Nguyen TKL, Au VH, Phan TCT, et al. Seasonal variation of phytoplankton in My Thanh River, Mekong delta, Vietnam. *Israeli Journal of Aquaculture - Bamidgeh*. 2023;75(1):1-13. doi:10.46989/001c.77858

Original Research Articles

Seasonal variation of phytoplankton in My Thanh River, Mekong delta, Vietnam

Thi K. L. Nguyen[1][a], Van H. Au[1], Thi C. T. Phan[1], Trung G. Tran[1], Truong G. Huynh[1], Ngoc U. Vu[1], Thanh P. Nguyen[1]

[1] College of Aquaculture and Fisheries, Can Tho University, 3/2 Street, Ninh Kieu District, Can Tho City 94000, Vietnam

Keywords: Algae density, My Thanh River, phytoplankton composition, rainy and dry seasons, Shannon-Weiner diversity index (H')

https://doi.org/10.46989/001c.77858

Israeli Journal of Aquaculture - Bamidgeh

Vol. 75, Issue 1, 2023

A study on the seasonal variation of phytoplankton composition was conducted at the upper, middle, and lower parts of the My Thanh River, which supplies an important source of water for aquaculture. Qualitative and quantitative samples of phytoplankton were collected monthly at both high and low tide. The results showed that a total of 171 phytoplankton (algae) species were recorded, belonging to 59 genera and 5 phyla. Diatoms were the most abundant group with the highest species number, followed by green algae. The other phyla possessed a lower number of species. The species composition was more diverse in the rainy season and at high tide at most of the sampling sites. The mean density of algae varied from 30,900-43,521 ind.L^{-1}. The density of diatoms was higher in the middle and lower parts. At the same time, euglenoids displayed the highest density in the upper part, showing a difference in the dominant algae group under the influence of salinity. Salinity was found to be significantly positively correlated ($p<0.01$) with diatoms, whereas it was negatively correlated ($p<0.05$) with blue-green algae and euglenoids. The algae composition was quite diverse, with the H' index ranging from 2.0-3.3, showing the water quality was slightly to moderately polluted.

INTRODUCTION

The My Thanh river, located in Soc Trang province, has a length of about 25 km. This river is the primary source of water for agricultural production, especially brackish aquaculture in the dry season. In order to develop aquaculture more sustainably, water management needs to be taken into consideration, especially where there are significant changes in ecological conditions from freshwater to brackish. Management of large rivers requires a balance between human needs and ecological integrity, although, until quite recently, ecological principles have played a minor role in river management.[1] Water quality parameters such as temperature, salinity, turbidity, and nutrient contents often fluctuate widely in these areas,[2] which affect the distribution of aquatic organisms, including phytoplankton (algae).

Algae are an important part of the food chain and play a central role in the functioning of large rivers. Algal communities are major producers and crucial food sources for planktonic consumers, and they may represent the primary oxygen source in many low-gradient rivers.[3] Phytoplankton communities also contribute approximately 50% of global primary production in many food webs of estuary ecosystems.[4] However, phytoplankton communities are sensitive to alterations in their habitats, and thereby, their biomass and species are utilized as indicators of aquatic habitat qualifications.[5] Some species thrive in highly eutrophic waters, whereas others are very sensitive to environmental changes. Some species thrive in highly eutrophic waters, whereas others are very sensitive to environmental changes. Seasonal variations in phytoplankton are related to a variety of environmental factors in aquatic environments.[6] In addition, seasonal variation of phytoplankton biomass, species composition, and productivity differ markedly among the estuarine habitat types.[7] According to Lien et al.,[8] the fluctuation of algae composition in the estuary of the Hau River in the Mekong delta was influenced by the seasonal characteristics and tidal regime. Phytoplankton of Sefid Rud River could be considered as bio-indicators of water quality in several areas subjected to anthropogenic disturbance.[9] Good water quality in fish or shrimp ponds is essential for survival and adequate growth.[10] Water quality in the aquaculture ponds mainly depends on the quality of the water source in the surrounding area. At present, little is known about the spatial and temporal changes of phytoplankton populations in the river transition areas

a * Corresponding author. E-mail: ntklien@ctu.edu.vn

Table 1. Sampling sites in My Thanh river of Soc Trang province

No	Sites	Geographical coordinates of sampling points	Description of sampling locations
1	Nhu Gia (upper part of the river)	N: 9°30'08.0", E: 105°51'11.9"	This location, near a residential area, is about 25 km from the My Thanh estuary, surrounded by rice and shrimp farming areas. The aquatic environment has very low salinity in the rainy season
2	My Thanh (middle part of the river)	N: 9°25'38.0", E: 105°59'40.1"	This collection site is about 12–13 km from the My Thanh estuary. The surrounding area has a few households and mainly whiteleg shrimp farming.
3	My Thanh Estuary (lower part of the river)	N: 9°24'33.1", E: 106°12'36.4"	This is the coastal area that is strongly affected by the tidal regime. The water quality factors change significantly between the rainy and dry seasons.

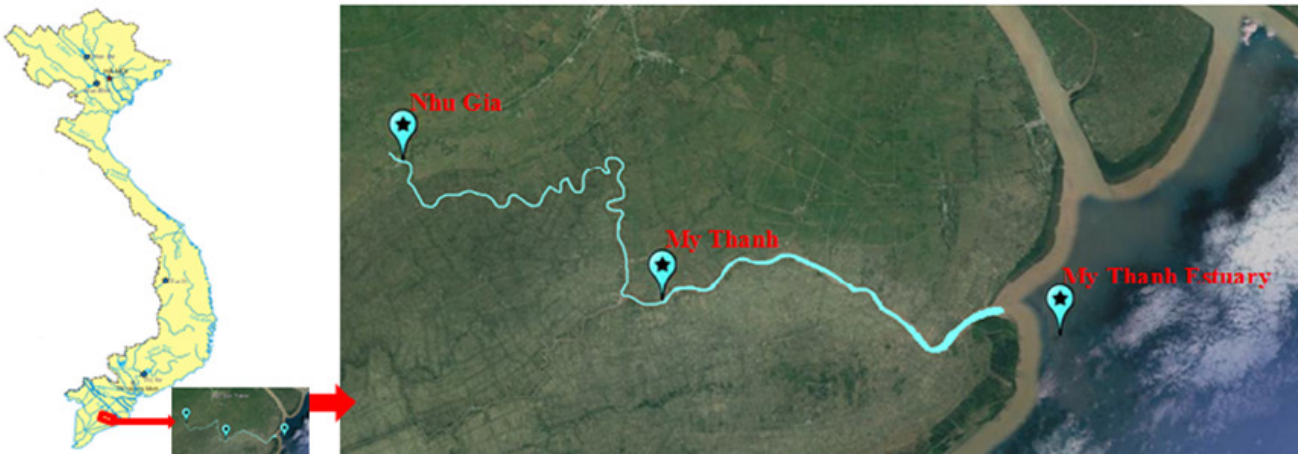

Figure 1. Sampling sites in My Thanh river

from freshwater to brackish water, especially in the Mekong Delta. The aim of this study was therefore to determine the seasonal succession, overall structure, and diversity of phytoplankton populations on the My Thanh River, one of the largest rivers in the Soc Trang province coastal area. Findings from this study would serve as a baseline for water quality management, particularly for aquaculture in the region.

MATERIALS AND METHODS

Phytoplankton samples were collected on the My Thanh River in Soc Trang province at three main sampling sites, including the upper (Nhu Gia), middle (My Thanh), and lower (My Thanh River mouth) parts of the river (**Table 1** and **Figure 1**). Sampling was undertaken monthly for six periods in the rainy season (May to October) and six periods in the dry season (November to April of the following year). Quantitative and qualitative samples were collected during both high and low tides at the study locations.

Qualitative samples of phytoplankton were collected by a phytoplankton net with a mesh size of 25 µm which was dragged along the sampling sites. Quantitative samples were collected by a settling method by filling a 1L bottle with water from a bucket that was taken from different points of the sampling site. All samples were fixed with commercial formalin at a concentration of 2-4%. Identification of algae species was implemented based on common taxonomic keys including Shirota,[11] An,[12] Carmelo et al.,[13] Tien and Hanh,[14] Tuyen,[15] and Bellinger and Sigee.[16] Densities of algae were determined at the species level using the Sedgewick-Rafter counting chamber developed by Boyd and Tucker.[17] Water quality parameters including temperature, pH, salinity, TSS, DO, BOD_5, COD, TAN, NO_3^-, TN, PO_4^{3-}, and TP were also recorded and collected at the same time with algae sampling and analyzed following the APHA.[18] The water parameters were used to explain the effects of water quality on the phytoplankton composition in the study area.

The Shannon-Weiner diversity index (H') was calculated by the formula:

$$H' = -\sum_{i=1}^{n} Pi * LnPi$$

(Where $Pi = n_i / N$; n_i is the density of species i, and N is the total density of algae)

Algae density by phylum was used to determine the correlation between phytoplankton population and water quality parameters and assess the similarity of the composition of phytoplankton among sampling sites by the cluster analysis method[19] using SPSS 22.0 software.

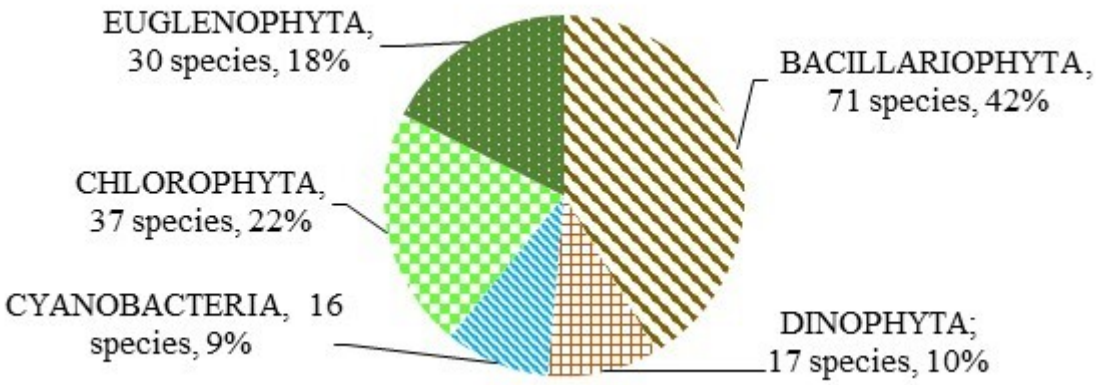

Figure 2. Species composition of algae in My Thanh river

RESULTS

SPECIES COMPOSITION OF PHYTOPLANKTON IN THE MY THANH RIVER, SOC TRANG PROVINCE

A total of 171 phytoplankton species was recorded on the My Thanh River belonging to 59 genera and 5 phyla. Diatoms (Bacillariophyta) had the highest number of species (71 species, accounting for 42%) belonging to 23 genera, followed by green algae (Chlorophyta) with 37 species (22%) of 15 genera. Other groups, including euglenoids (Euglenophyta), dinoflagellates (Dinophyta), and blue-green algae (Cyanobacteria), possessed 16-30 species (9-18%) of 4-12 genera (**Figure 2**). Diatoms were more diverse in species number compared to the others.

SEASONAL FLUCTUATION OF PHYTOPLANKTON COMPOSITION ON THE MY THANH RIVER

The species number of phytoplankton in the rainy season was higher than that in the dry season, but no significant difference was found between the sampling sites. The number of species recorded in the rainy and dry seasons was 141-149 species and 127-148 species, respectively. Dinophyta and Bacillariophyta displayed a tendency of increasing species numbers from the middle to lower parts, while Cyanobacteria and Chlorophyta showed the opposite trend (**Figure 3**). Some common algae species discovered in the My Thanh river such as *Coscinodiscus radiatus, Gyrosigma attenuatum, Melosira granulata, Thalassiothrix frauenfeldii* (Bacillariophyta), *Oscillatoria limosa, Spirulina major* (Cyanobacteria), *Pediastrum biradiatum* (Chlorophyta), *Peridinium sp.* (Dinophyta), *Euglena acutissima, Euglena oxyuris, Phacus alata, Phacus longicauda, Phacus torta, Trachelomonas hispida, Trachelomonas lagenella* (Euglenophyta).

The total species number of phytoplankton was always higher at high tide than at low tide at all sampling sites. The composition of algae at high and low tides varied from 101-118 species and 80-95 species, respectively. The species composition of diatoms and dinoflagellates in the middle and lower parts was likely higher than that in the upper part (**Figure 4**).

COMPOSITION AND DENSITY OF PHYTOPLANKTON IN DIFFERENT PARTS OF MY THANH RIVER

The mean species number of phytoplankton was not significantly different between sampling sites. The total number of species recorded in the upper part, middle part, and lower part was 27±3-42±5, 28±3-40±8, and 31±5-44±6 species, respectively. The mean species number in the rainy season was higher than that in the dry season. In the upper part, the phytoplankton composition varied from 23 to 48 species during the sampling stages. The species composition of algae at low tide (LT) and high tide (HT) ranged from 23 to 39 species and 34 to 48 species, respectively. There was no significant difference in species composition between euglenoids, green algae, and diatoms. However, the number of dinoflagellate species was the lowest. The common algae species identified were *Coscinodiscus, Cyclotella, Melosira, Navicula, Nitzschia, Surirella* (Bacillariophyta), *Oscillatoria* (Cyanobacteria), *Closterium, Pediastrum, Scenedesmus* (Chlorophyta), *Peridinium* (Dinophyta), *Euglena, Phacus,* and *Trachelomonas* (Euglenophyta). The structure of the phytoplankton community in the middle and lower parts was similar, with diatoms being more abundant than others. The closer to the estuary zone, the higher the species numbers of diatoms and dinoflagellates were found. The species numbers of diatoms in the middle part and lower part ranged from 13-17 species and 18-23 species, respectively, while this group in the upper part was very low with 7-13 species. The variation in species composition of dinoflagellates was similar to that of diatoms. The number of dinoflagellate species in the upper part, middle part, and lower part was 1-3, 1-4, and 3-7 species, respectively. However, the variation of species composition of blue-green algae, euglenoids, and green algae from the upper part to the lower part of the My Thanh river tended to be opposite to that of diatoms and dinoflagellates (**Figure 5**).

The mean density of phytoplankton in the study area varied from 30,900±15,473 to 83,122±72,956 ind.L^{-1} (**Fig-**

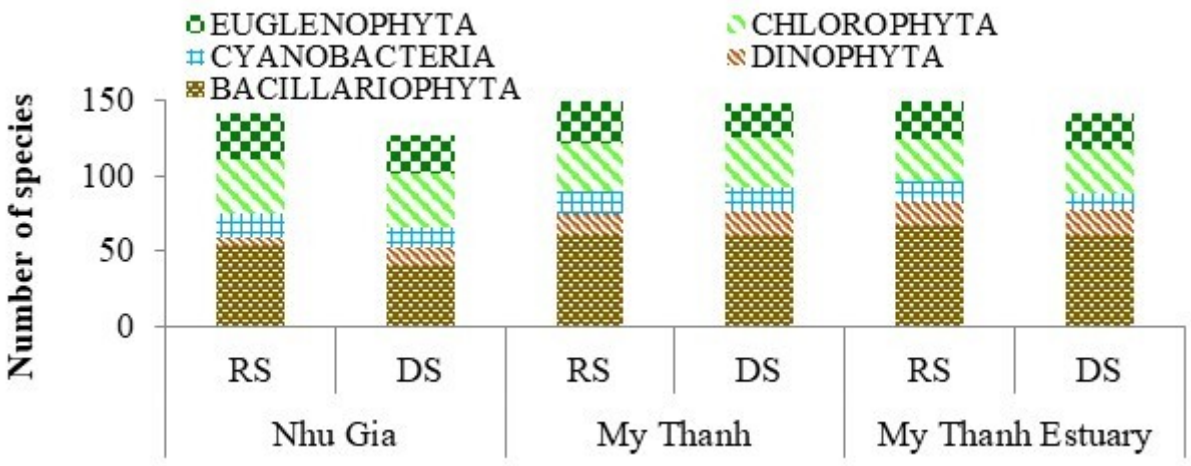

Figure 3. Total number of phytoplankton species at sampling sites in the rainy season (RS) and dry season (DS) in the My Thanh river of Soc Trang province

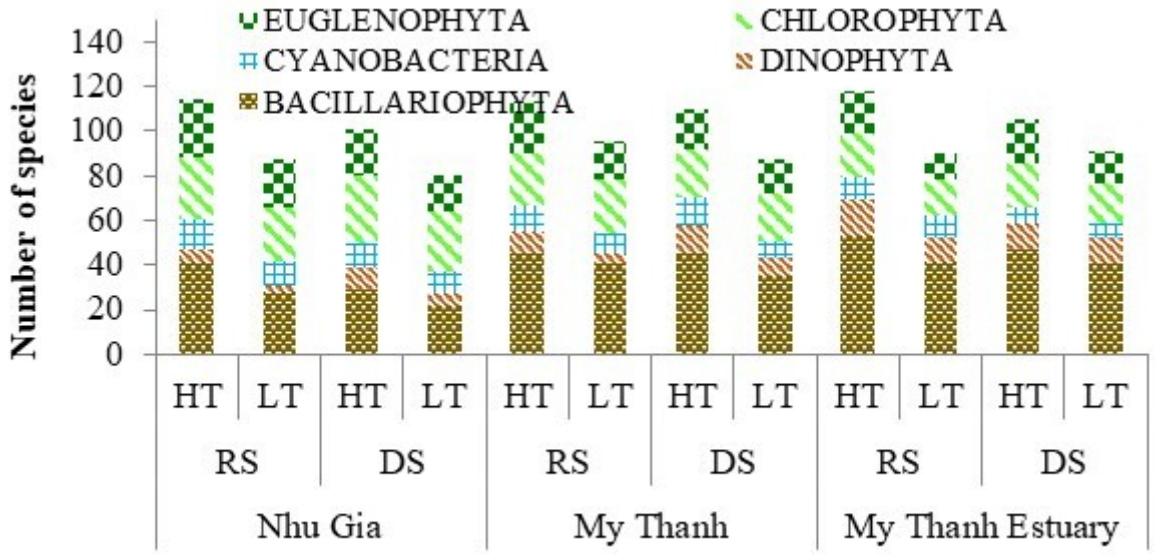

Figure 4. Total number of phytoplankton species at sampling sites at high and low tides in the My Thanh river, Soc Trang province

ure 6). A remarkable difference in density was found between sampling sites. In the upper part, density was high in the rainy season and low in the dry season. The mean density of algae ranged from 30,900 to 66,056 ind.L^{-1}, in which euglenoids accounted for a high proportion with a density ranging from 11,688 to 21,463 ind.L^{-1}. The dominant genera belonging to eugleoids consisted of *Euglena, Phacus,* and *Trachelomonas*. Blue green algae and green algae presented lower densities, with 4,460-9,620 ind.L^{-1} and 6,926-9,292 ind.L^{-1}, respectively. In the middle part, there was no significant difference in density between the rainy and dry seasons, varying from 38,070 to 51,624 ind.L^{-1}. The densities of blue-green algae, green algae, and euglenoids in the middle part tended to decrease at a slower rate than those in the upper part. In the lower part, the algae density was relatively higher than the other sites (36,346-83,122 ind.L^{-1}), and diatoms accounted for the highest proportion both in the rainy and dry seasons and even at high and low tides. This finding demonstrated that diatoms play a critical role in algae production in the My Thanh estuary (lower part). The seasonal fluctuation of algae density in the My Thanh River did not follow any obvious trend. Dominant diatom genera included *Biddulphia, Coscinodiscus, Cyclotella, Cymbella, Melosira, Navicula, Thalassiosira, and Thalassiothrix.*

DIVERSITY OF PHYTOPLANKTON IN THE MY THANH RIVER, SOC TRANG PROVINCE

In general, the species composition of algae in the My Thanh River was relatively diverse. The diversity of algae manifested by the Shannon-Wiener index (H') ranged from 2.0-3.1 and did not differ significantly between the rainy

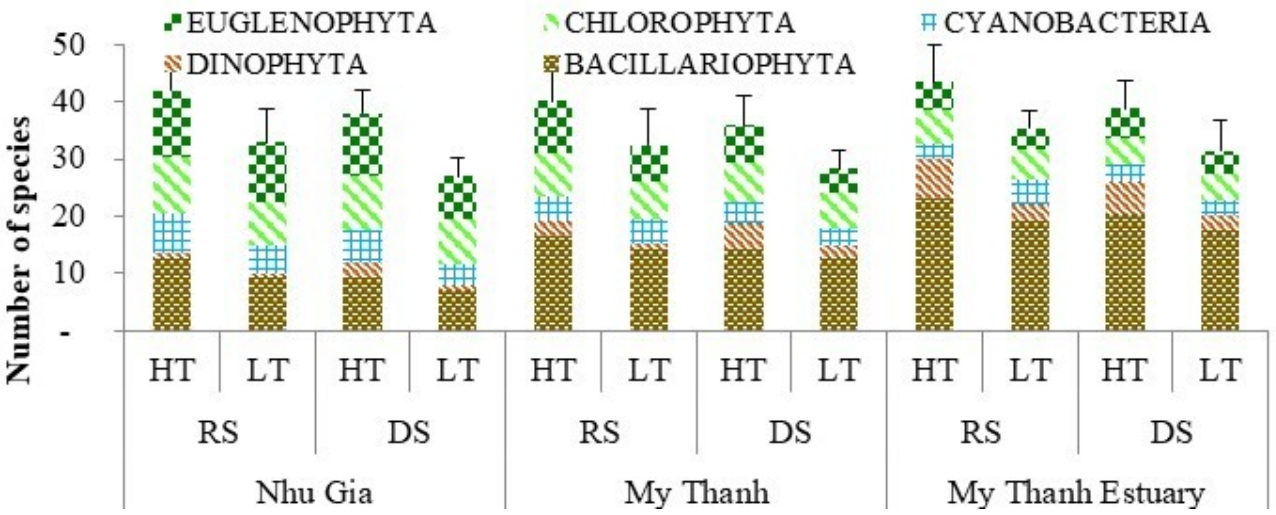

Figure 5. The mean phytoplankton composition at the sampling sites in the rainy and dry seasons of the My Thanh River

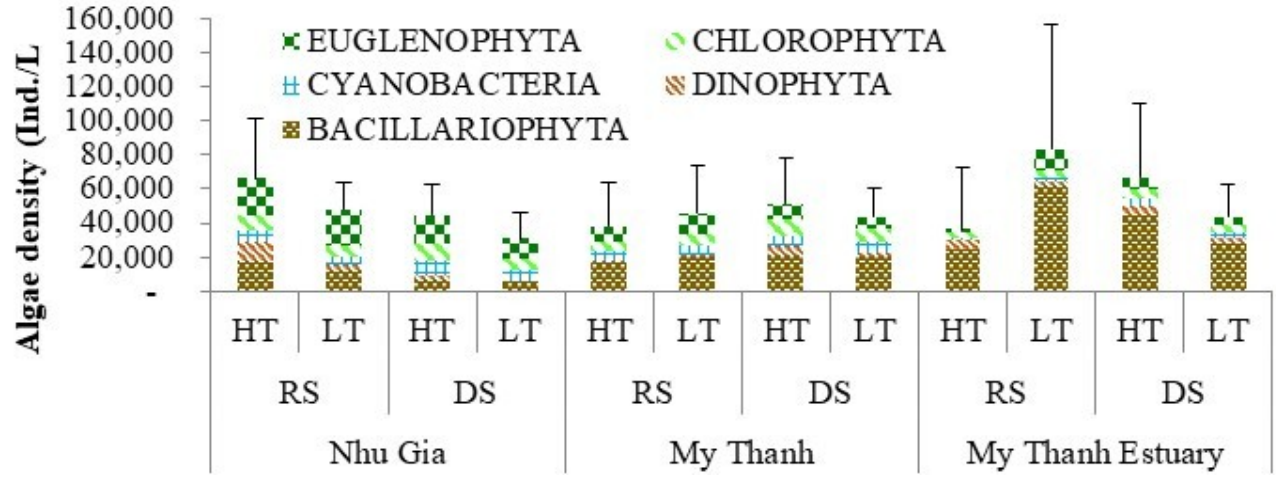

Figure 6. The mean density of phytoplankton in the rainy and dry seasons of the My Thanh river

and dry seasons (Figure 7). The H' value in the rainy and dry seasons varied in a range of 2.5-3.1 and 2.6-3.0, respectively. Based on the H' index, the results revealed that the diversity of algae was significantly positively correlated ($p<0.05$) with COD level (Table 2). In addition, the H' index can be used to assess the ecological status of the water bodies. Zheng *et al.*[20] categorized water quality based on the H' index as H': > 4.5, very clean; H': 3.0-4.5, clean; H': 2.0-3.0, slightly polluted; H': 1.0-2.0, moderately polluted; and H': <1.0, heavily polluted. From the above results, the water quality in the study area was evaluated as slightly to moderately polluted. The density of algae determined at a low level shows a water environment with low nutrient levels

CORRELATION BETWEEN PHYTOPLANKTON AND PARAMETERS OF WATER QUALITY IN THE MY THANH RIVER

The relation between water quality parameters and algae densities is presented in Table 2. The abundance of green algae, euglenoids, and total density of algae had a significantly positive relationship ($p<0.05$) with temperature. The algal diversity shown through the H' index had a significantly negative relationship ($p<0.01$) with pH level. Diatoms and total density of algae showed a significantly positive correlation ($p<0.01$) with salinity, while there was a significantly negative correlation with blue-green algae ($p<0.05$) and euglenoids ($p<0.01$) with salinity. In addition, the distribution of diatoms was also considerable, depending upon the concentrations of TSS, DO, BOD_5, NO_3^-. When the concentration of these water quality parameters is high, diatoms will thrive and increase in density. However, diatoms were negatively correlated with COD ($p<0.05$) and TP ($p<0.05$) elements. A significantly positive relationship was found between algae abundance and salinity ($p<0.05$), TSS ($p<0.01$), COD (0.05) and TP ($p<0.05$) levels. In addition, the H' index showed a positive correlation with COD concentration. No significant relation was found between dinoflagellate density and water environment factors as well as salinity.

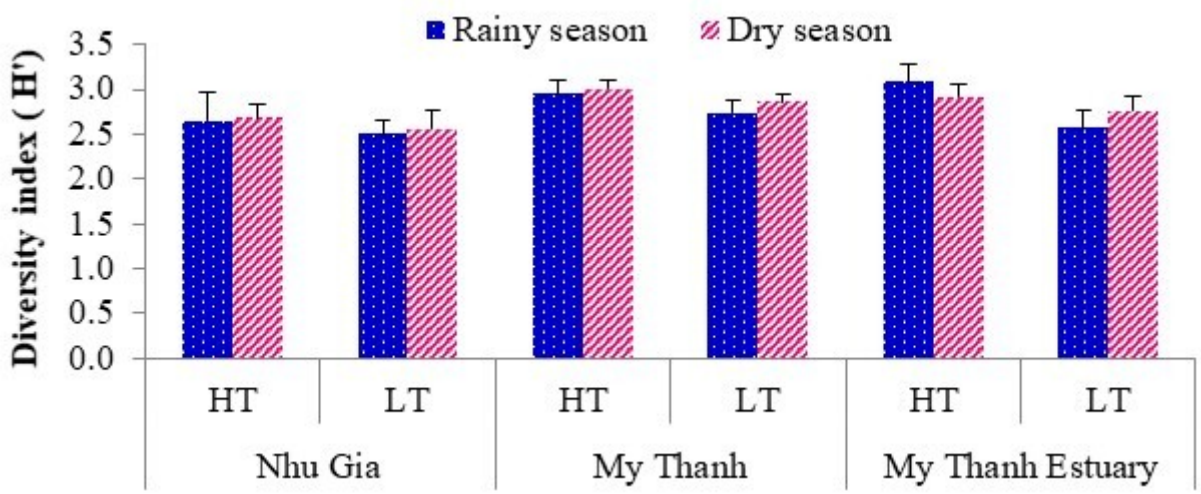

Figure 7. Shannon-Weiner diversity index (H') at sampling locations of the My Thanh river

Table 2. Correlation between phytoplankton abundance and water quality parameters in My Thanh River

	BA	DI	CY	CH	EU	Total	H'
Tem.	0.16	-0.01	0.08	0.26*	0.25*	0.24*	0.20
pH	-0.05	-0.03	-0.08	-0.16	-0.18	- 0.13	-0.31**
Salinity	0.43**	0.20	-0.24*	0.03	-0.33**	0,24*	-0.03
TSS	0.54**	-0.08	-0.06	0.01	-0.01	0,37**	-0.09
DO	0,26*	0.06	-0.22	-0.10	-0.29*	0.09	0.22
BOD_5	0.30**	0.11	-0.07	0.06	-0.26*	0.17	-0.06
COD	-0.25*	-0.08	-0.06	-0.21	-0.18	-0,29*	0.27*
TAN	-0.18	-0.09	0.15	0.02	0,32**	-0.04	0.15
NO_3^-	0.35**	0.12	-0.09	0.19	-0,23*	0.23	-0.11
TN	-0.05	-0.01	-0.02	-0.04	-0.22	-0.11	-0.06
PO_4^{3-}	0.01	-0.14	-0.05	-0.25*	0.26*	0.02	0.19
TP	-0.25*	0.03	-0.09	-0.21	-0.06	-0.23*	0.20

Note: *. *Correlation is significant at the 0.05 level (2-tailed), **. Correlation is significant at the 0.01 level (2-tailed). Tem.: Temperature, BA: Bacillariophyta, DI: Dinophyta, CY: Cyanobacteria, CH: Chlorophyta, EU: Euglenophyta, Total: Total density of algae*

SIMILARITY ASSESSMENT OF PHYTOPLANKTON COMMUNITY AT SAMPLING LOCATIONS IN THE RAINY AND DRY SEASONS

The cluster analysis results in **Figure 8.1** and **Figure 8.2** showed that the sampling sites with similar Euclid distances would have high similarity in phytoplankton composition. In the rainy season, the distribution of phytoplankton in the My Thanh River could be divided into 3 water body groups. Group 1 included the lower, middle, and upper parts. Group 2 consisted of the lower and middle parts, and group 3 was just the lower part. In the dry season, the distribution of phytoplankton was distinguished into two obvious groups. Group 1 consisted of the upper and middle parts, which had high similarity in the composition of phytoplankton at both high and low tides. Group 2 contains only the lower part (the estuary area) at both high and low tides.

DISCUSSION

The species composition of phytoplankton recorded in My Thanh River was relatively lower (171 species) than that in the Hau River estuary (221 species),[8] but higher (157 species) than that in the Ham Luong River of Ben Tre Province, Vietnam.[21] Although the total number of phytoplankton species identified in these rivers was different, the common five phyla, including Cyanobacteria, Chlorophyta, Euglenophyta, Bacillariophyta, and Dinophyta, were consistent in all locations. Diatoms (Bacillariophyta) were more diverse than other groups. In this study, the results found 71 species of diatoms, while the downstream area of the Tien and Hau Rivers in the Mekong Delta identified a total number of 119 diatom species.[22] Total diatoms abundance appears to vary seasonally. Diatoms were present throughout the year under all temperatures and salinities constituting major part of phytoplankton.[23] The total phytoplankton species were generally not significantly differ-

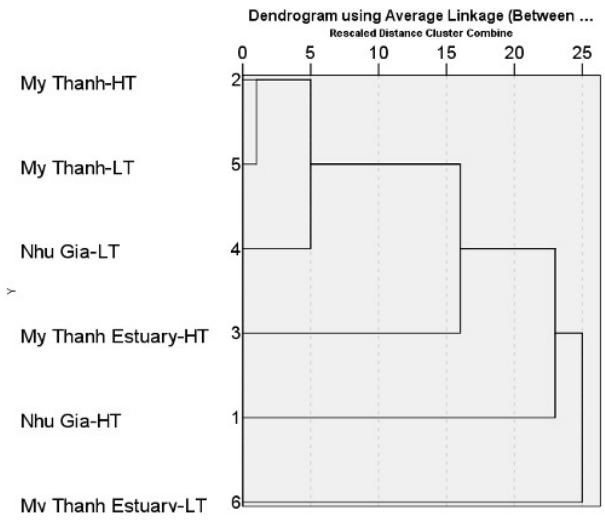

Figure 8.1. Similarity of phytoplankton between sampling locations in My Thanh in the rainy season

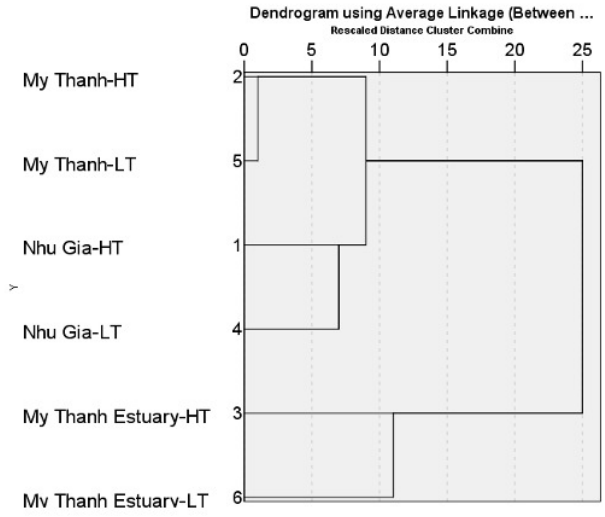

Figure 8.2. Similarity of phytoplankton between sampling locations in My Thanh river in the dry season

ent between the rainy and dry seasons. However, the influence of tidal regimes on the distribution of phytoplankton was recognized, as the species number at high tide was always higher than that at low tide at all sampling sites. At high tide, water from the sea enters inland water bodies carrying brackish-saltwater algae species, thereby increasing the number of algae species at this time. The species composition of diatoms increased more than that of other algae species. In contrast, at low tide, water from rivers and canals flows into estuaries, so the species composition is lower than that at high tide. Simlar results were also identified by Lien et al.[8] in a study on seasonal variation of phytoplankton composition in the estuary of the Hau River, Soc Trang Province, Vietnam. Some common algae genera were detected during the survey periods both in the rainy and dry seasons, such as *Coscinodiscus, Cyclotella, Gyrosigma, Navicula, Nitzschia* (Bacillariophyta), *Oscillatoria* (Cyanobacteria), and *Euglena* (Euglenophyta). These algae are able to adapt to a wide range of salinities and are categorized as euryhaline algae. They are distributed in both freshwater and brackish environments with salinity varying from 0-27‰, because they can move temporarily with water flow from upstream to downstream or the opposite.

The closer the collection sites were to the river mouth, the more diverse the species of diatoms became. Diversity and abundance of phytoplankton were related to the physicochemical parameters in general and more particularly to temperature, DO, BOD, salinity, and nutrient availability. In addition, salinity was reported as the major factor determining phytoplankton distribution.[24] In the current study, salinity in the My Thanh River was highly variable (0-27 ‰) over the survey periods. An increase in the diversity of algae species in the estuary area compared to other collecting sites was associated with increased salinity. The mean salinity through the study periods in the estuarine area of My Thanh was higher (10.7-14.8 ‰) than the salinity in the upper part (2-3 ‰) and middle part (2.3-6.3 ‰). According to Badsi et al.,[25] the estuaries form a transitional zone between two aquatic biomes, the freshwater and the marine biomes. Marine organisms are adapted to high salinity and cannot survive in freshwater areas. Freshwater organisms are adapted to low salinity and do not survive in seawater. Some marine or freshwater species have evolved a tolerance to intermediate salinity or to salinity fluctuations and can therefore survive in the brackish water of the estuary. Therefore, the structure of species composition, frequency of occurrence, and dominance of phytoplankton were different among sampling sites. In the rainy season, some algae genera adapted to low salinity displayed a very high frequency of occurrence at the upper part, while their frequency of occurrence was very low at locations with higher salinity. These include *Closterium, Scenedesmus, Staurastrum* (Chlorophyta), *Lyngbya* (Cyanobacteria), *Trachelomonas,* and *Phacus* (Euglenophyta). In contrast, during the dry season, high-salinity adaptive algae were present in the lower and middle parts and reduced the frequency of occurrence in the upper part, where salinity was lower than the middle part. That was the distribution characteristics of algae like *Biddulphia, Cyclotella, Gyrosigma, Surirella, Thalassiosira, Thalassiothrix* (Bacillariophyta), *Ceratium,* and *Peridinium* (Dinophyta). Especially, *Thalassiosira* and *Thalassiothrix* were not found in the upper part in the dry season. The results again showed that salinity was the main factor affecting the distribution of algae in the estuarine region.

The survival and replication of phytoplankton are greatly influenced by various environmental parameters.[26] In this study, diatoms had a positive correlation with the contents of TSS ($p<0.01$), DO ($p<0.05$), and BOD_5 ($p<0.01$). The mean DO concentration was recorded highest in the lower part of the My Thanh River during the rainy and dry seasons, which coincided with the highest algae density. Under the photosynthesis process by algae, oxygen was produced, resulting in high DO content in this area. According to Raven et al.,[27] changes in pH in natural waters

are likely to have profound effects on algal physiology. Additionally, pH can affect the rates of photosynthesis and growth of algae directly by altering acid-base balance or via the effects on speciation of dissolved inorganic carbon.[28] In the estuarine ecosystem, turbidity, salinity, and nutrients are the main environmental variables influencing the phytoplankton communities.[29] George et al.[30] also confirmed that phosphate and nitrogen are the main factors influencing phytoplankton composition in many estuarine ecosystems. Blue-green algae and dinoflagellates generally did not have a strong correlation with the nutrient content of the My Thanh River. However, green algae had a positive correlation with PO_4^{3-} concentration. Euglenoids developed strongly when TAN and PO_4^{3-} contents were high. The average TAN content in the upper part was higher than that in other sites in both rainy and dry seasons, as this factor favored the growth of euglenoids. Diatom density increased with high NO_3^- content ($p<0.01$), but with low COD ($p<0.05$) and low TP ($p<0.05$) levels. Bacillariophyta usually like to live in water environments with high nitrate concentrations.[31] The abundance and distribution of diatoms are also known to determine water quality as indicators of nutrient rich environment. Organic loads decreased the abundance and diversity of diatom communities in the region.[23] Diatoms are sensitive to limnological and environmental variables, and their community structure may quickly respond to changing physical, chemical, and biological conditions in the environment.[32] Therefore, the community structure of phytoplankton may differ, however, depending on the hydrodynamic conditions and nutrient levels within the water body.[33]

The results of the assessment of phytoplankton composition similarity in the survey area showed that their composition in the rainy season was not clearly distinct between sampling sites due to the great influence of the tidal regime and seasonal factors. The sampling locations were categorized into three groups. The first group covered the upper and middle parts where algae densities at the low tide were similar, ranging from 38,070-48,183 ind.L^{-1}. As these areas were influenced by the inland water, algae densities were not remarkably different. Therefore, they were arranged in the same group. The highest algae density was recorded in group two, ranging from 66,056-83,122 ind.L^{-1}. Although the upper and lower parts were in the same group, euglenoids were abundant in the upper part while diatoms were dominant in the lower part. The last group was only the middle part, where algae density was lowest (36,383 ind.L^{-1}) in all sampling points in the rainy season. The species composition and density of algae in the dry season were strongly different between sampling sites in the upper part (Nhu Gia), middle part (My Thanh), and lower part (My Thanh estuary). **Figure 8.1** allows for the distinction of two groups. The first group includes the sampling locations of the upper and middle parts in both high and low tides, which had high similarity in algae density, so they were classified in the same group with algae densities ranging from 30,900-51,624 ind.L^{-1}. Similarly, the second group belonged to the lower part, which contained the highest algae density, varying from 43,521-66,773 ind.L^{-1}. This distribution could be explained by salinity and temporal gradients with seasonal effects and the existence of similar conditions in the stations of the same group.[25]

The species composition of phytoplankton in the My Thanh River was generally quite diverse, but there was no significant difference between the rainy and dry seasons as well as at high and low tides (**Figure 7**). However, the diversity of algae at the sampling locations through the survey periods fluctuated highly. The H' index ranged from 2.0-3.1. This result showed that the diversity of algae was dependent on the seasonality characteristic and tidal regimes. The nutrient contents of water in the dry season, such as TAN, TN, and TP, were quite higher than those in the rainy season. Hence, algae composition in the rainy season tended to be lower than that in the dry season in both high and low tides, but this difference was not statistically significant ($p>0.05$). In addition, an increase in species diversity may be associated with higher salinity and anthropogenic contaminants in the dry season. This indicated that the diversity index could be used for the evaluation of water quality in the My Thanh River. The density and diversity of phytoplankton are biological indicators for evaluating water quality and the degree of eutrophication.[34] The results of the H' index from the present study revealed that the water quality in the My Thanh River ranged from light to moderate pollution. In general, the overall findings of this study showed that tidal regimes as well as seasonal characteristics of the ecosystem influence the species composition and their relative abundance of phytoplankton in the My Thanh estuarine region.

CONCLUSIONS

The phytoplankton species composition, structure, and density changed significantly as the water environment changed from freshwater to brackish water in the estuarine area. The species composition of phytoplankton in the My Thanh River was quite diverse. Water quality in the study area ranged from light to moderate pollution. The management of water quality in the My Thanh River should be conducted periodically in order to support ecological health monitoring. This could also help shrimp farming owners use surface water sources more effectively by predicting changes in water environment elements as well as phytoplankton population.

ACKNOWLEDGMENTS

The authors are also thankful to the colleagues and students of Faculty of Aquatic Biology and Environmental Science, College of Aquaculture and Fisheries, Can Tho University for their support.

AUTHOR CONTRIBUTIONS

Methodology: Thi K. L. Nguyen (Equal), Van H. Au (Equal), Trung G. Tran (Equal). Formal Analysis: Thi K. L. Nguyen (Equal), Van H. Au (Equal), Trung G. Tran (Equal). Investi-

gation: Thi K. L. Nguyen (Equal), Van H. Au (Equal), Trung G. Tran (Equal). Writing – original draft: Thi K. L. Nguyen (Equal), Thi C. T. Phan (Equal), Truong G. Huynh (Equal). Writing – review & editing: Thi K. L. Nguyen (Equal), Ngoc U. Vu (Equal), Thanh P. Nguyen (Equal). Resources: Thi K. L. Nguyen (Equal), Van H. Au (Equal). Data curation: Thi C. T. Phan (Equal), Trung G. Tran (Equal). Funding acquisition: Truong G. Huynh (Equal), Ngoc U. Vu (Equal), Thanh P. Nguyen (Equal). Project administration: Truong G. Huynh (Equal), Ngoc U. Vu (Equal), Thanh P. Nguyen (Equal). Conceptualization: Ngoc U. Vu (Equal), Thanh P. Nguyen (Equal).

Submitted: March 26, 2023 CST. Accepted: May 30, 2023 CST.
Published: June 15, 2023 CST.

REFERENCES

1. Edwards R. *The Ecological Basis for the Management of Water Quality. The Ecological Basis for River Management*. Wiley; 1995.

2. Baytut Ö, Gönülol A. Phytoplankton distribution and variation along a freshwater-marine transition zone (Kızılırmak River) in the Black Sea. *International Journal of Oceanography and Hydrobiology*. 2016;45(4):453-465. doi:10.1515/ohs-2016-0039

3. Kohler J. Growth, production and losses of phytoplankton in the lowland River Spree: carbon balance. *Freshwater Biology*. 2006;34(3):501-512. doi:10.1111/j.1365-2427.1995.tb00908.x

4. Boopathi T, Lee JB, Youn SH, Ki JS. Temporal and spatial dynamics of phytoplankton diversity in the East China Sea near Jeju Island (Korea): A pyrosequencing-based study. *Biochemical Systematics and Ecology*. 2015;63:143-152. doi:10.1016/j.bse.2015.10.002Get

5. Chellappa NT, Câmara FRA, Rocha O. Phytoplankton community: indicator of water quality in the Armando Ribeiro Gonçalves Reservoir and Pataxó Channel, Rio Grande do Norte, Brazil. *Braz J Biol*. 2009;69(2):241-251. doi:10.1590/s1519-69842009000200003

6. Cetin AK, Sen B. Seasonal distribution of phytoplankton in Orduzu Dam Lake (Malatya, Turkey. *Turk J Bot*. 2004;28:279-285.

7. Cloern JE, Cole BE, Wong RLJ, Alpine AE. Temporal dynamics of estuarine phytoplankton: A case study of San Francisco Bay. *Hydrobiologia*. 1985;129(1):153-176. doi:10.1007/bf00048693

8. Liên NTK, Khiem NT, Ut VN, et al. Seasonal variation of Phytoplankton composition in estuary of Hau river, Soc Trang province. *Can Tho University Journal of Science*. 2020;56(Aquaculture issue):80. doi:10.22144/ctu.jsi.2020.010

9. Pourafrasyabi M, Ramezanpour Z. Phytoplankton as bio-indicator of water quality in Sefid Rud River – Iran (South Caspian Sea. *Caspian J Env Sci*. 2014;12(1):31-40.

10. Burford M. Phytoplankton dynamics in shrimp ponds. *Aqua Res*. 2008;28(5):351-360. doi:10.1046/j.1365-2109.1997.00865.x

11. Shirota A. *The Plankton of South Vietnam Freshwater and Marine Plankton*. Oversea Techical Cooperation Agency; 1966.

12. An TN. *Taxonomic Keys for the Marine Diatom of Vietnam*. Science and Technics Publishing House; 1993.

13. Carmelo RJ, Hasle GR, Syvertsen EE, Steidinger KA, Jangen K. *Identifying Marine Diatom and Dinoflagellates*. Academic Press, Inc. Harcourt Brace and Company; 1996.

14. Tien DD, Hanh V. *Identification of the Order Chlorococcales*. Agriculture Publishing House; 1997.

15. Tuyen NV. *Biodiversity of Algae in the Inland Waters of Vietnam. Agriculture Publishing House*. In Vietnamese; 2003.

16. Bellinger EG, Sigee DC, eds. *Freshwater Algae: Identification, Enumeration and Use as Bioindicators*. Wiley; 2015. doi:10.1002/9781118917152

17. Boyd CE, Tucker CS. *Water Quality and Pond Soil Analysis for Aquaculture*. Auburn University Alabana; 1992.

18. APHA. *Standard Methods for the Examination of Water and Wastewater*. 23rd ed. American Public Health Association, Inc; 2017.

19. Son VN, Phuong NT. *Multivariate Statistic Applied in Aquaculture*. Can Tho University Publishing House; 2016.

20. Zheng BH, Tian ZQ, Zhang L, Zheng FD. The characteristics of the hydrobios'distribution and the analysis of water quality along the west shore of Taihu Lake. *Acta Ecologica Sinica*. 2007;27(5):4214-4223. doi:10.1016/s1872-2032(07)60041-9

21. Luu TP, Yen TTH, Thai TT, Quang XN. Relationship between phytoplankton community and environmental variables in the Ham Luong river, Ben Tre province. *Viet Nam Journal of Marine Science and Technology*. 2017;17(4A):235-245. doi:10.15625/1859-3097/17/4A/13287

22. Hanh V, Kha LK. Diversity of diatoms in the lower Tien and Hau rivers. *Biology Journal*. 2011;33(4):35-41. doi:10.15625/0866-7160/v33n4.777

23. Naz T, Zaib-Un-Nisa B, Sonia M, Pirzada JAS. Seasonal abundance of diatoms in correlation with the physical-chemical parameters from coastal waters of Pakistan. *Pak J Bot*. 2013;45(4):1477-1486.

24. Scavia D, Bricker SB. Coastal eutrophication assessment in the United States. *Biogeochemistry*. 2006;79(1-2):187-208. doi:10.1007/s10533-006-9011-0

25. Badsi H, Oulad AH, Loudiki M, Aamiri A. Composition along the Salinity Gradient of the Massa Estuary. *American Journal of Human Ecology*. 2012;1(2):58-64. doi:10.11634/21679622150480

26. Baek SH, Lee M, Park BS, Lim YK. Variation in phytoplankton community due to an autumn typhoon and winter water turbulence in southern Korean coastal waters. *Sustainability*. 2020;12(7):2781. doi:10.3390/su12072781

27. Raven JA, Gobler CJ, Hansen PJ. Dynamic CO2 and pH levels in coastal, estuarine, and inland waters: Theoretical and observed effects on harmful algal blooms. *Harmful Algae*. 2020;91:101594. doi:10.1016/j.hal.2019.03.012

28. Maberly SC. Exogenous sources of inorganic carbon for photosynthesis by marine macroalgae. *J Phycol*. 1990;26(3):439-449. doi:10.1111/j.0022-3646.1990.00439.x

29. Nche-Fambo FA, Scharler UM, Tirok K. Resilience of estuarine phytoplankton and their temporal variability along salinity gradients during drought and hypersalinity. *Estuarine, Coastal and Shelf Science*. 2015;158:40-52. doi:10.1016/j.ecss.2015.03.011

30. George B, Kumar JN, Kumar RN. Study on the influence of hydro-chemical parameters on phytoplankton distribution along Tapi estuarine area of Gulf of Khambhat, India. *The Egyptian Journal of Aquatic Research*. 2012;38(3):157-170. doi:10.1016/j.ejar.2012.12.010

31. Guo XQ, Yang Y, Yu Y, Zhao XG, Liu XB. Structural characteristics of and environmental impact on phytoplankton in Changli Gold Coast National Nature Reserve in summer 2019. *J Tianjin Univ Sci Technol*. 2019;36:48-55.

32. Moser KA, Macdonald GM, Smol JP. Applications of freshwater diatoms to geographical research. *Progress Physical Geog*. 1996;20(1):21-52. doi:10.1177/030913339602000102

33. Zhu W, Wan L, Zhao L. Effect of nutrient level on phytoplankton community structure in different water bodies. *J Environ Sci (China)*. 2010;22(1):32-39. doi:10.1016/s1001-0742(09)60071-1

34. Shekhar RT, Kiran BR, Puttaiah ET, Shivaraj Y, Mahadevan KM. Phytoplankton as index of water quality with reference to industrial pollution. *J Environ Biol*. 2008;29:233-236.