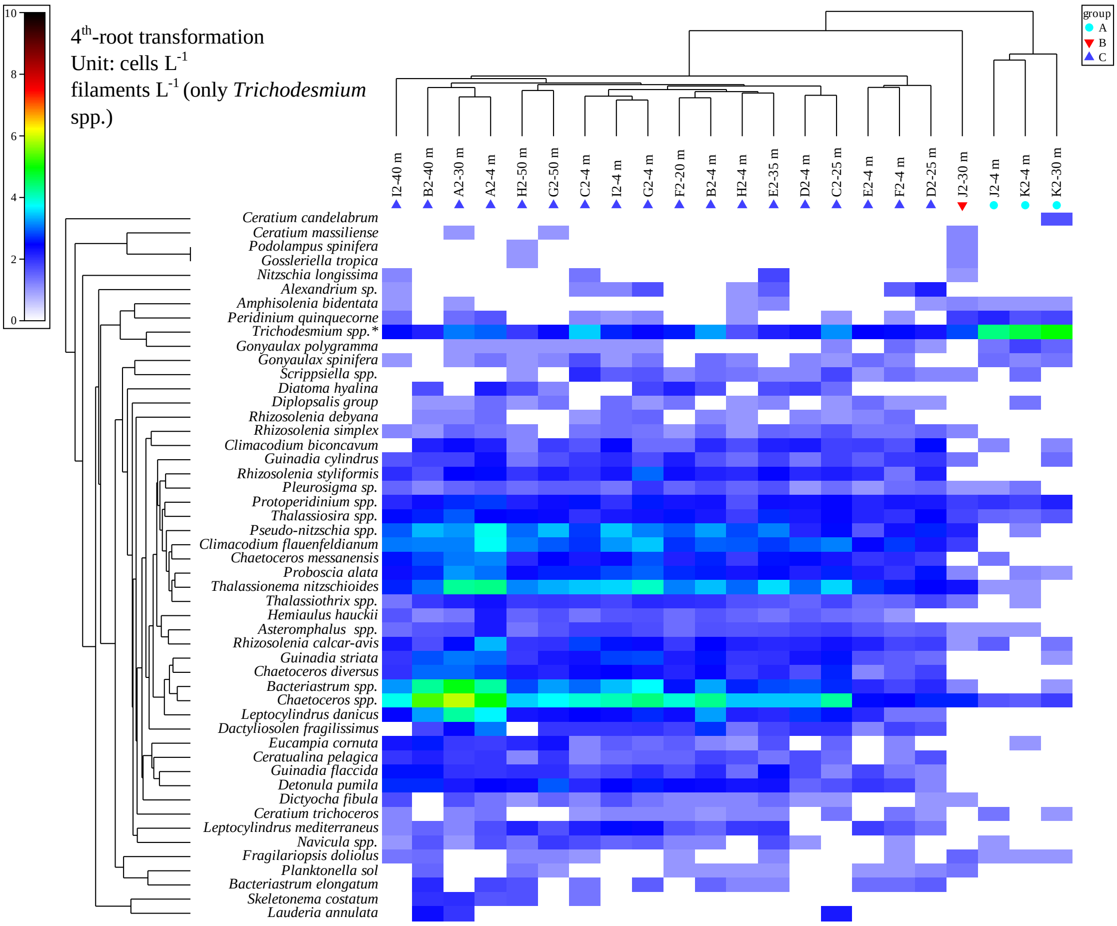


Figure 8. Shade plot of abundance (50% reduced species set off) for the northeast monsoon samples with linear spectrum scale intensity proportional to 4th-root transformed. Letters and numbers indicate the sample stations and sampling depths.

Forward selection indicated that from all fifteen environmental parameters included in the analysis, only seven environmental factors explained the variance in the phytoplankton group when analysed together. When all the forward selected variables were analysed together (conditional effects, referred as λ_a), the salinity was the most significant explanatory variable (λ_a=0.72, P=0.001), followed by silicate concentration (λ_a=0.08, P=0.002), dissolved oxygen (λ_a=0.03, P=0.065), oxygen saturation (λ_a=0.03, P=0.048), nitrate (λ_a=0.02, P=0.071), pH (λ_a=0.02, P=0.035), and PAR (λ_a=0.02, P=0.072). Other environment factors (TSS, nitrite, TN, flu-orescence, temperature, TP, ammonia, and phosphate) were not significantly explanatory variables and possibly did not influence the phytoplankton abundance pattern along the Si-milan Island transect during the SW 2007.

3.5.2 Northeast monsoon

The associations in the ordination diagram (Figure 8B) show that the abundance of *Trichodesmiun* spp. (cyanophyta) was correlated positively with several environmental factors (temperature, PAR, dissolved oxygen, pH, salinity, and fluorescence) and chemical concentrations (nitrate and silicate). Dinophyta and heterokontophyta groups dominated in water where ammonia and nitrite concentrations were high. Moreover, these groups had an inverse positive correlation with cyanophyta. TP and phosphate concentrations were inversely correlated with all phytoplankton groups which indicated these nutrients were not related to phytoplankton abundance during the NE. The x axis of the analysis explained most of the variance (eigenvalue=75.5%, cumulative percentage variance between abundance and environmental parameters=88.7%), whereas all canonical axes explained 99.3% of the variance. Forward selection indicated that from all 14 environmental parameters included in the analysis, only six environmental factors explained the variance in the phytoplankton group when analysed together. When all the forward selected variables were analysed together (conditional effects, referred as λ_a), the PAR value was the most significant explanatory variable (λ_a=0.22, P=0.020), followed by fluorescence concentration (λ_a=0.12, P=0.033), pH (λ_a=0.08, P=0.038), TP (λ_a=0.12, P=0.033), temperature (λ_a=0.07, P=0.073), and nitrite (λ_a=0.11, P=0.077). Other environmental factors (nitrate, silicate, ammonia, TSS, TN, dissolved oxygen, phosphate, and silicate) were not significantly explanatory variables and possibly did not influence the phytoplankton abundance pattern during the NE.

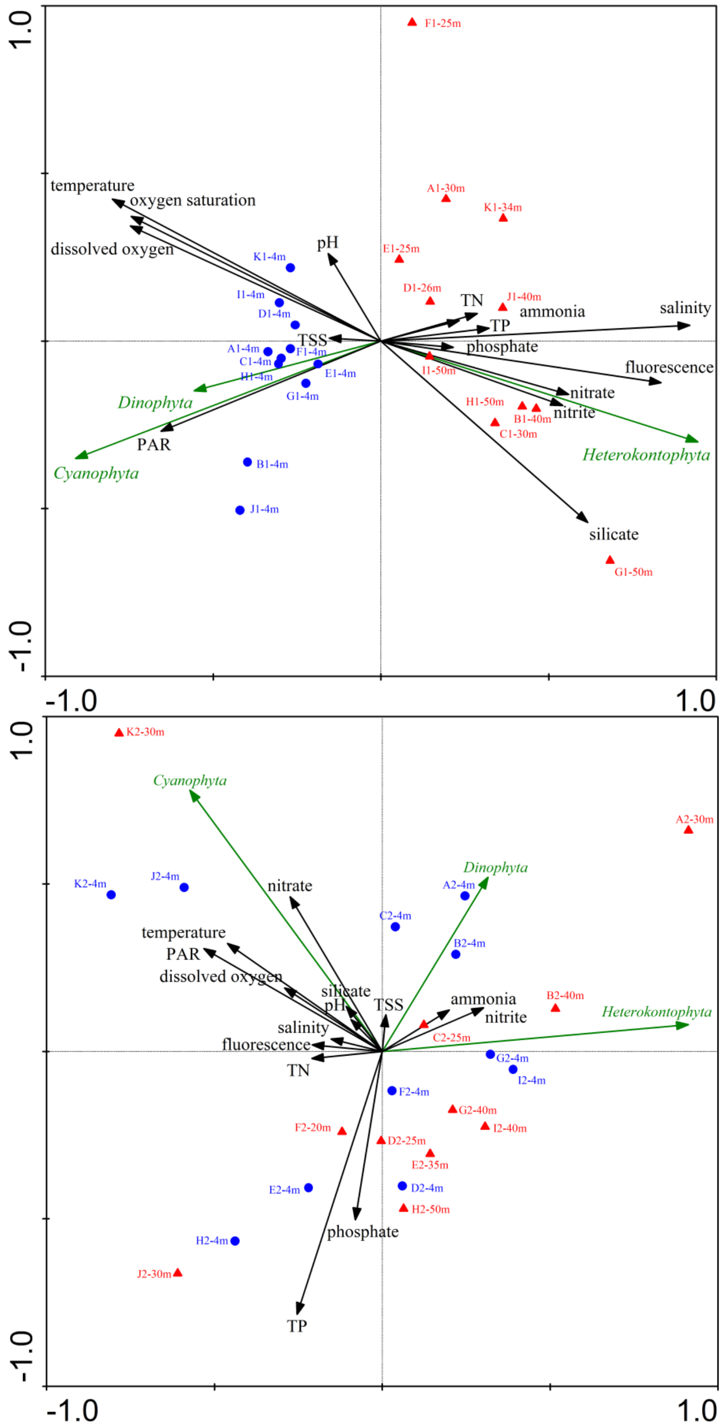


Figure 9. Ordination diagram generated from redundancy analysis (RDA) along the Similan Island transect, Andaman Sea in October 2007 (A) and in March 2008 (B). Triplot represents phytoplankton taxa (green lines), the significant explanatory variables (black lines) and sampling depths (close colour symbol; blue=surface, red=FM).

Increased availability of sufficient light levels and nutrient concentrations led to faster growth rates of diatoms during the NE. Along both transects the diatoms dominated in waters at the FM depth that was rich in nutrient concentrations as reported by Paul *et al.* (2008) this group led below 40 m in the Bay of Bengal and by Nielsen *et al.* (2004) in the Andaman Sea off Phuket. Forced by nutrient limitations, competetion of the species regulated species diversity and dominance which resulted in their predominance in this area.

4. Conclusions

The present study highlights the marine phytoplankton composition and distribution, and the relationship between the phytoplankton community and environmental factors observed during the SW (October 2007) and the NE (March 2008) along the transect across the Similan Islands in the Andaman Sea. The dominant phytoplankton groups in the SW were the diatoms at the surface and *Trichodesmium* spp. at the FM depth while the diatoms were prevalent in both sampling depths in the NE. The nutrient availability and physical variables showed a correlation with phytoplankton abundance during both sampling periods. However, further investigations are needed to understand phytoplankton community response to the changing trace elements and their effect on the higher trophic levels in the Andaman Sea.

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