Phytoplankton and relationship between phytoplankton community and environmental parameters of some water bodies in Soc Trang province

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Abstract:

This study was carried out to evaluate the seasonal variation of phytoplankton and its relationship with environmental parameters of some inland water bodies in Soc Trang province. A total of 171 phytoplankton taxa belonging to Cyanophyta (24 species), Chrysophyta (2 species), Bacillariophyta (65 species), Chlorophyta (43 species), Euglenophyta (34 species), and Dinophyta (3 species) were studied. The phytoplankton species composition during the rainy season was higher than in the dry season, in which Bacillariophyta dominated in both seasons. Surface water quality was classified into class A2 for pH, phosphate, and nitrate whereas class B2 for dissolved oxygen (DO), total suspended solids (TSS), ammonium, chemical oxygen demand (COD), and biochemical oxygen demand (BOD) (according to QCVN 08:2015/BTNMT). Canonical correspondence analysis (CCA) results revealed that environmental factors influenced the phytoplankton community. Of which the factors of pH, electric conductivity (EC), salinity, turbidity, TSS, and phosphate affected the phytoplankton assemblage in both seasons. The results confirm the potential of using phytoplankton as a bioindicator for surface water quality assessment.

Keywords: **correlation, phytoplankton, Soc Trang province, water quality.**

Classification numbers: **5.1, 5.3**

1. Introduction

Phytoplankton, also known as microalgae, are small-sized organisms that live floating in the water. Various species live solitary like *Closterium*, *Navicula*, *Phacus*; colonies like *Volvox*, *Microcystis*, *Merismopedia;* filament like *Oscillatoria*, *Arthrospira, Lyngbya*, and chain like *Melosira, Anabaena, Skeletonema.* They are present in all kinds of water bodies. Phytoplankton play a significant role in aquatic ecosystems because they are the base of several aquatic food webs [1, 2]. Phytoplankton are extremely sensitive to environmental changes, so they are usefully applied to evaluate water quality status [3]. Community structure and abundance of phytoplankton are mainly controlled by nutrient availability and other factors e.g., temperature, light availability, mixing, and current circulation [4]. Analysing basic information from phytoplankton to improve water quality and prevent the occurrence of water blooms has been necessary [5]. Some species of phytoplankton can be considered as an indicator organism of environmental pollution and eutrophication [6].

In Vietnam, phytoplankton have been studied for some time such as several works [7-11]. However, studies on the relationship between the phytoplankton community and environmental parameters are still minimal. T.T. Duong, et al. (2014) [12] reported that suspended solid factors affected the distribution of phytoplankton structure in the Red river. In another study, T.S. Dao (2016) [13] announced the phytoplankton distribution had closely relation to the factors of pH, turbidity, EC, COD, iron, and aluminium in Lak lake, whereas the transparency indicated the most evident correlation with phytoplankton distribution in Bien Ho. T.S. Dao and T. Bui (2016) [14] studied the correlation of species number and biodiversity with environmental parameters in the Vam Co river. T.L. Pham (2017b) [15] described that nutrient concentration and turbidity related to the distribution of phytoplankton structure in the Dong Nai river. Phytoplankton assemblage was affected by nitrate, phosphate, and salinity in the Can Gio mangrove [2].

Soc Trang is one of the provinces in the Mekong delta of southern Vietnam and has relatively high biodiversity.

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The aquatic flora, especially the phytoplankton of Soc Trang province, have not yet been fully explored. The previous investigations reported 82 species of phytoplankton in the Cu Lao Dung mangrove ecosystem in Soc Trang province [16]. However, the overall investigation of phytoplankton and their interaction with environmental parameters have not yet been carried out here. Thus, this study aims to determine the composition, abundance, distribution of phytoplankton, and the relation between phytoplankton and environmental factors in water bodies of the Soc Trang province.

2. Materials and methods

2.1. Study area

Soc Trang is a province in the Mekong delta system, Vietnam. It is surrounded by Tra Vinh, Vinh Long, Bac Lieu, and Hau Giang provinces, and the East Sea. There are 72 km seaside, three main river mouths, and 30,000 ha alluvium ground.

The study was implemented in April (dry season) and October (rainy season) 2020. The samples were collected at eighteen sites in some inland water bodies of Soc Trang province (Table 1, Fig. 1).

Table 1. Coordinates and locations of the sampling sites.

Sampling sites	Local names	Longitude	Latitude
M1	Kenh Xang bridge - Soc Trang city	105°57′51.67	9°36′51.29
M2	30/4 bridge - Soc Trang city	105°58′36.63	9°36′21.90
M3	Maspero bridge - Soc Trang city	105°59′37.78	9°36′31.05
M4	Rach Mop bridge -Nhon My commune, Ke Sach district	106°02′20.91	9°46′43.87
M5	Thanh Loi bridge - My Xuyen district	105°59′57.78	9°33′20.29
M6	Co Co market - My Xuyen district	105°56′25.15	9°25′37.56
M7	Vinh Chau bridge -Vinh Chau town	105°58′49.05	9°19′35.11
M8	Saintard bridge - Soc Trang city	106°02′13.52	9°37′25.72
M9	Ke Sach market, Ke Sach district	105°59′10.60	9°46′08.93
M10	Nhu Gia bridge - Thanh Phu commune, My Xuyen district	105°51′10.52	9°30′09.25
M11	Phu Loc market - Thanh Tri district	105°44′44.56	9°25′43.60
M12	Nga 5 market, Nga Nam town	105°35′53.05	9°33′54.19
M13	Cai Con bridge - An Lan Thon commune, Ke Sach district	105°53′27.75	9°55′48.00
M14	Huynh Huu Nghia bridge - My Tu district	105°48′39.19	9°38′10.13
M15	Lich Hoi Thuong bridge - Tran De district	106°08′48.47	9°28′38.64
M16	Thuan Hoa bridge -Chau Thanh town	105°37′21.35	9°37′59.23
M17	Khoan Tan bridge -Long Phu town	106°07′12.04	9°37′16.26
M18	Dinh river station - Soc Trang city	106°01′21.47	9°36′13.28

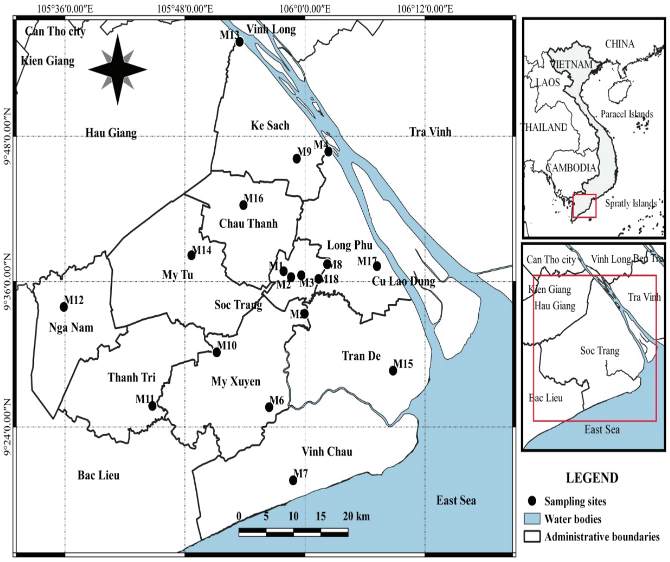

Fig. 1. Map of sampling sites of some water bodies in Soc Trang province.

2.2. Sample collection

Water samples such as temperature, pH, EC, salinity, turbidity, and DO were measured *in situ* using a multi-parameter (AAQ Rinko). Besides, surface water samples for other chemical parameter analyses were also taken, kept in ice, and carried to the laboratory. The process of taking samples and preserving samples was ensured by QCVN 08:2015/BTNMT [17].

The qualitative samples of phytoplankton were collected by a towing phytoplankton net (mesh size of 25 µm). Quantitative phytoplankton samples were done by filtering water samples as large as 60 l through the net. Then, the samples were preserved in the bottle with a volume of 250 ml and fixed with 5% formalin. The sampling method was performed by APHA (2012) [18].

2.3. Sample analysis

The water quality parameters such as COD, BOD_5, TSS, ammonium (NH_4^+), nitrate (NO_3^-), phosphate (PO_4^{3-}), and total P were analysed according to the standard method [18].

Phytoplankton were observed under Olympus BX41 optical microscope with magnification from 100 to 400 times and morphologically identified according to classification books [7-11, 19]. A Sedgewick Rafter counting chamber was used to determine phytoplankton cell density and the counting way was according to G.B. Edward and D.C. Sigee (2015) [20]. The phytoplankton taxon was arranged according to AlgaeBase's taxonomy system [21].

2.4. Data analysis

Using Excel 2010 software to analyse statistical data. CCA was used to determine the main environmental factors affecting the phytoplankton community by PAST software. Only species that have an abundance higher than 5% in each sample were used in this analysis to minimise the effect of rare species.

3. Results

3.1. Environment parameters

The results of the characteristics of the physical and chemical parameters from 18 collected samples for each factor in Soc Trang are presented in Table 2. The temperature of surface water ranged from 28.3°C to 31.1°C, relatively stable among the sampling sites. The pH and turbidity were between 6.58-7.53 and 19-265 Nephelometric turbidity unit (NTU), respectively. Both pH and turbidity in the dry season were lower than those in the rain season. The EC of the water was from 29.5-1428 mS/m in the dry season and from 14.5-329.7 mS/m in the rainy season. Salinity of water varied from 0.33-6.99‰ (mean 0.99‰) in the dry season and from 0.00-1.51‰ (mean 0.16‰) in the rainy season. During both the dry and rainy seasons, the DO concentration ranged from 2.05-6.12 mg/l. The TSS fluctuated from 16.0-290.7 mg/l in the dry season and 20.3-245.3 mg/l in the rainy season.

The COD and BOD_5 concentrations in dry season ranged from 9.7-44.9 mg/l and 3.1-11.8 mg/l, respectively. Those concentrations in the rainy season were 11.0-36.9 mg/l and 2.6-10.8 mg/l, respectively. The ammonium concentration in the dry season (0.00-1.31 mg/l) was higher than those in the rainy season (0.03-0.79 mg/l). The nitrate and phosphate concentrations in the dry season were from 0.04-0.71 mg/l and 0.00-0.17 mg/l, respectively. Those concentrations in the rainy season fluctuated 0.10-0.64 mg/l and 0.01-0.59 mg/l, respectively. The total phosphorus concentration was from 0.17-0.83 mg/l in the dry season, and 0.21-0.99 mg/l in the rainy season (Table 2).

Table 2. The water quality parameters of 18 sites in Soc Trang during the 2020 dry and rainy seasons.

Parameters	Dry season			Rainy season		
	Min	*Max*	*Mean±SE*	*Min*	*Max*	*Mean±SE*
Temperature (°C)	28.3	31.1	29.7±0.2	29.3	30.9	30.0±0.1
pH	6.72	7.28	7.06±0.03	6.58	7.53	6.93±0.05
EC (mS/m)	29.5	1428.0	233.7±100.2	14.5	329.7	53.5±16.7
Salinity (‰)	0.03	6.99	0.99±0.49	0.00	1.51	0.16±0.08
Turbidity (NTU)	19.0	186.8	84.6±11.2	30.2	265.0	110.4±16.6
DO (mg/l)	2.05	6.09	3.17±0.25	2,14	6.12	3.28±0.26
TSS (mg/l)	16.0	290.7	92.9±16.1	20.3	245.3	98.7±16.5
COD (mg/l)	9.7	44.9	29.7±2.6	11.0	36.9	23.3±1.8
BOD_5 (mg/l)	3.1	11.8	5.7±0.7	2.6	10.8	5.2±0.5
NH_4^+ (mg/l)	0.00	1.31	0.66±0.11	0.03	0.79	0.42±0.07
NO_3^-(mg/l)	0.04	0.71	0.30±0.04	0.10	0.64	0.32±0.05
PO_4^{3-} (mg/l)	0.00	0.17	0.06±0.01	0.01	0.59	0.17±0.04
Total P (mg/l)	0.17	0.83	0.34±0.04	0.21	0.99	0.60±0.07

3.2. Phytoplankton

A total of 171 algal species were recorded, and species belonging to 6 divisions, namely, Cyanobacteria, Chrysophyta, Bacillariophyta, Chlorophyta, Euglenophyta, and Dinophyta. Of these, Bacillariophyta was the most diverse group with 65 species occupying 38.0% of the total species, followed by Chlorophyta with 43 species occupying 25.1%. Euglenophyta and Cyanobacteria had 34 and 24 species, respectively. Finally, Chrysophyta and Dinophyta had the lowest species group with 2 and 3 species, respectively. The number of phytoplankton species in the rainy season was higher than that in the dry season (Table 3). Representatives of phytoplankton genera in the study area were *Anabaena, Microcystis, Oscillatoria, Navicula, Nitzschia, Cyclotella, Melosira, Synedra, Closterium, Cosmarium, Dictyosphaerium, Pandorina, Pediastrum, Scenedesmus, Euglena, Lepocinclis,* and *Phacu*s. These genera are typically for freshwater. Besides, a few of them originated from the estuary or coastal region like *Coscinodiscus, Gyrosigma,* and *Thalassionema*.

The cell number of phytoplankton ranged from 5050-212983 cells/l in the dry season and from 1596-448243 cell/l in the rainy season (Fig. 2). These results showed that phytoplankton abundance in the rainy season decreased for eleven of eighteen sampling sites compared with the dry season. In both seasons, the dominant species were mainly species belonging to the cyanobacteria group such as *Oscillatoria perornata*, *O. acuta*, *O.* sp., and *Jaaginema* sp. These species had dominant rates ranging from 26.8 to 78.8% of the total densities in the dry season, and from 16.3 to 73.9% in the rainy season, respectively. Besides, diatoms species (*Coscinodiscus subtilis*, *Aulacoseira granulata*) and green algae species (*Pandorina morum*) were also dominant at several sites, which occupied from 22.5-81.6% in the dry seasons and from 31.9-43.7% in the rainy season.

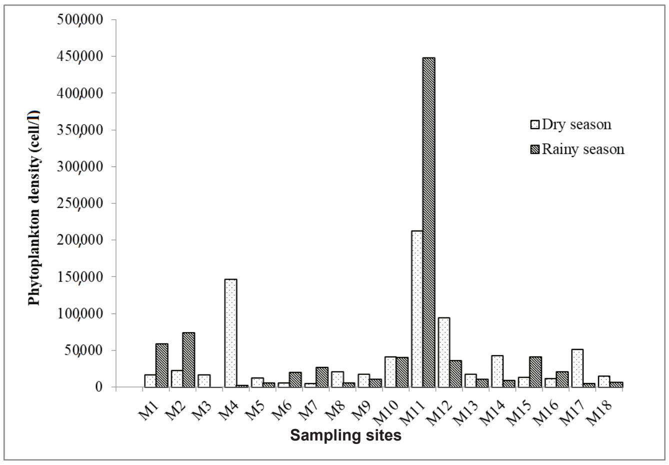

Fig. 2. The temporal and seasonal distributions of phytoplankton density in Soc Trang.

Table 3. List of phytoplankton taxa of water bodies in Soc Trang province (K = dry season, M = rainy season).

No	Taxa
Phylum Cyanobacteria	
1	*Anabaenopsis circularis* (G.S.West) Woloszynska & V.V. Miller, 1923$^{K M}$
2	*Aphanocapsa delicatissima* West & G.S.West, 1912^{M}
3	*Arthrospira platensis* Gomont, 1892$^{K M}$
4	*Dolichospermum circinale* (Rabenhorst ex Bornet & Flahault) P.Wacklin, L.Hoffmann & J.Komárek, 2009^{M}
5	*Dolichospermum affine* (Lemmermann) Wacklin, L.Hoffmann & Komárek, 2009^{M}
6	*Dolichospermum spiroides* (Klebhan) Wacklin, L.Hoffmann & Komárek, 2009^{M}
7	*Geitlerinema splendidum* (Greville ex Gomont) Anagnostidis, 1989$^{K M}$
8	*Jaaginema* sp.$^{K M}$
9	*Komvophoron schmidlei* (Jaag) Anagnostidis & Komárek, 1988$^{K M}$
10	*Lyngbya martensiana* Menegh. ex Gomont, 1892$^{K M}$
11	*Merismopedia tranquilla* (Ehrenberg) Trevisan, 1845$^{K M}$
12	*Microcystis aeruginosa* Kützing, 1846$^{K M}$
13	*Microcystis panniformis* Komárek, 2002$^{K M}$
14	*Microcystis protocystis* Crow, 1923^{K}
15	*Microcystis wesenbergii* Komárek, 2006^{M}
16	*Oscillatoria acuta* Bruhl et Biswas, 1932$^{K M}$
17	*Oscillatoria perornata* Skuja, 1949$^{K M}$
18	*Oscillatoria princeps* Vaucher ex Gamont, 1892$^{K M}$
19	*Oscillatoria tenuis* Agardh, 1813$^{K M}$
20	*Oscillatoria* sp.$^{K M}$
21	*Phormidium chalybeum* (Mertens ex Gomont) Anagnostidis & Komárek, 1988^{M}
22	*Planktothrix agardhii* (Gomont) Anagnostidis & Komárek, 1988$^{K M}$
23	*Raphidiopsis mediterranea* Skuja, 1937^{M}
24	*Sphaerospermopsis aphanizomenoides* (Forti) Zapomelová, Jezberová, Hrouzek, Hisem, Reháková & Komárková, 2010$^{K M}$
Phylum Chrysophyta	
25	*Dinobryon sertularia* Ehrenberg, 1834^{M}
26	*Mallomonas caudata* Iwanoff [Ivanov], 1899^{M}
Phylum Bacillariophyta	
27	*Actinoptychus annulatus* (Wallich) Grunow, 1883$^{K M}$
28	*Amphiprora alata* (Ehrenberg) Kützing, 1844^{K}
29	*Biddulphia mobiliensis* (Bailey) Grunow, 1882^{K}
30	*Campylodiscus daemelianus* Grunow, 1874^{K}
31	*Campylodiscus undulatus* Greville, 1863^{K}
32	*Climacosphenia moniligera* Ehrenberg, 1843$^{K M}$
33	*Coscinodiscus asteromphalus* Ehrenberg, 1844$^{K M}$
34	*Coscinodiscus jonesianus* (Greville) Ostenfeld, 1915^{K}
35	*Coscinodiscus excentricus* Ehrenberg, 1839$^{K M}$
36	*Coscinodiscus gigas* Ehrenberg, 1841$^{K M}$
37	*Coscinodiscus lineatus* Ehrenberg, 1841$^{K M}$
38	*Coscinodiscus marginatus* Ehrenberg, 1843$^{K M}$
39	*Coscinodiscus radiatus* Ehrenberg, 1841$^{K M}$
40	*Coscinodiscus rothii* (Ehrenberg) Grunow, 1878$^{K M}$
41	*Coscinodiscus subtilis* Ehrenberg, 1841$^{K M}$
42	*Coscinodiscus* sp.$^{K M}$
43	*Cocconeis* sp.$^{K M}$
44	*Cyclotella comta* (Ehrenberg) Kützing, 1849$^{K M}$
45	*Cyclotella meneghiniana* Kützing, 1844$^{K M}$
46	*Cymbella lanceolata* (C.Agardh) Kirchner 1878$^{K M}$
47	*Cymbella cistula* (Ehrenberg) Kirchner, 1878$^{K M}$
48	*Diploneis crabro* (Ehrenberg) Ehrenberg,1854^{M}
49	*Eunotia rabenhorstiana* (Grunow) Hustedt, 1949$^{K M}$
50	*Eunotia pectinalis* (Kützing) Rabenhorst, 1864$^{K M}$
51	*Fragliria* sp.$^{K M}$
52	*Gomphonema angustatum* (Kützing) Rabenhorst, 1864^{M}
53	*Gyrosigma acuminatum* (Kützing) Rabenhorst, 1853$^{K M}$
54	*Gyrosigma attenuatum* (Kützing) Rabenhorst, 1853^{K}
55	*Gyrosigma balticum* (Ehrenberg) Rabenhorst, 1853$^{K M}$
56	*Gyrosigma sinensis* (Ehrenberg) Desikachary, 1988 $^{K M}$
57	*Gyrosigma fasciola* (Ehrenberg) J.W.Griffith & Henfrey, 1856$^{K M}$
58	*Hydrosera triquetra* G.C.Wallich, 1858$^{K M}$
59	*Licmophora flabellata* (Greville) C.Agardh 1831^{M}
60	*Aulacoseira granulata* (Ehrenberg) Simonsen 1979$^{K M}$
61	*Melosira varians* C. Agardh, 1827$^{K M}$
62	*Navicula cryptocephala* Kützing, 1844$^{K M}$
63	*Navicula marina* Ralfs, 1861$^{K M}$
64	*Navicula radiosa* Kützing, 1844$^{K M}$
65	*Navicula placentula* (Ehrenberg) Kützing 1844^{K}
66	*Navicula* sp.$^{K M}$
67	*Nitzschia closterium* (Ehrenberg) W.Smith, 1853$^{K M}$
68	*Nitzschia lorenziana* Grunow, 1880$^{K M}$
69	*Nitzschia paradoxa* (J.F.Gmelin) Grunow, 1880$^{K M}$
70	*Nitzschia plana* W.Smith, 1853$^{K M}$
71	*Nitzschia sigma* (Kützing) W. Smith, 1853 $^{K M}$
72	*Nitzschia sigmoidea* (Nitzsch) W.Smith, 1853^{M}
73	*Paralia sulcata* (Ehrenberg) Cleve, 1873$^{K M}$
74	*Pinnularia braunii* (Grunow) Cleve, 1895$^{K M}$
75	*Pinnularia major* (Kützing) Rabenhorst, 1853$^{K M}$
76	*Pleurosigma angulatum* (Queckett) W.Smith, 1853$^{K M}$
77	*Pleurosigma elongatum* W.Smith, 1852^{K}
78	*Skeletonema costatum* (Greville) Cleve, 1873^{K}
79	*Synedra ulna* (Nitzsch) Ehrenberg, 1832$^{K M}$
80	*Synedra* sp.^{M}
81	*Surirella biseriata* Brébisson, 1835$^{K M}$
82	*Surirella gemma* Ehrenberg, 1839^{K}
83	*Surirella robusta* Ehrenberg, 1840$^{K M}$
84	*Surirella ovata* Kützing 1844$^{K M}$
85	*Surirella tenera* W.Gregory, 1856^{K}
86	*Thalassionema nitzschioides* (Grunow) Mereschkowsky, 1902$^{K M}$
87	*Trachyneis aspera* (Ehrenberg) Cleve, 1894^{K}
88	*Trachyneis debyi* (Leuduger-Fortmorel) Cleve,1894^{K}
89	*Triceratium alternans* J.W.Bailey, 1851$^{K M}$
90	*Triceratium favus* Ehrenberg, 1839$^{K M}$
91	*Vanheurckia lewisiana* (Greville) Brébisson, 1869$^{K M}$

No.	Taxa
Phylum Chlorophyta	
92	*Actinastrum hantzschii* Lagerheim, 1882$^{K M}$
93	*Ankistrodesmus falcatus* (Corda) Ralfs 1848^{M}
94	*Ankistrodesmus gracilis* (Reinsch) Korshikov, 1953^{M}
95	*Chlamydomonas* sp.^{M}
96	*Chodatella subsalsa* Lemmermann, 1898^{M}
97	*Coelastrum microporum* Nägeli, 1855^{M}
98	*Cosmarium obtusatum* (Schmidle) Schmidle, 1898^{M}
99	*Cosmarium quadrum* P.Lundell, 1871^{M}
100	*Closterium gracile* Brébisson ex Ralfs, 1848$^{K M}$
101	*Closterium intermedium* Ralfs, 1848$^{K M}$
102	*Closterium kuetzingii* Brébisson, 1856^{M}
103	*Closterium macilentum* Brébisson, 1856^{M}
104	*Closterium moniliferum* Ehrenberg ex Ralfs, 1848$^{K M}$
105	*Closterium* sp.$^{K M}$
106	*Crucigenia quadrata* Morren, 1830$^{K M}$
107	*Crucigenia lauterbornii* Schmidle, 1900^{M}
108	*Desmidium baileyi* (Ralfs) Nordstedt, 1880^{M}
109	*Dictyosphaerium pulchellum* H.C.Wood, 1873$^{K M}$
110	*Dimorphococcus lunatus* A.Braun, 1855^{M}
111	*Eudorina elegans* Ehrenberg, 1832^{M}
112	*Hyalotheca dissiliens* Brébisson ex Ralfs, 1848^{M}
113	*Micractinium pusillum* Fresenius, 1858$^{K M}$
114	*Mougeotia* sp.^{M}
115	*Gonium pectorale* O.F.Müller, 1773^{M}
116	*Oedogonium vulgare* (Wittrock ex Hirn) Tiffany,1934$^{K M}$
117	*Pandorina morum* (Müller) Bory de Saint-Vincent, 1824$^{K M}$
118	*Pediastrum biradiatum* Meyen 1829^{M}
119	*Pediastrum duplex* Meyen, 1829$^{K M}$
120	*Pediastrum simplex* Meyen, 1829$^{K M}$
121	*Pediastrum tetras* (Ehrenberg) Ralfs, 1845$^{K M}$
122	*Scenedesmus acuminatus* (Lagerheim) Chodat, 1902$^{K M}$
123	*Scenedesmus arcuatus* Lemmermann, 1899^{M}
124	*Scenedesmus denticulatus* Lagerheim, 1882^{K}
125	*Scenedesmus quadricauda* (Turpin) Brébisson, 1835$^{K M}$
126	*Sphaerocystis schroeteri* Chodat, 1897^{M}
127	*Sphaerocystis polycocca* Korshikov, 1953^{M}
128	*Spirogyra ionia* Wade, 1949$^{K M}$
129	*Staurastrum arctiscon* (Ehrenberg ex Ralfs) P.Lundell, 1871^{M}
130	*Staurastrum gracile* Ralfs ex Ralfs, 1848^{M}
131	*Staurastrum dickiei* Ralfs, 1848$^{K M}$
132	*Staurastrum leptocladum* Nordstedt, 1870^{M}
133	*Tetraëdron gracile* (Reinsch) Hansgirg, 1889$^{K M}$
134	*Volvox aureus* Ehrenberg, 1832^{M}
Phylum Euglenophyta	
135	*Euglena acus* Ehrenberg, 1830$^{K M}$
136	*Euglena deses* Ehrenberg 1834 $^{K M}$
137	*Euglena gracilis* Klebs, 1883$^{K M}$
138	*Euglena oxyuris* Schmarda, 1846 $^{K M}$
139	*Euglena oblonga* F.Schmitz, 1884^{M}
140	*Euglena polymorpha* P.A.Dangeard, 1902$^{K M}$
141	*Euglena rostrifera* L.P.Johnson, 1944$^{K M}$
142	*Euglena spirogyra* Ehrenberg, 1832$^{K M}$
143	*Euglena viridis* Ehrenberg, 1830$^{K M}$
144	*Euglena* sp.$^{K M}$
145	*Lepocinclis fusiformis* (H.J. Carter) Lemmermann, 1901$^{K M}$
146	*Lepocinclis ovum* (Ehrenberg) Lemmermann, 1901$^{K M}$
147	*Lepocinclis reeuwykiana* W.Conrad, 1934$^{K M}$
148	*Lepocinclis salina* F.E.Fritsch, 1914$^{K M}$
149	*Phacus contortus* Bourrelly, 1952$^{K M}$
150	*Phacus hamatus* Pochmann, 1942$^{K M}$
151	*Phacus helikoides* Pochmann, 1942$^{K M}$
152	*Phacus lefevrei* Bourrelly, 1952$^{K M}$
153	*Phacus longicauda* (Ehrenberg) Dujardin 1841$^{K M}$
154	*Phacus ovalis* (Woronichin) Popowa 1955$^{K M}$
155	*Phacus pleuronectes* (O.F. Müller) Dujardin, 1841$^{K M}$
156	*Phacus trapezoides* Stawinski, 1969$^{K M}$
157	*Phacus tortus* (Lemmermann) Skvortzov, 1928$^{K M}$
158	*Phacus suecicus* Lemmermann, 1910^{M}
159	*Strombomonas australica* (Playfair) Deflandre, 1930$^{K M}$
160	*Strombomonas fluviatilis* (Lemmermann) Deflandre,1930$^{K M}$
161	*Strombomonas limonensis* Yacubson$^{K M}$
162	*Strombomonas longicauda* (Swirenko) Deflandre,1930$^{K M}$
163	*Strombomonas napiformis* (Playfair) Deflandre, 1930$^{K M}$
164	*Trachelomonas armata* (Ehrenberg) F.Stein, 1878$^{K M}$
165	*Trachelomonas acanthostoma* A.C.Stokes,1887^{K}
166	*Trachelomonas hispida* (Perty) F.Stein, 1878$^{K M}$
167	*Trachelomonas volvocina* (Ehrenberg) Ehrenberg, 1834$^{K M}$
168	*Trachelomonas volzii* Lemmermann, 1906$^{K M}$
Phylum Dinophyta	
169	*Ceratium hirundinella* (O.F.Müller) Dujardin, 1841$^{K M}$
170	*Protoperidinium pentagonum* (Gran) Balech, 1974$^{K M}$
171	*Peridinium* sp.$^{K M}$

3.3. Relationship between phytoplankton community and environmental parameters

The study used CCA for analysis of the relationship between phytoplankton and environmental factors. In the dry season, thirteen taxa were chosen with a relative abundance ≥5% and were included in data analysis using CCA (Table 4). The first two axes explain 76.9% of the total variance with 52.1% for axis 1 and 24.8% for axis 2 (Fig. 3A). The first axis was positively correlated with nitrate and DO, but negatively related to EC and COD. The second axis was positively correlated with PO_4^{3-}, turbidity, total P, TSS, pH, NH_4^+, and BOD_5, but negatively correlated with temperature. Besides, Fig. 3A showed that the abundance of *Geitlerinema splendidum*, *Oscillatoria acuta,* and *O. tenuis* were positively related to turbidity (r=0.54-0.64; p=0.01-0.02) and TSS (r=0.72-0.74; p<0.01). Meanwhile, the abundance of *Coscinodiscus subtilis* was positively correlated with DO (r=0.58; p=0.01) and NO_3^- (r=0.50; p=0.04). The abundance of *Microcystis aeruginosa* was positively related to pH (r=0.55; p=0.02), EC (r=0.82; p<0.01), and salinity (r=0.80; p<0.01). The abundance of *Microcystis panniformis* was positively related to EC (r=0.61; p<0.01) and salinity (r=0.58; p=0.01). Some factors of COD, BOD_5, NH_4^+, and PO_4^{3-} were positively correlated with the abundance of *Arthrospira platensis* (r=0.55-0.65; p=0.01-0.02).

Table 4. Codes of key species were collected in dry and rainy in Soc Trang for the canonical correspondence analysis.

Species	Code	Dry	Rainy	Dry abundance (mean ± SE) cell/litre	Rainy abundance (mean ± SE) cell/litre
Sphaerospermopsis aphanizomenoides	Saph		+	-	150±123
Arthrospira platensis	Apla	+	+	238±67	1158±619
Geitlerinema splendidum	Gspl	+		379±337	-
Jaaginema sp.	Jaag	+	+	7318±3400	15920±15117
Microcystis aeruginosa	Maer	+	+	42±27	249±89
Microcystis panniformis	Mpan	+	+	35±25	37±15
Oscillatoria acuta	Oacu	+	+	1475±815	224±47
Oscillatoria perornata	Oper	+	+	14517±6820	16067±6652
Oscillatoria princeps	Opri		+	-	168±42
Oscillatoria tenuis	Oten	+	+	277±143	230±42
Oscillatoria sp.	Osci	+	+	1902±703	1022±409
Phormidium chalybeum	Pcha		+	-	59±36
Planktothrix sp.	Plan	+	+	2098±1105	1760±614
Coscinodiscus subtilis	Csub	+	+	12740±7809	139±40
Aulacoseira granulata	Agra		+	-	741±391
Eudorina elegans	Eele		+	-	151±63
Pandorina morum	Pmor		+	-	1873±1014
Lepocinclis salina	Lsal	+	+	203±111	1744±756
Phacus longicauda	Plon		+	-	187±50
Strombomonas longicauda	Slon	+		55±36	-
Protoperidinium pentagonum	Ppen		+	-	390±187
Total species		**13**	**19**		

(- : not available).

In the rainy season, nineteen taxa were collected with relation abundance ≥5% and were included in data analysis using CCA (Table 4). A total of 63.4% of the relationship between selected species and environmental variables were elucidated by the first two axes of CCA with 39.5% for axis 1 and 23.9% for axis 2 (Fig. 3B). The first axis was negatively related to NO_3^-, PO_4^{3-}, pH, and BOD_5. The second axis was positively correlated with temperature and ammonium and negatively related to DO, TSS, turbidity, and total P. Fig. 3B showed that the abundance of *Coscinodiscus subtilis* was positively correlated with the turbidity (r=0.69; p<0.01) and TSS (r=0.69-0.64; p<0.01). Meanwhile, the abundance *Phacus longicauda* was negatively related to the turbidity (r=-0.55; p=0.01) and TSS (r=-0.54; p=0.01). Some factors of pH, EC, and salinity were positively correlated with the abundance of *Oscillatoria acuta* (r=0.50-0.63; p=0.01-0.04). The abundance of *Arthrospira platensis* and *Oscillatoria* sp. were positively related to PO_4^{3-} (r=0.81; p<0.01 and r=0.55; p=0.01, respectively). The abundance of *Phormidium chalybeum* was positively correlated with turbidity (r=0.49; p=0.03) and negatively related to the temperature (r=-0.64; p<0.01).

4. Discussion

The water temperature at the water bodies of Soc Trang was within the range of 28-31°C, which was similar to the water temperature of some other water bodies in Southern Vietnam [14, 15]. However, this temperature was higher than those in the Red river from Northern Vietnam (around 24°C) [12]. The water quality of Soc Trang has a water pH of slightly neutral, which was higher compared to the pH in the Vam Co river (pH=3.9-7.0) [14] but lower than in the Red river (pH=7.5-7.7) [12], Dong Nai river (pH=6.2-8.9) [15], and Ba Lai river (pH=7.2-8.5) [22]. The current study, the mean salinity of water in the rainy season (0.16±0.08‰) was lower than in the dry season (0.99±0.49‰). In the dry season, except at the Vinh Chau site with the highest salinity of 6% near the coastal area of Soc Trang, the remaining sites had salinity less than 0.5‰. Whereas, in the rainy season,

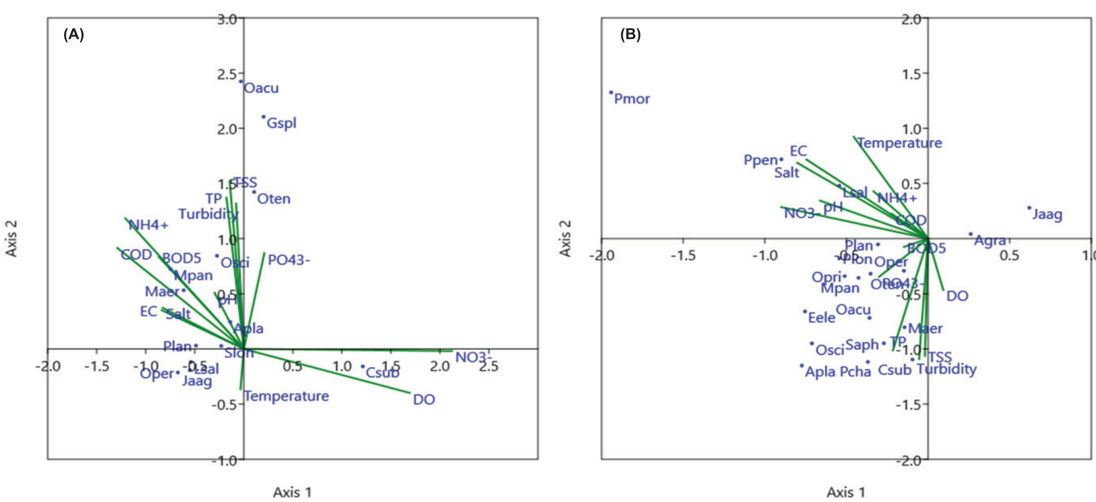

Fig. 3. CCA based on environment parameters and relative abundance of phytoplankton for sampling sites in Soc Trang province in (A) dry season and (B) rainy season.

the salinity in Vinh Chau cut down to 1.51‰ and the other sampling sites had salinities less than 0.2‰. Soc Trang is one of the provinces in the Mekong delta affected by salinization. However, at the time of the study, the inland water bodies of Soc Trang were not saline. The salinity of water in Soc Trang was lower than Ba Lai river (Ben Tre province, 4.8±3.2‰) [22]. The turbidity of the water in this study area was quite high thus it should strongly contribute to the TSS (16-290.7 mg/l in the case of water bodies of Soc Trang), which was clearly shown by in situ measurement. The value of DO in Soc Trang was lower than that in the Red river [12], Dong Nai river [15], and Ba Lai river [22]. In addition, the COD and BOD_5 values recorded were higher than in Bien Ho and Lak lake [13]. The nitrate and ammonium concentrations in this study were within the range of inorganic nitrogen concentration from Vam Co river at 0.28-0.43 mg/l [14] and not as high as that in the Red river, which ranged from 0.23-0.86 mg/l [12]. The phosphate concentration in Soc Trang ranged from 0.00-0.59 mg/l (Table 1) and the total phosphorus concentration should be higher than the phosphate concentration. According to C.F. Reynolds (2006) [23], the water bodies within Soc Trang are characterised by mesotrophic and eutrophic conditions, therefore, they are favourable for the development of phytoplankton. Generally, according to QCVN 08:2015/BTNMT [17], the value of pH and nutrients (nitrate, phosphate) were classified into class A2, which is only acceptable for domestic purposes, whereas the concentration of COD, BOD_5, DO, TSS, and ammonium matched into class B2, which is only acceptable for irrigation and transportation.

Regarding phytoplankton, many studies have been conducted and published. T.S. Dao and T. Bui (2016) [14] found 290 algal species belonging to 7 groups in the Vam Co river, and green algae were the dominant species in number. T.L. Pham (2017b) [15] recorded 139 species of phytoplankton in the Dong Nai river, and diatom was the most abundant in the phytoplankton composition structure. In another study, H.T.T. Hoang, et al. (2018) [24] identified 87 taxa belonging to 7 groups in the Day river, and green algae had the highest number of species of them. In the current study, 172 species of phytoplankton were recorded and the phytoplankton in Soc Trang were higher than in the Day and Dong Nai rivers, but lower than that of the Vam Co river. Besides, the salinity recorded in the study area was at a low level, which is suitable for freshwater species to grow. Phytoplankton densities during the monitoring period were relatively high with a mean value of 40,370 cells/l in the dry season and 56,243 cells/l in the rainy season. This high density will be an abundant food source for aquatic species, especially in aquaculture. On the other hand, N.G. Jafari and V.R. Gunale (2006) [25] found some genera such as *Oscilatoria*, *Microcystis*, *Euglena*, and *Phacus,* which indicate organically-polluted water. Similar genera were also recorded in the present investigation.

The life and growth of phytoplankton depends on their environmental conditions. Therefore, the seasonal variations of environmental factors would lead to the change of phytoplankton. The CCA analysis was carried out to reflect the correlation between phytoplankton communities and environmental factors. Z. Ke, et al. (2012) [4] reported that silicate, nitrate, and temperature were the most relevant environmental factors to regulate the horizontal pattern of early-summer phytoplankton. Some other studies conduct CCA analysis like that of H.J. Zhao, et al. (2015) [26] showed that total nitrogen, salinity, and COD influenced the growth of *Pseudanabeana limnetica*, temperature and COD affected the growth of *Raphidiopsis curvata*, and temperature, phosphate, ammoniacal nitrogen, and pH impacted the growth of *Chlorella vulgari* and *Cosmarium* sp. Then, Z. Xu, et al. (2016) [27] presented that the abundance of *Dinophysis fortii* was negatively correlated with seawater temperature suggesting that harmful algal blooms caused by this species may primarily occur in spring. W. Zhenjiang and Y. Hongxian (2017) [6] recorded the distribution of phytoplankton was affected by iron ion, transparency, pH, water depth, and temperature. Another study by N. Wang, et al. (2018) [28] using redundancy analysis revealed that the most significant environmental factors influencing the phytoplankton community were water temperature, dissolved total phosphorus, salinity, and total nitrogen. In Vietnam, there are published studies involving the relationship between phytoplankton and environmental parameters in Refs. [2, 5, 12-15, 22, 29]. Those studies present phytoplankton assemblages that are correlated with environmental factors. However, depending on the water quality characteristics in each area, certain parameters were the key factors affecting the phytoplankton assemblage there. In the present study, during the dry season, the abundance of *Coscinodiscus subtilis* was affected by DO and NO_3^- while the abundance of *Geitlerinema splendidum*, *Oscillatoria acuta,* and *O. tenuis* were influenced by turbidity and TSS. Besides, the pH, EC, and salinity impacted the abundance of *Microcystis aeruginosa* and *M. panniformis* and the abundance of *Arthrospira platensis* was affected by COD, BOD_5, NH_4^+, and PO_4^{3-}. Whereas during the rainy season, the phytoplankton-environment relationship changed such as the turbidity and TSS impacting the abundance of *C. subtilis* and *Phacus longicauda*; the abundance of *Phormidium chalybeum* was influenced by turbidity; the PO_4^{3-} affected the abundance of *A. platensis* and *Oscillatoria* sp., and the pH, EC, and salinity influenced the abundance of *O. acuta*. Most of the phytoplankton species that had relationships with environmental factors were freshwater species. In general, the phytoplankton assemblage was influenced by pH, EC, salinity, turbidity, TSS, and PO_4^{3-} during both seasons.

5. Conclusions

In the current study, the environmental parameters and phytoplankton community were seasonally investigated of some water bodies in Soc Trang province. Results showed that water quality was placed into class B2, except for pH, nitrate, and phosphate, which were placed into class A2. The nutrient concentration (nitrate, phosphate) in Soc Trang are appropriate for the growth of phytoplankton. There are 171 phytoplankton taxa belonging to the six divisions Cyanophyta, Chrysophyta, Bacillariophyta, Chlorophyta, Euglenophyta, and Dinophyta of which Bacillariophyta had the highest contribution in species number. The phytoplankton community is related to environmental factors during both dry and rainy seasons. The phytoplankton assemblage was influenced by environmental factors. The results of this study contributed not only essential information on phytoplankton composition and abundance, but possibly also using algae as an indicator for surface water quality assessment in Soc Trang province.

CRediT author statement

Thi Trang Le: Sample analysis, Taxonomic identification, Data processing, Writing the manuscript; Doan Dang Phan: Samples collection, Supporting data analysis; Van Tien Tran: Samples collection, Map drawing; Van Tu Nguyen: Supervise and comment on editing the manuscript for completeness.

COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

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