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Environmental Gradients Regulate the Spatio-temporal Variability of Phytoplankton Assemblages in the Can Gio Mangrove Biosphere Reserve, Vietnam

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Abstract – This paper covers spatial and temporal variation in phytoplankton communities and physico-chemical variables in the Can Gio Mangrove Biosphere Reserve (CGMBR), Vietnam, based on field measurement conducted monthly at nine stations during February 2009 to January 2010. Species diversity, richness and phytoplankton abundance were calculated. Canonical Correspondence Analysis (CCA) was used to investigate the relationship between environmental factors and phytoplankton community. A total of 126 species were recorded with a clear dominance of Bacillariophyceae, which formed about 76.4% of the total phytoplankton counts with an annual average of 44.900 cells/L. Other algal classes like Dinophyceae, Cyanophyceae and Chrysophyceae sustained low counts, forming collectively about 14% of the total abundance of phytoplankton. Although *Chaetoceros* and *Coscinodiscus* were the most dominant genera, *Schroederella* and *Skeletonema* showed high abundance during the studied period. Among the nine environmental parameters tested in this study, salinity, nitrate and ammonium were found to be significantly different between two seasons. On the other hand, no significant difference was found between stations for the studied variables. Results of CCA indicated that phytoplankton assemblage in the CGMBR was influenced by salinity, nitrate and phosphate concentration. This is the first study simultaneously investigating the phytoplankton communities and their environment in this area and it is essential in order to set up the baseline of future studies.

Keywords – phytoplankton, mangrove zones, diversity indices, seasonal successions

1. Introduction

Plankton communities are primary producers of many marine and freshwater food webs (Nassar et al. 2015). They contribute approximately 50% of global primary production (Boopathi et al. 2015). Their community composition and structure undergo continual changes in aquatic systems due to varying environmental conditions (Reynolds 2006). Hydrological conditions affecting the phytoplankton structure include nutrients, light, turbidity, temperature and salinity (Nassar et al. 2015). Phytoplankton are known to exhibit rapid responses to changes in environmental conditions and are therefore commonly used as excellent bio-indicators in coastal ecosystems (Li et al. 2014; Nassar et al. 2015). Their spatial and temporal distribution is therefore essential in understanding community dynamics and biological processes in marine ecosystems (Ward et al. 2014). In addition, recent climate changes could affect ocean ice cover, temperature, precipitation, and circulation, and could lead to drastic changes in the community structure, composition, and productivity of phytoplankton (Harding et al. 2015; Bussi et al. 2016). An estimate of the phytoplankton standing stock can provide useful information on biological production. On the other hand, any changes in the water quality parameters will directly affect the community structure and abundances of phytoplankton.

In the estuary and coastal waters, salinity and nutrients are two main environmental variables influencing the phytoplankton communities (Nche-Fambo et al. 2015). For nutrients, phosphate was found to be the most important factor influencing phytoplankton composition in the Gulf of Khambhat, India (George et al. 2012) and in the Changjiang Estuary, China (Gao and Song 2005), whereas nitrogen availability increased the phytoplankton abundance in the İzmit Bay, Turkey

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(Aktan et al. 2005). In contrast, higher algal diversity was found in the pre-monsoon period when salinity and nitrate concentrations were low in the Bay of Bengal (Thangaradjou et al. 2012). Furthermore, water temperature was reported to be the key factor influencing bloom formation of dinoflagellate in the Nauset estuary, USA (Ralston et al. 2014) while salinity, dissolved oxygen and pH were responsible for the variations in phytoplankton and zooplankton community structure in Mediterranean Sea (Heneash et al. 2015). Given these varied results, the determination of the key environmental factors driving primary production in coastal water continues to be actively discussed. However, there is still a limited number of studies on the phytoplankton community structure, dynamics and resilience in estuary systems of Southeast Asia, especially in Vietnam's East Sea.

Estuaries associated with mangrove forests are one of the vital coastal ecosystems, which exist only in tropical and subtropical countries (Kuenzer and Tuan 2013). Mangroves provide nutrients for phytoplankton growth, thus enhancing the secondary production and promotion of commercial fishery production (McDonough et al. 2014). However, the large amount of suspended organic/inorganic matter brought into the mangrove by tides and rivers from the marine sources and upper catchment areas, respectively, have damaged the ecological balance of the estuarine ecosystem. Mangrove ecosystems may be affected by anthropogenic activities to various degrees (Halpern et al. 2008). The main objectives of this paper are to describe the phytoplankton community structure, explore the spatial and temporal distribution of species composition and determine the environmental factors that control these elements in the Can Gio Mangrove Biosphere Reserve.

2. Materials and Methods

Study area

The Can Gio Mangrove Biosphere Reserve (CGMBR) (10°22'–10°40'N, 106°46'–107°00'E) spans approx. 72,000 ha

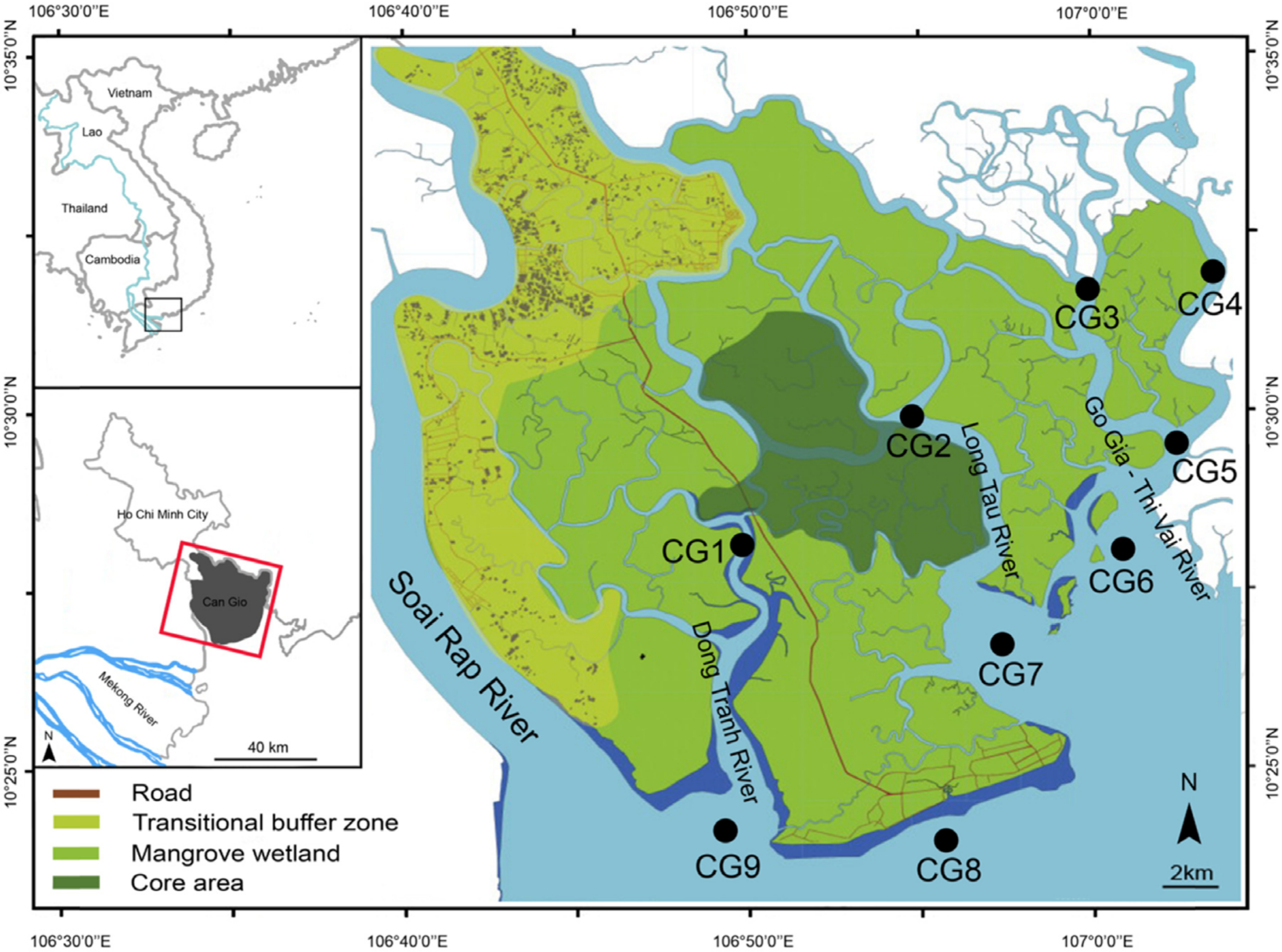

Fig. 1. Map of the Can Gio Mangrove Biosphere Reserve showing the study area. CG stand for Can Gio

and is located 65 km southeast from Ho Chi Minh City, Vietnam (Fig. 1). The area experiences a very dynamic semi-diurnal tidal regime, ranging from 2 to 4 m tidal amplitude depending on the season (Van-Loon et al. 2007). The climate of the Can Gio is typical for tropical monsoonal zones with two distinct seasons. The dry season is from November to April and the rainy season is from May to October. The annual average temperature is 25.8°C, average annual precipitation ranges from 1300 to 1400 mm, and mean annual relative humidity is 80% (Kuenzer and Tuan 2013). As a result of global climate change, the CGMBR has been threatened by sea level rise and a depletion of sediment nutrients (Kuenzer and Tuan 2013).

Physico-chemical parameters

Sampling was carried out between February 2009 and January 2010 along nine sampling stations coded CG1 to CG9 (Fig. 1) on a monthly interval basis. The conventional parameters like water temperature, water pH, water salinity and dissolved oxygen (DO) were measured in situ by using a portable multimeter (Sension156, Hach, USA). For measuring inorganic nutrient parameters, surface water sample was collected using plastic containers (2-L capacity). The plastic containers were rinsed thoroughly with sampling water before use. After filling the containers, they were sealed, kept in an ice-box and transferred to the laboratory for the physico-chemical analysis.

The Total Suspended Solids (TSS) was determined by filtering a defined volume of water samples using pre-weighed filters and drying at 110 ± 5°C until a constant weight was achieved (about 3 hours). The concentration of total suspended solids was then estimated gravimetrically on glass-fiber filters (Whatman GF/C), after drying to a constant weight at 110°C. NO_3^-, NH_4^+, PO_4^{3-} and SiO_2 were determined according to the methods described by APHA (2005).

Biological parameters

Phytoplankton samples were collected from the surface waters by towing a plankton net (mouth size, 0.3 m^2, mesh size, 25 μm). Quantitative samples of the phytoplankton were collected using 60L of raw water samples concentrated to approximately 50 mL through the plankton net in 100 mL vials. Samples were preserved with 3 mL 37–40% formalin, and then identified to species level as far as possible using the standard methods of Fukuyo et al. (1990), Tomas (1997), Wehr et al. (2003), Ton (2009) and Edward and David (2015), and counted using a Sedgewick-Rafter counting chamber (Wetzel and Likens 2000; Lund et al. 1958) under an inverted microscope (CK40, Olympus, Japan) at 200× or 400× magnification.

The classification of phytoplankton into taxonomic groups and verification of currently accepted taxonomic names followed AlgaeBase (Guiry and Guiry 2016).

The dominant species of phytoplankton were determined based on the dominance value and the occurrence frequency of each species by using the equation of Jiang et al. (2014):

$$Y = \left(\frac{n_i}{N}\right) * f_i$$

where, n_i is the number of individuals of species i within a given area in the whole year, N is the total number of individuals of all species within the given area in the whole year, and n_i/N represents the relative proportion of species i. f_i is the occurrence frequency of species i which is calculated by the ratio of the number of samples with species i to the total number of samples within the given area in the whole year.

Data analysis

One-way analysis of variance (ANOVA) was used to test the significance of the differences among the sites based on the transformed water physical and chemical variables and the phytoplankton species structure metrics. The analysis was completed using Tukey's Honestly Significant Difference (HSD) test significant difference. The Pearson correlation analysis was used to determine the correlation among phytoplankton metrics and environmental variables. All statistical analyses were performed using SPSS v.16.0 (IBM Corp., Armonk, NY, USA).

The phytoplankton community structural attributes of species richness Margalef's index (S), the Shannon–Weiner diversity index (H'), Pielou's evenness index (J') and Simpson's diversity index (D), the commonly used indices in water quality bio-assessment (Agrawal and Gopal 2013), were used to characterize the phytoplankton community at each site. These metrics were calculated by using the PRIMER VI analytical package developed by Plymouth Marine Laboratory, U.K.

Canonical Correspondence Analysis (CCA) was used to determine the major patterns of variation in species composition data and to elucidate the main environmental driving force in the phytoplankton community (Braak and Verdonschot 1995). All variables were log-transformed to normalize their distributions before analysis. Monte Carlo permutation test was used to reduce further the environmental variables to those correlated significantly with the derived axes. Only those taxa that were observed in more than 5% of the samples were included in analyses of taxa abundances to minimize the influence of rare taxa. All ordinations were performed using CANOCO version 4.5 for Windows (Leps and Smilauer 2003).

3. Results

Environmental conditions

The monthly average and standard deviation of physico-chemical variables from the surface waters of the CGMBR are shown in Fig. 2. The results of One-way ANOVA and Tukey's HSD test showed that the means of salinity, nitrate and ammonium in the dry season were significantly different to the rainy season ($p < 0.05$). But no significant difference in other environmental variables was detected between the two seasons ($p > 0.05$). The surface water temperature ranged from 28.5 to 31.9°C. The monthly fluctuations in the pH varied from 6.5 to 8.2. Salinity was significantly different between the two seasons and ranged from 23.8 to 31.3 ppt with the minimum in the rainy season and the maximum in the dry season. The mean dissolved oxygen values were high during rainy and dry seasons and ranged from 6.3 to 7.9 mg/L, respectively. TSS covered a wide range of concentrations and ranged from 31 to 112 mg/L. Nutrients such as nitrate and ammonium exhibited a clear variation with higher values in the dry season and ranged from 0.6 to 1.5 mg/L and from 0.15 to 0.3 mg/L, respectively. In contrast, inorganic phosphate did not show a clear difference between the dry and the rainy seasons and ranged from 0.15 to 0.32 mg/L. Silicate varied from 2.8 to 5.2 mg/L during the sampling period.

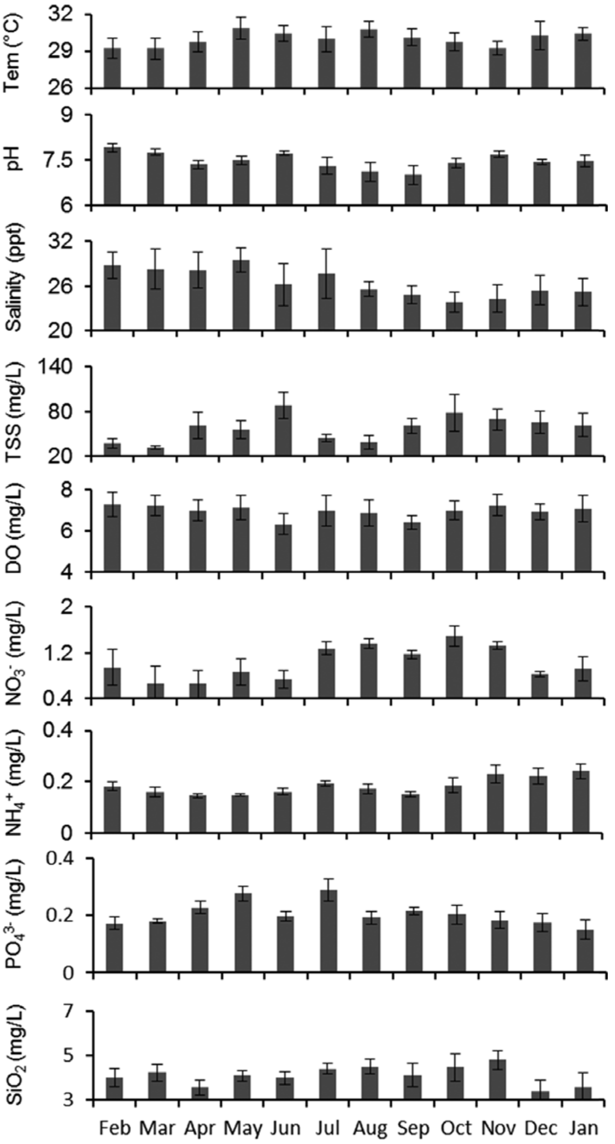

Fig. 2. Mean values of physico-chemical variables concentrations from the surface waters of the Can Gio Mangrove Biosphere Reserve. Data were presented as mean values ± SD

Species composition of phytoplankton

In total, 126 species of phytoplankton were identified, and species belonging to four groups, namely, diatom, dinoflagellates, blue greens and golden-brown were recorded. Of these,

Table 1. Species diversity and phytoplankton composition (%) in the Can Gio Mangrove Biosphere Reserve. Taxonomic classification of the phytoplankton taxa followed Guiry and Guiry (2016)

Phylum	Class	Species diversity	Composition, %	Relative abundance, %
Cyanobacteria	Cyanophyceae	7	5.6	3.9
Dinophyta	Dinophyceae	19	15.1	12.5
Bacillariophyta	Bacillariophyceae	32	25.4	13.7
	Coscinodiscophyceae	29	23.0	21.4
	Mediophyceae	38	30.2	48.3
Ochrophyta	Dictyochophyceae	1	0.8	0.2
Total		126	100	100

diatoms represented the most diverse group with 99 species, dinoflagellates formed the next group with 19 species, blue greens with 7 species and golden-brown came last with 1 species in all the stations (Table 1). The most dominant according to number of taxa, in almost all locations, was *Chaetoceros* (11 taxa). Other genera such as *Coscinodiscus*, *Odontella*, *Rhizosolenia* exhibited high species richness. The species diversity of dinoflagellates, the second largest contributor, was represented by genus *Protoperidinium* with 6 taxa and 4 species of *Ceratium*.

The list of the most abundant species from the CGMBR is shown in Table 2. Among the diatoms, *Odontella obtusa*, *O. reticumlum*, *Schroederella schroederi* and *Skeletonema costatum* were found to be the commonly occurring species in the samples. Among dinoflagellates, *Ceratium furca, Prorocentrum micans*, and among blue greens algae, *Trichodesmium erythraeum,* showed consistency in their occurrence in the samples collected in the CGMBR (Table 2).

The temporal and spatial distributions of phytoplankton abundance in the Can Gio Mangrove Biosphere Reserve are shown in Fig. 3. Total phytoplankton abundance varied widely from 12.207 up to 48.824 cells/L (23.852 ± 8.887 cells/L on average) across the studied area. The highest abundances of phytoplankton were found during dry months and in the outer sites (CG6 and CG9), while the lowest abundances were found during rainy months and were associated with sites in the inner zone (CG1 and CG3) of the CGMBR (Fig. 3A, B). High abundances of phytoplankton were supported by the development of small-sized chain-forming diatoms *Chaetoceros* spp., *Schroederella* spp., and *Skeletonema* sp. In general, diatoms numerically prevailed in terms of phytoplankton abundance and contributed over 83% to the total phytoplankton abundance, followed by dinoflagellates (12.5%), blue greens (4%) and golden-brown (< 1%) (Fig. 3A, B).

Biological indices

The average variation of biological indices is given in Table 3. The species richness Margalef's index (S) ranged between 3.32 and 3.99 with an average of 3.72. The Shannon–Weiner diversity index (H′) varied from 1.71 to 2.59. Species Pielou's evenness index (J′) fluctuated from 0.47 to 0.74. Simpson's diversity index (D) varied from 0.59 to 0.88 with the maximum in September at CG4 and the minimum in April at CG8 (Table 3). The Pearson correlation displayed significant ($p < 0.05$) and positive correlations in terms of the taxon richness in relation to ammonium, PO_4^{3-} and SiO_2 concentrations; whereas taxon richness was negatively correlated with abundance and salinity concentrations. Phytoplankton

Table 2. List of the 36 most abundant species from the Can Gio Mangrove Biosphere Reserve. The code number of species was used in CCA analysis

Code	Specific name	Dominance value
	Cyanophyta	
1	*Trichodesmium erythraeum* Ehrenberg	0.0016
	Chryophyta	
2	*Dictyocha fibula* Ehrenberg	0.0005
	Bacillariphyta	
3	*Actinoptychus annulatus* (Wallich) Grunow	0.0036
4	*Amphiprora gigantea* Grunow	0.0008
5	*Asterionella japonica* Cleve	0.0107
6	*Chaetoceros affinis* Lauder	0.0039
7	*Chaetoceros curvisetus* Cleve	0.0078
8	*Coscinodiscus asteromphalus* Ehrenberg	0.0021
9	*Coscinodiscus bipartitus* Rattray	0.0097
10	*Coscinodiscus gigas* Ehrenberg	0.0004
11	*Coscinodiscus jonesianus* (Greville) Ostenfeld	0.0032
12	*Coscinodiscus lineatus* Ehrenberg	0.0068
13	*Coscinodiscus marginatus* Ehrenberg	0.0005
14	*Coscinodiscus radiatus* Ehrenberg	0.0064
15	*Coscinodiscus subtilis* Ehrenberg	0.0017
16	*Ditylum brightwellii* (T. West) Grunow	0.0087
17	*Ditylum sol* Grunow	0.0051
18	*Melosira sulcata* Ehrenberg	0.0027
19	*Nitzschia longissima* (Bréb.) Ralfs	0.0022
20	*Nitzschia paradoxa* (Gmelin) Grunow	0.0063
21	*Odontella aurita* (Lyngbye) Brébisson	0.0168
22	*Odontella heteroceros* Grunow	0.0015
23	*Odontella mobilensis* (J. W. Bailey) Grunow	0.0024
24	*Odontella obtusa* (Kütz) Hust	0.0209
25	*Odontella regia* (Schultze) Ostenfeld	0.0016
26	*Odontella reticulum* (Ehr.) Boyer	0.0345
27	*Rhizosolenia imbricata* Brightwell	0.0007
28	*Rhizosolenia setigera* Brightwell	0.0020
29	Schroederella schroederi (Bergon) Pavillard	0.1311
30	*Skeletonema costatum* (Grev.) Cleve *Thalassionema nitzschioides* (Grunow)	0.0535
31	Mereschkowsky	0.0125
32	*Thalassiothrix frauenfeldii* Grunow	0.0050
33	*Triceratium scitulum* Brightwell	0.0075
	Dinophyta	
34	*Ceratium furca* (Ehrenberg) Claparède et Lachmann	0.0222
35	*Dinophysis caudata* Saville-Kent	0.0005
36	*Prorocentrum micans* Ehrenberg	0.0006

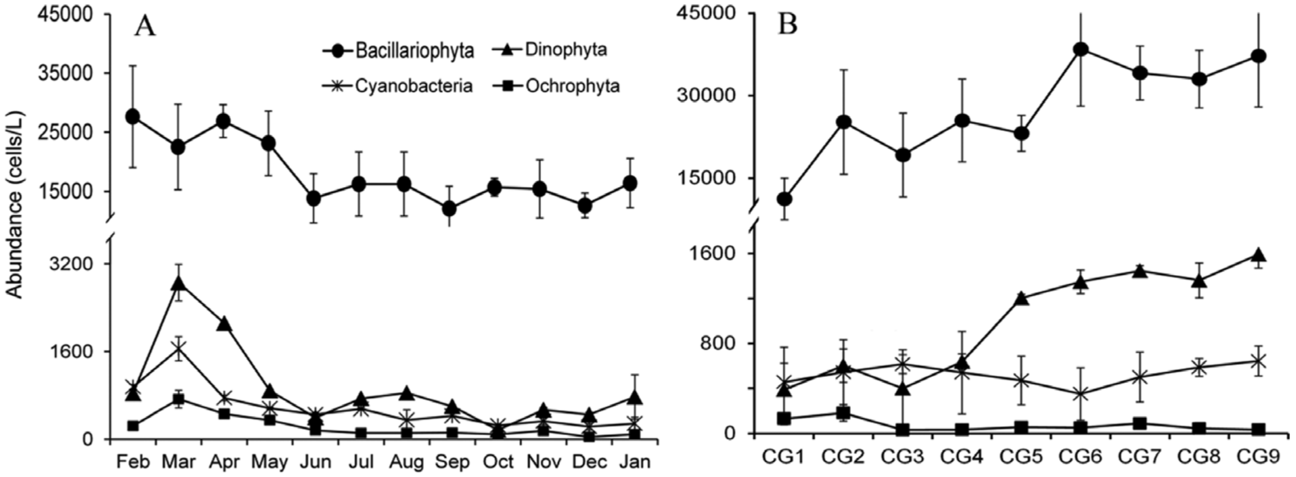

Fig. 3. The temporal (A) and spatial (B) distributions of phytoplankton abundance in the Can Gio Mangrove Biosphere Reserve. Data were presented as mean values ± SD

Table 3. The average temporal variation of diversity indices (S, H', J', D) in the Can Gio Mangrove Biosphere Reserve

	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
S	3.64	3.53	3.86	3.32	3.41	3.99	3.94	3.79	3.90	3.86	3.70	3.71
H'	2.30	1.91	1.71	1.75	2.36	2.18	2.20	2.60	2.40	2.37	2.23	2.33
J'	0.65	0.53	0.47	0.50	0.68	0.63	0.62	0.74	0.69	0.66	0.64	0.67
D	0.81	0.69	0.59	0.62	0.82	0.76	0.74	0.88	0.83	0.83	0.78	0.79

Table 4. Pearson correlation and p value (*$p \leq 0.05$, **$p \leq 0.01$) calculated for all variables in the CGMBR (only significant variables were showed)

	Abundance	Temperature	Salinity	TSS	NO_3^-	NH_4^+	PO_4^{3-}	SiO_2
Taxon richness	-0.551**	-0.048	-0.413*	0.139	-0.183	0.345*	0.242*	0.365*
Abundance	1.000	0.021	0.576**	-0.215*	0.507**	-0.141	0.578**	-0.138

abundance was positively correlated with salinity, NO_3^- and PO_4^{3-} but negatively correlated with TSS (Table 4).

Relationship of phytoplankton assemblages to environment variables

Of the 126 phytoplankton species identified in this investigation, 36 taxa were included in data analysis using CCA (Table 2; Fig. 4). Although there were significant correlations between total abundance and taxa richness with salinity, TSS, NO_3^-, NH_4^+, PO_4^{3-} and SiO_2 concentrations, the CCA showed that individual taxa respond differently to these variables. Results from a CCA analysis for phytoplankton data in dry months based on normalized environmental variables showed that axis 1, which explained 49.7% of the variation, was positively correlated with salinity, PO_4^{3-} and NO_3^- concentrations but negatively correlated with TSS, while the second axis (accounting for 21.3% of the variance) was related to NH_4^+ and temperature. The trends related to salinity, TSS, PO_4^{3-} and NO_3^- almost completely governed the major phytoplankton species in the dry season (Fig. 4A). In the wet season, the first 2 axes explained about 58.6% of the variance for phytoplankton assemblages (Axis 1 accounting for 35.2% and axis 2 accounting for 23.4% of the variance). Axis 1 was positively correlated with PO_4^{3-}, NO_3^-, SiO_2, salinity and to a lesser extent DO. Axis 2 was correlated with NH_4^+ and TSS (Fig. 4B). The trends of main nutrients (PO_4^{3-}, NO_3^- and SiO_2) and salinity were regulated almost half of all major phytoplankton species in the wet season (Fig. 4B).

4. Discussion

Although the CGMBR has been well studied for its biodiversity and ecosystem services (Ngo et al. 2007; Kuenzer and Tuan 2013) there has been no previous study on phytoplankton community in this area. The phytoplankton community in the CGMBR is composed mainly of diatoms, dinoflagellates

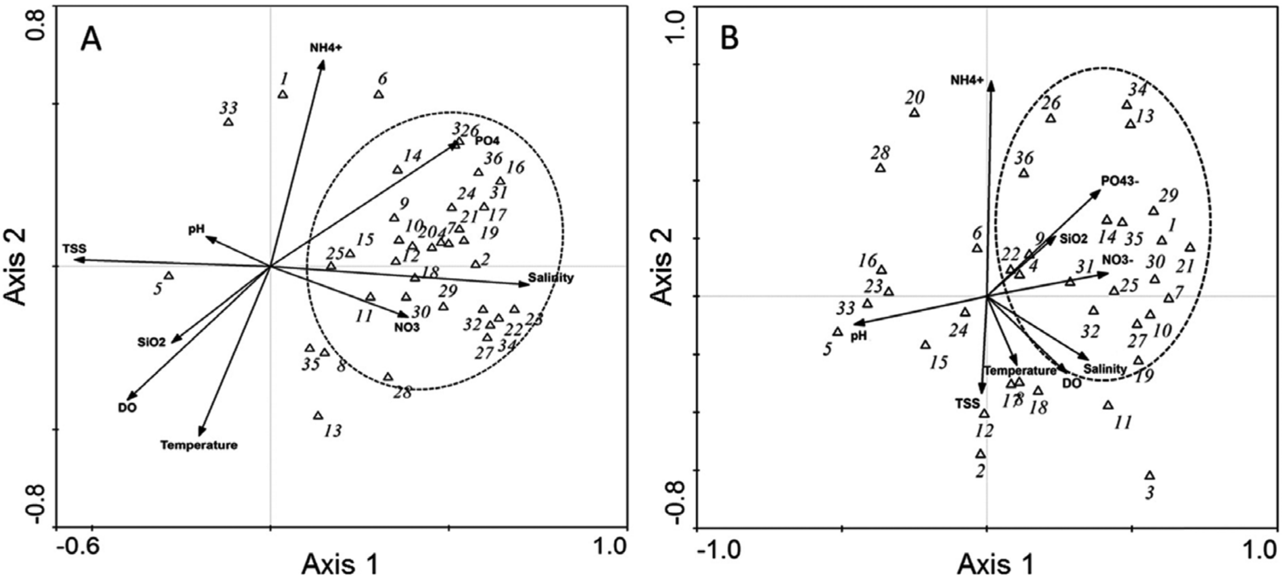

Fig. 4. Biplot of canonical correspondence analysis relating abundance of dominant taxa and physico-chemical variables in (A) dry season and (B) rainy season. The first axis was determined as the horizontal axis and the second axis was determined as the vertical axis

and cyanobacteria, which agrees well with previous studies from other tropical estuarine systems (Costa et al. 2009; Canini et al. 2013; Arumugam et al. 2016). The total number of species (126) identified in this study was higher than in the Mindanao and Pichavaram mangroves (Rajkumar et al. 2009; Canini et al. 2013), within the 130–132 species found in the Pearl River estuary (Huang et al. 2004), but lower than in the Tagus estuary (Brogueira et al. 2007). These kinds of variations could be attributed to differences in the ecological distribution of the types of organisms as well as to climatic and geographical circumstances.

Among the vast array of diatoms and dinoflagellates identified in this region, *Schroederella schroederi* and *Skeletonema costatum* were the two most common species, and they predominated almost throughout the year. Although *S. schroederi* is rarely reported elsewhere, the euryhaline species *S. costatum* has been reported to dominate or commonly occur from temperate to tropical estuaries (Arumugam et al. 2016; Brogueira et al. 2007; Rajkuma et al. 2009).

The current study revealed the typical pattern of abundance for many phytoplankton species in the study area, whereby abundance peaks in the dry season and lower densities in the wet season were recorded. Lu and Gan (2015) recorded a similar observation in the Pearl River Estuary: during the dry season when river discharge was relatively small, the phytoplankton growth rate was greater than in wet season. The lower abundance recorded during the wet season could be attributed to further dilution of essential growth nutrients in the area and stable hydrographical conditions (Rajkumar et al. 2009; Barroso et al. 2016). Among all the stations, maximum density was recorded at marine outer sites and minimum density was recorded at inner sites. These variations are well pronounced in the sheltered system of estuarine waters (Perumal et al. 2009; Rajkumar et al. 2009).

Previous studies have shown that species diversity may decrease with an increase in population abundance (Boopathi et al. 2015; Arumugam et al. 2016). The present study indicated that the diversity indices (S, H’, J’, D) in the dry season were a little lower than in the rainy season. Most likely, a decrease in species diversity is associated with higher salinity and anthropogenic contaminants in the dry season. Thus biological indices can be used for the evaluation of water quality in the CGMBR. The results of phytoplankton metrics showed that ecological quality status in the CGMBR was classified as moderate status based on the classification systems of Agrawal and Gopal (2013).

The environmental parameters such as temperature, pH and DO concentration play an important role in determining the phytoplankton community succession and then diversity, favoring or limiting the growth of different groups of phytoplankton (Iain and David 2009). The climate of the CGMBR is typical for tropical monsoonal zones. Hence the water temperature is often high and did not vary much over the seasons. The pH values ranged from slightly acidic to slightly alkaline and were within a similar range observed in the Pichavaram and Muthupet mangroves in India (Rajkumar et al. 2009; Arumugam et al. 2016), and in the Pernambuco mangrove in Brazil (Koening and Macêdo 1999). DO and TSS were a little higher whereas the salinity was lower compared with the variables in the Muthupet, Pichavaram and Pernambuco mangroves. This might be due to the freshwater discharge from the Soai Rap, Dong Tranh, Long Tau and Go Gia-Thi Vai river systems combined with significant mixing from the intertidal zone of the mudflat along the coastal line (Schwarzer et al. 2016).

In shallow eutrophic and turbid estuary systems, light availability (Kromkamp et al. 1995; Gameiro et al. 2011) and salinity (Lionard et al. 2005; Reynolds 2006; Heneash et al. 2015) seem to play a key role in the control of biomass-specific productivity. The light attenuation by suspended sediments confines the photic zone to a small fraction of the water column (Uncles and Cloern 1987). Therefore, light limitation and TSS are major factors controlling phytoplankton growth. In addition, salinity was reported as being a major factor determining phytoplankton distribution (Nche-Fambo et al. 2015). Fewer species were also recorded with an increase in salinity in the CGMBR ($r = -0.413, p < 0.05$), since there may be not many species able to osmoregulate to adapt to hypersaline environments. This result agreed well with Nche-Fambo et al. (2015) who showed low values of taxon richness but higher abundance with an increase in salinity in several South African estuaries. The CGMBR is constituted by several shallow estuaries and creeks where suspended matter dynamics is strongly governed by tidal action, current velocity and rainfall (Schwarzer et al. 2016). TSS was negatively correlated with cell density ($r = -0.215$, $p < 0.05$), while salinity was positively correlated with phytoplankton abundance ($r = 0.576, p < 0.01$) during the present study. The results of this study agreed well with other studies published on other turbid estuaries, such as the Pearl River estuary (China) (Huang et al. 2004), Changjiang Estuary (China) (Gao and Song 2005), and Philippine mangrove estuary (Canini et al. 2013) where phytoplankton abundances generally decrease in the landward direction, where the TSS is high and salinity is low.

Besides light, salinity and TSS, nutrients such as nitrogen, phosphorus and silicate concentrations are very important factors that regulate the phytoplankton assemblages (Huang et al. 2004; Nche-Fambo et al. 2015), among which phosphorus is the major fundamental regulating factor (Gao and Song 2005; Brogueira et al. 2007; Li et al. 2014). Phosphate concentration in coastal waters was influenced by the mixing of the freshwater with the seawater in the land–sea interaction zone (Satpathy et al. 2010). On the other hand, physical mixing, factors like adsorption of reactive silicate from suspended sedimentary particles, chemical interaction with clay minerals, and biological removal and utilization by phytoplankton can significantly influence the spatio-temporal variation of silicate (Satpathy et al. 2010). Nutrients such as nitrate, ammonium, inorganic phosphate and silicate were abundant in the CGMBR (Fig. 2). This might be due to the discharge of nutrient-rich water from urban sources and the intensification of agriculture and land runoff (Davidson et al. 2014). In addition anthropogenic activities associated with shrimp farms may be factors that contribute to the higher amount of inorganic nitrate and phosphate (McDonough et al. 2014). It has been suggested that in coastal waters phytoplankton counts at the surface are positively correlated with inorganic nitrogen and phosphate but negatively correlated with SiO_4 (Li et al. 2014; Ly et al. 2014; Nassar et al. 2015). In the present study, phytoplankton abundance was positively correlated to nitrate and phosphate.The results of this study were also consistent with previous reports that salinity, turbidity and nutrients are the main environmental variables influencing the abundance of the phytoplankton community in temperate and tropical estuary systems (Brogueira et al. 2007; Canini et al. 2013).

Many approaches have been used to estimate the influence of nutrients on the production of phytoplankton (Howarth and Marino 2006; Ly et al. 2014; Choudhury and Bhadury 2015). Lower nitrate concentration in the dry season may limit phytoplankton growth in the CGMBR. Probably, nitrogen acted as a limiting factor on phytoplankton growth. It is known that the elemental N:P, N:Si and Si:P ratios for the growth of phytoplankton under optimal conditions are 16:1, 1:1 and 16:1, respectively, as proposed by Redfield (1960). This has been widely used by many authors, in spite of criticisms, to infer which of the nutrients could be potentially limiting phytoplankton growth (Tett et al. 1985; Trommer et al. 2013; Spilling et al. 2015). However, recent studies have demonstrated that phytoplankton growth seems to occur over a wide range of N:P:Si ratios, ranging from 5 to 34 (Geider and La Roche 2002; Garnier et al. 2010). This study indicated that the N:P and Si:P ratios in the CGMBR ranged from 4 to 9 and from 15 to 28, respectively (data not shown).

Based on the above mentioned approach, the present study proved again that nitrogen acted as a limiting factor on phytoplankton growth in the CGMBR.

CCA results indicated that salinity, nitrate, phosphate and TSS accounted for most of the explained variance in the community composition and abundance of phytoplankton (Fig. 4). This was also confirmed by the observation of Huang et al. (2004) whereby different salinity and nutrient levels result in variations in taxonomic diversity and phytoplankton abundance in the Pearl River estuary. In this study, an increase in salinity had a stronger effect on the algal community composition than nutrients (N, P ad Si). Nursuhayati et al. (2013) also reported that salinity gradients in estuary systems were more important than variation in nutrient concentrations in determining the composition of phytoplankton communities. Probably, salinity is the most common factor affecting phytoplankton community in many river estuaries.

5. Conclusions

Over the course of twelve months, this study demonstrated that there was a spatial and seasonal variation in phytoplankton assemblages that was related to environmental parameters in the CGMBR. The main species contributing to the phytoplankton composition were *Coscinodiscus* spp., *Chaetoceros* spp., *Nitzschia* spp., *Odatella* spp. and *Rhizosolenia* spp. Species composition and abundance at each site varied with time and space. It became apparent that salinity and nutrients played the most important roles in setting the environmental conditions of the CGMBR and, subsequently, on the distribution and abundance of phytoplankton species in this mangrove biosphere reserve. Salinity and the nutrient enrichment of coastal waters are generally the main factors driving the succession and composition of phytoplankton communities. This study further contributes to our understanding of phytoplankton structure and composition in the Can Gio mangrove ecosystem with respect to environmental variables. Since nutrient enrichment is generally the main factor driving the succession and composition of phytoplankton communities in coastal waters, further work is now needed to identify the sources of nutrients in this region.

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