DRIVING FACTORS OF PHYTOPLANKTON COMMUNITY AND ASSESSMENT OF THE WATER QUALITY IN A SMALL EUTROPHIC WUXING LAKE, NORTHEAST CHINA

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Abstract. The community structure, spatiotemporal variation and influencing factors of phytoplankton accompanied with water quality in Wuxing Lake, northeast China were studied during spring, summer and autumn from summer 2019 to spring 2020. Our purpose was to reveal the driving factors influencing phytoplankton community, combined with water quality, discussing methods on improving water quality in the lake.112 species of phytoplankton including 8 phyla and 74 genera were identified. The phytoplankton community structure demonstrated obvious seasonal and spatial variation. 20 dominant species were selected during three seasons. Redundancy analysis (RDA) result showed that transparency (SD), total phosphorous (TP), chemical oxygen demand (COD_{Cr}), turbidity (Tur), dissolved oxygen (DO) and conductivity (EC) were main factors influencing the abundance of dominant species. Results of Shannon-Wiener index (*H'*) and Pielou's evenness index (*J'*) indicating slight to light pollution in the lake. Considering the risk of deterioration of water quality is still a possibility, measures to improve SD may be effective to prevent Cyanophyta blooms in summer. Our findings will provide a reference for water quality protection and management in small eutrophic lakes similar to Wuxing Lake.

Keywords: *Wuxing Lake, temporal and spatial succession, dominant species, diversity index, water quality, redundancy analysis (RDA)*

Introduction

Water eutrophication affecting rivers, lakes, reservoirs et cetera caused by human activities is becoming a global problem (Vincon-Leite and Casenave, 2019; Wang et al., 2019; Bouraï et al., 2020). Input of large amount of nutrients (mainly nitrogen and phosphorus) into freshwater ecosystems caused the proliferation of phytoplankton which eventually leads to algal blooms (especially harmful cyanobacteria) (Barcante et al., 2020). Algal blooms consume the majority of the dissolved oxygen in the water and release algal toxins, leading to the destruction of ecological functions (such as diversity protection, drinking water supply and recreation etc.) and sustainable development of aquatic ecosystem (Sakamoto et al., 2021; Preece et al., 2017; Huisman et al., 2018). Phytoplankton is main primary producer of aquatic ecosystems and plays an important role in material flow and energy cycle (Jiang et al., 2014). Due to sensitivity to environmental factors, phytoplankton community were widely used to evaluate water quality and predict changes of water quality in freshwater bodies (Yang et al., 2016; Boyer et al., 2009; Thiebaut et al., 2006). Various characteristics of phytoplankton with numbers types destined the result that algae surviving in environment consistent with

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ecological demand and be eliminated when the environment was inappropriate, which leading the diversity of phytoplankton community under diversified types of environmental, namely, the temporal and spatial heterogeneity of phytoplankton community structure (Padisák et al., 2003). Studies showed that nutrients, light condition, physical factors (water temperature, transparency, dissolved oxygen etc.), climate change (precipitation, water level fluctuation, monsoon, hydrological connectivity etc.) were factors influencing the spatiotemporal variation of phytoplankton community structure (Liu et al., 2021; Cao et al., 2018; Liu et al., 2019; Xiao et al., 2011; Yuan et al., 2018). Which were different due to features of water environment.

Wuxing Lake is located in the experimental area of Naolihe National Nature Reserve in Heilongjiang Province which is surrounded by paddy. Drainage from paddy production was directly injected into the lake, resulting in high nutrient concentrations of water. Cyanobacteria blooms were observed in summer during recent years in the lake, indicating water quality is deteriorating. However, studies on phytoplankton community structure and their relationship with environmental factors in the lake have not been reported up to now. In this study we investigated characteristics of phytoplankton community and environmental factors in Wuxing Lake during one year. Our purposes were to (1) reveal the spatiotemporal succession of phytoplankton and their driving factors;(2) evaluate of water quality and offer proposals on improving water quality.

Materials and methods

Study area

Wuxing Lake locates in hinterland of Sanjiang plain, Heilongjiang Province, China (132°22′29″-134°13′45″E,46°30′22″-47°24′32″N) (*Fig. 1; Table 1*) and could be summarized as small eutrophic lake with a surface area 250 hectares and high centration of nutrients due to dewatering of surrounding farmland (mainly rice fields) (*Table 2*). Water depth is shallow with an average of 2 m and maximum no more than 3 m. The lake contains rich wildlife resources with great economic value including mammal, bird, fish and benthic macroinvertebrate and plays important role in preservation of biodiversity. The annual distribution of precipitation is mainly in summer (June to August), accounts for 64.5% of total annual rainfall while spring and autumn accounted for 14.3% and 18.7%, respectively.

Table 1. *Nine sampling sites coordinates in Wuxing Lake*

Sampling sites	Latitude	Longitude
1#	N46°48′41.8212″	E132°59′31.3008″
2#	N46°48′37.6884″	E132°59′56.3100″
3#	N46°48′37.6956″	E132°59′44.8332″
4#	N46°48′39.4092″	E132°59′35.4084″
5#	N46°48′12.1680″	E132°59′17.0556″
6#	N46°48′30.5316″	E132°59′12.2208″
7#	N46°48′51.1632″	E132°59′24.2664″
8#	N46°49′5.9700″	E132°59′45.4380″
9#	N46°49′2.2620″	E133°0′8.1684″

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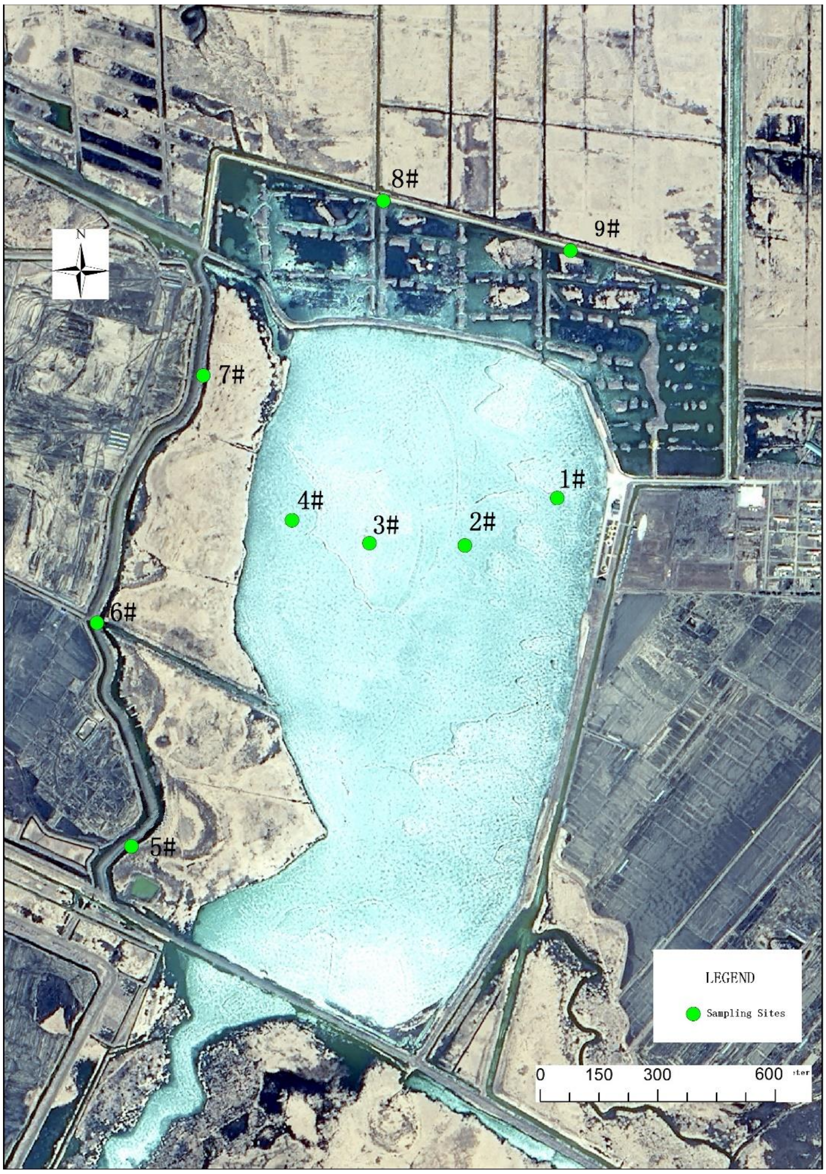

Figure 1. *Sampling sites in Wuxing Lake. 1#–4# are located in lake center (LC), 5#–9# are located in inlet channel (IC)*

Sampling and analysis

Nine representative sampling sites were selected from Wuxing Lake with 4 in lake center (LC, 1#-4#) and 5 in inlet channel (IC, 5#-9#). Samples were collected in summer (June, 2019), autumn (October, 2019) and spring (May, 2020), no sampling was conducted in winter for reason of coverage of ice and snow.

Water temperature (WT), conductivity (EC), dissolved oxygen (DO), turbidity (Tur,) and potential of hydrogen (pH) were recorded in situ by multi-parameter probe (YSI 6600, USA), transparency (SD) was measured using Secchi disk and water depth (WD) by band tape. 500 ml water sample was collected from subsurface water (5–50 cm) at each sampling site for analysis of total phosphorus (TP), total nitrogen (TN) and chemical oxygen demand (COD_{Cr}) and then be measured within 24 h according to methods described by HACH (Yuan et al., 2018). Another 1 L water sample was

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collected and poured into clean plastic bottle for phytoplankton quantification, and then fixed with 15 ml Lugol's iodine solution. The fixed samples were sedimented for 48 h in dark and then concentrated to 30 mL. Identification and counting of phytoplankton were conducted with Motic biological microscope (BA400T) at 400×magnification according to the freshwater algae of China (Hu and Wei, 2006), phytoplankton biomass was estimated by biovolumes (Long et al., 2020).

Statistical analysis

The dominance index (Y) was calculated in *Equation 1* (Lampitt et al., 1993), Shannon-Wiener index (H') and Pielou's evenness index (J') were calculated as shown in *Equations 2-3* (Shannon and Weaver, 1963; Pielou, 1966).

$$Y = \left(\frac{n_i}{N}\right) * f_i \quad \text{(Eq.1)}$$

$$H' = -\sum_{i=1}^{S} P_i \ln p_i \quad \text{(Eq.2)}$$

$$J' = \frac{H'}{\log_n S} \quad \text{(Eq.3)}$$

where n_i is the abundance of species i, N is the total abundance and f_i is the occurrence frequency of species i in all sampling sites. S is the richness of phytoplankton and P_i is the relative abundance of species i which was calculated by n_i/N. Explanations for three indices were expressed as follow: Y > 0.02 indicates that species i is the dominant specie (Lampitt et al., 1993); *H'* and *J'* were used to evaluate water quality of the lake. For *H'*, the value of which vary range from 0 to 1.0 indicates heavy pollution, the values range from 1.0 to 2.0 indicates moderate pollution, the value range from 2.0 to 3.0 indicates light pollution, and the value range from 3.0 to 4.5 indicates slight pollution (Shanthala et al., 2009). While for *J'*, the values of which range between 0 and 0.3 indicates heavy pollution, the value range between 0.3 and 0.5 indicates moderate pollution, the value range between 0.5 and 0.8 indicates light pollution, and the value range between 0.8 and1.0 indicates clean (Kong, 2000).

Spatial and temporal succession of phytoplankton community (one-way ANOVA with Tukey's HSD post hoc test) and Pearson correlation analysis between abundance of phytoplankton and Environmental Factors were performed using SPSS 22.0. $P < 0.05$ indicated that the difference and correlation were statistically significant. Redundancy analysis (RDA) was used to assess relationship between environmental factors and abundance of dominant species with Canoco 5.0 software for the reason that detrended correspondence analysis (DCA) showed the result of the maximum gradient length less than 3 standard deviation units (1.4 SD). Prior to analysis, abundance of phytoplankton and the environmental factors except pH were normalized using the formula log (1 + x).

Results

Environmental variable

The result of mean values of physicochemical variables and one-way ANOVA are presented in *Table 2*. In this study all ten environmental factors in this study showed

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significant seasonal difference. WT varied between 7.25 ℃ and 24.51 ℃ with the maximum value in summer and minimum in autumn. WD and EC both increased from spring to autumn, values of WD in autumn (222.78 cm) were significantly higher than that in spring (154.78 cm) ($p < 0.01$), while EC varied significantly among different seasons ($p < 0.01$). SD varied from 49.33 cm to 74.22 cm with the values in spring > autumn > summer. The values of DO and pH ranged from 6.25 to 10.71 and 7.22 to 7.61 mg/L respectively with maximum values both in autumn, values of DO in summer was significantly lower than that in spring and autumn ($p < 0.01$), while pH in autumn was higher than spring and summer ($p < 0.01$). Tur increased significantly from spring to summer ($p < 0.01$) and then reduced rapidly due to high water level caused by rainfall in autumn. COD_{Cr} and nutrients (TN, TP) showed a decreasing trend from spring to autumn with the lowest values 14.37 mg/L, 1.93 mg/L and 0.15 mg/L, respectively. Spatial heterogeneity of some environmental factors existed in all seasons. WD was significant different between LC and IC throughout the year ($p < 0.05$). EC, DO, Tur, COD_{Cr} and TN showed significant difference between LC and IC in spring ($p < 0.05$). In autumn, WD, SD and Tur showed significant spatial difference ($p < 0.05$).

Table 2. *The seasonal variation (spring, summer and autumn) of physicochemical variables (mean ± SE) in Wuxing Lake.*

	Spring	Summer	Autumn	P Value
WT (℃)	11.85 ± 0.06^{b}	24.51 ± 0.28^{a}	7.25 ± 0.29^{c}	0.000
WD (cm)	154.78 ± 11.53^{b}	$176.11 \pm 12.07^{a, b}$	222.78 ± 23.39^{a}	0.024
SD (cm)	74.22 ± 4.25^{a}	39.44 ± 1.63^{c}	49.33 ± 2.06^{b}	0.000
EC (ms/m)	0.061 ± 0.01^{c}	0.065 ± 0.01^{b}	0.071 ± 0.01^{a}	0.000
pH	7.22 ± 0.09^{b}	7.35 ± 0.04^{b}	7.61 ± 0.05^{a}	0.001
DO (mg/L)	10.14 ± 0.19^{a}	6.25 ± 0.19^{b}	10.72 ± 0.63^{a}	0.000
Tur (NTU)	1.44 ± 0.39^{c}	20.28 ± 1.44^{a}	11.04 ± 1.16^{b}	0.000
COD_{Cr} (mg/L)	24.59 ± 0.95^{a}	20.33 ± 0.55^{b}	14.37 ± 0.32^{c}	0.000
TN (mg/L)	3.73 ± 0.18^{a}	2.25 ± 0.15^{b}	1.93 ± 0.14^{c}	0.000
TP (mg/L)	0.46 ± 0.04^{a}	0.27 ± 0.02^{b}	0.15 ± 0.01^{c}	0.000

WT, water temperature; WD, water depth; SD, transparency, EC, conductivity; DO, dissolved oxygen; Tur, turbidity; CODcr, chemical oxygen demand; TN, total nitrogen; TP, total phosphorous
P values were from one-way ANOVA test. The significance level of mean difference is 0.05

Succession of phytoplankton community

A total of 112 species of phytoplankton belonging to 8 phyla and 74 genera were identified during three seasons in Wuxing Lake, including Chlorophyta (47 species), Bacillariophyta (35 species), Cyanophyta (12 species), Euglenophyta (8 species), Chrysophyta (4 species), Cryptophyta (2 species), Xanthophyte (2 species) and Pyrrophyta (2 species). Among these species, Chlorophyta, Bacillariophyta and Cyanophyta were main species of phytoplankton community which account for 42.0%,31.1% and 10.5% of the total species respectively (*Fig. 2a*). Species richness was the highest in spring (83 species), Chlorophyta (38.6%) and Bacillariophyta (34.9%) were main species, a decrease of phytoplankton species number with 70 species was observed in summer, Species number of Chlorophyta increased and became

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dominant (54.3%); the number of phytoplankton species in autumn remained the same in summer (70 species) while Bacillariophyta (40.0%) and Chlorophyta (31.4%) dominated phytoplankton in autumn (*Fig. 2a, b*).

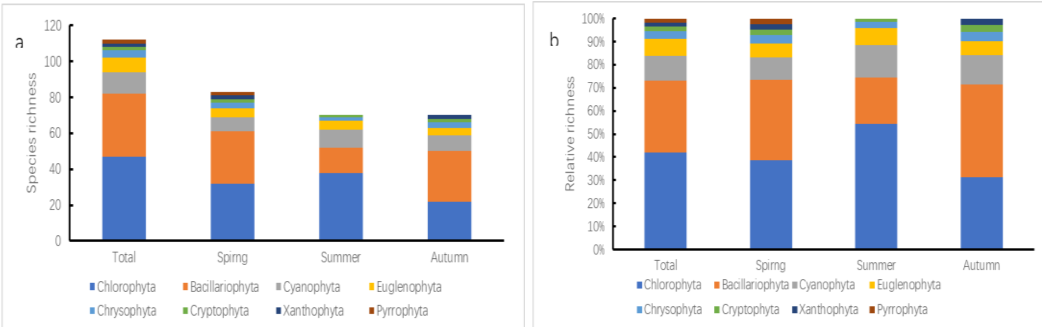
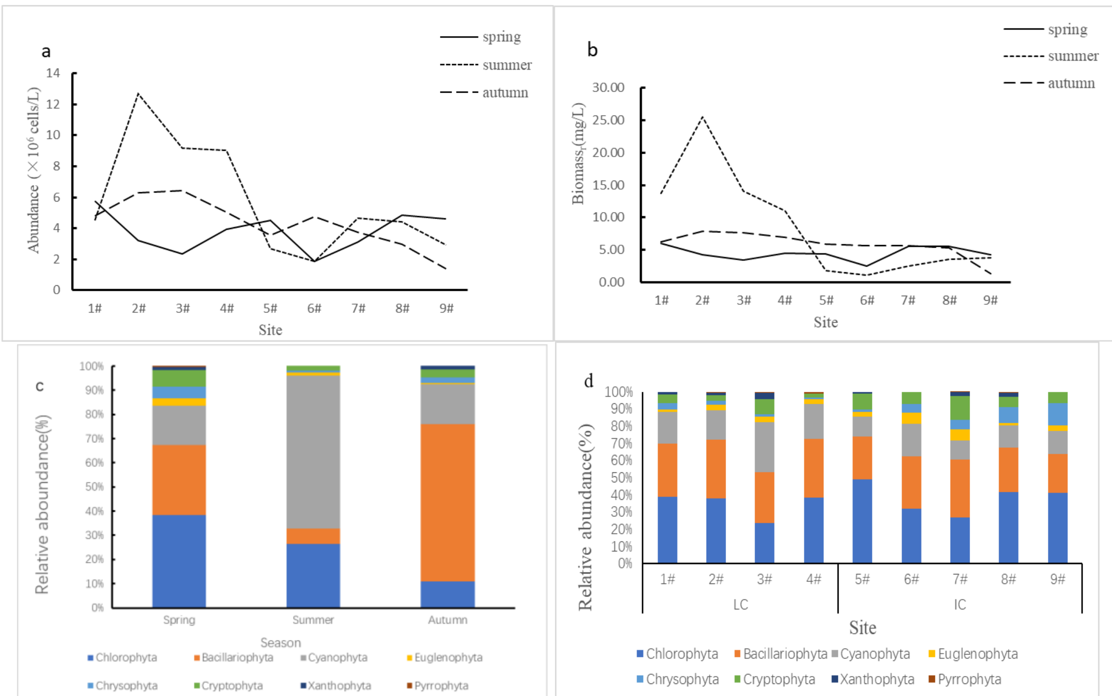


Figure 2. *Phytoplankton species richness (a), relative richness (b) in Wuxing Lake*

Phytoplankton abundance ranged from 1.38×10^6 to 1.27×10^7 cells/L and biomass ranged from 1.04 to 25.47 mg/L with the average 4.64×10^6 cells and 6.13 mg/L respectively in the lake. No statistically significant differences were observed in abundance and biomass among three seasons ($p > 0.05$), while both phytoplankton abundance and biomass showed the same seasonal variation as summer > autumn > spring (*Fig. 3a, b*). Maximum phytoplankton abundance (1.27×10^7 cells/L) and biomass (25.47 mg/L) both occurred at summer 2# while the minimum values of abundance (1.26×10^6 cells/L) and biomass (1.04 mg/L) appeared at 9# in autumn and 6 # in summer respectively. In terms of spatial distribution, the abundance and biomass of phytoplankton showed significant difference between LC and IC in summer ($P < 0.05$). While no significant spatial difference of phytoplankton abundance and biomass were found in spring and autumn.



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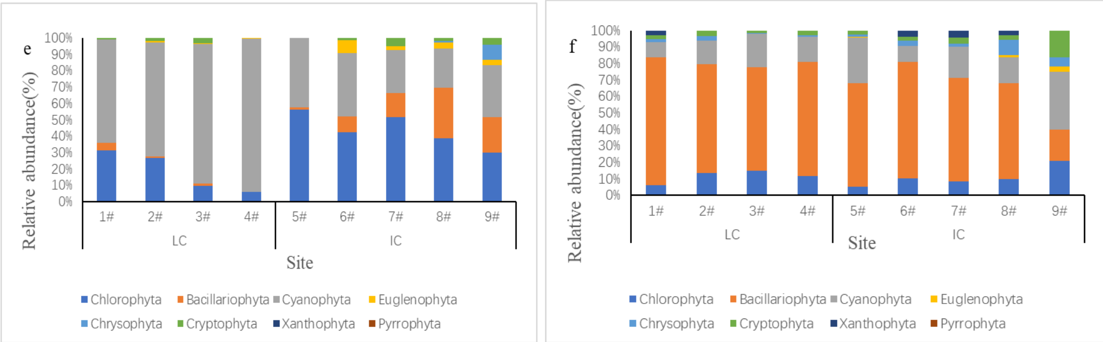

Figure 3. *Temporal and spatial variations of phytoplankton community in Wuxing Lake. (a) abundance of phytoplankton; (b) biomass of phytoplankton;(c) seasonal variation of relative abundance of phytoplankton community; (d-f) spatial variation of relative abundance of phytoplankton community at sampling sites in spring, summer and autumn*

Phytoplankton community Chlorophyta, Bacillariophyta and Cyanophyta are the main groups in the lake (*Fig. 3c*). In spring Chlorophyta and Bacillariophyta shared dominance with relative abundance of 38.32% and 29.00% respectively, meanwhile Cyanophyta also occupied high relative abundance (16.25%). Phytoplankton composition were similar at nine sampling sites (*Fig. 3d*). Relative abundance of Cyanophyta increased significantly and became dominant species (63.43%) in summer (*Fig. 3c*). Spatial, the relative abundance of Cyanophyta reigned supreme in LC with the highest value of 93.22%; while phytoplankton community was dominated by Chlorophyta and Cyanophyta in IC in the lake with 43.74% and 32.62% respectively (*Fig. 3e*). In autumn, Bacillariophyta became dominant species (*Fig. 3c*). The relative abundance of Bacillariophyta varied from 58.30% to 77.81% with a mean value 66.27% except site 9# (19.13%) (*Fig. 3f*).

According to the standard of dominant phytoplankton species ($Y > 0.02$),20 dominant species were selected during three seasons (*Table 3*). The number of dominant species was 15, 8 and 6 in spring, summer and autumn respectively with dominance index varied from 0.022 to 0.38. *Merismopedia minima* was the dominant specie existed in three seasons. The relative abundance of 20 dominant species (*Table 3*) predominant the phytoplankton abundance in spring (74.31%), summer (69.92%) and autumn (69.16%) in the lake, hence were used to analyze the relationship between phytoplankton community and environmental factors.

Table 3. *Dominant species and dominance index (Y) of phytoplankton during three seasons in Wuxing Lake*

Code	Species	Dominance index (Y)		
		Spring	Summer	Autumn
	Chlorophyta			
sp1	*Dictyosphaerium pulchellum*	0.099	0.059	
sp2	*Selenastrum minutum*	0.024		
sp3	*Ankistrodesmus falcatus*	0.066		
sp4	*Ankistrodesmus angustus*	0.037	0.024	
sp5	*Scenedesmus quadricauda*	0.022		
sp6	*Chlamydomonas aggregata*	0.031		
sp7	*nephrocytium agardhianum*		0.037	
sp8	*Chlorella pyrenoidosa*		0.026	0.043

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		Cyanophyta		
sp9	*Microcystis incerta*	0.029		
sp10	*Merismopedia minima*	0.120	0.06	0.061
sp11	*Synechocystis willei*		0.064	
sp12	*Anabaena circinalis*		0.380	
sp13	*Aphanizomenon flos-aquae*		0.029	
		Bacillariophyta		
sp14	*Nitzschia acicularis*	0.024		
sp15	*Cyclotella meneghiniana*	0.060		0.160
sp16	*Synedra acus*	0.061		
sp17	*Melosira granulata var. angustissima*	0.033		0.330
sp18	*Asterionella formosa*	0.046		0.030
		Chrysophyta		
sp19	*Dinobryon bavaricum*	0.035		
		Cryptophyta		
sp20	*Cryptomonas erosa*	0.049		0.025

Pearson correlation analysis

Results of Pearson correlation analysis (*Table 4*) showed that abundance of phytoplankton was positively correlated with WD, Tur and negatively correlated with SD. EC, COD_{Cr}, TP, pH and WT were the main factors influencing abundance of Chlorophyta. The abundance of Cyanophyta was very significant correlation with WT, DO ($p < 0.01$) while significantly relevant with SD and Tur ($P < 0.05$) (*Table 4*). In addition, abundance of Bacillariophyta was positive with WD, DO and EC while negative with WT, COD_{Cr}, and TP (*Table 4*).

Table 4. *Relationships between phytoplankton abundance (annual average abundance expressed as abundance, abundance of dominant species including Chlorophyta, Cyanophyta and Bacillariophyta) and environmental variables in Wuxing Lake*

	WT	WD	SD	EC	pH	DO	Tur	COD_{Cr}	TN	TP
Abundance		0.398*	-0.414*				0.417*			
Chlorophyta	0.400*			-.496**	-0.39*			0.437*		0.406*
Cyanophyta	0.539**		-0.445*			-0.497**	0.478*			
Bacillariophyta	-0.72**	0.598**		0.455*		0.689**		-0.595**		-0.418*

Variables without significant correlations are not included. * $p < 0.05$, ** $p < 0.01$

Diversity index of phytoplankton

The spatial and temporal variations of Shannon-Wiener index (*H'*) and Pielou's evenness index (*J'*) were presented in *Figure 4*. *H'* was higher in spring (3.11) than that in summer (2.30) and autumn (2.25) (*Fig. 4a*). The result Indicated that water quality was slight pollution in spring and light pollution in summer and autumn. Significant decline of *H'* values were observed at 3# (1.34) and 4# (1.05) in summer, indicating the water quality was deteriorated to moderate pollution in LC in summer. Similar variation trend of *J'* was observed with the highest values in spring (0.83) and Lower values in summer (0.69) and autumn (0.67) (*Fig. 4b*). The values of *J'* demonstrated that the water quality was clean in spring and slightly polluted in summer and autumn. The

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lowest J' values also appeared at 3# (0.43) and 4# (0.33) in summer, indicating the moderate pollution of water quality in LC.

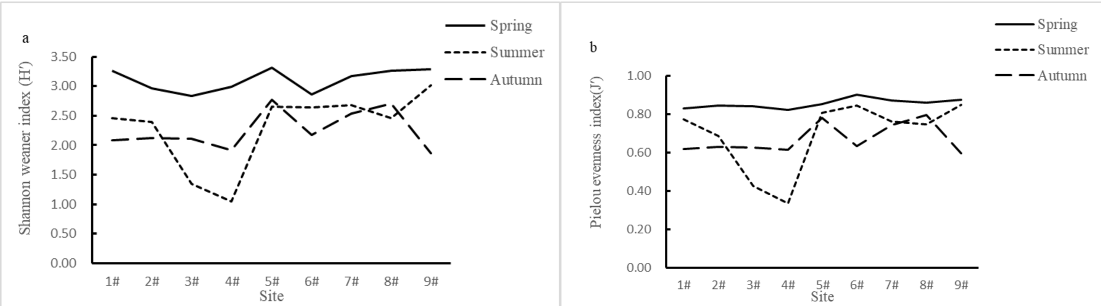

Figure 4. *Spatial and temporal variations of diversity index of phytoplankton: (a) Shannon-Wiener index (H'); (b) Pielou's evenness index (J')*

Relationship between dominant species and environmental factors

RDA ordination diagram of dominant species and environmental variables in Wuxing Lake was shown in *Figure 5*. Environmental variables explained 63.8% of the variations in phytoplankton abundance (*Fig. 5*). The eigenvalues of the first two RDA axes were 0.3322, 0.1997 and accounted for 53.18% of the cumulative variation. The Pseudo-canonical correlations for AX1 and AX2 were 0.9974 and 0.8907 respectively, indicating environmental variables can well explain species composition. SD, WD and TP were most important environmental factors influencing the abundance of dominant species, accounting for 27%, 16.3% and 6.5% respectively.

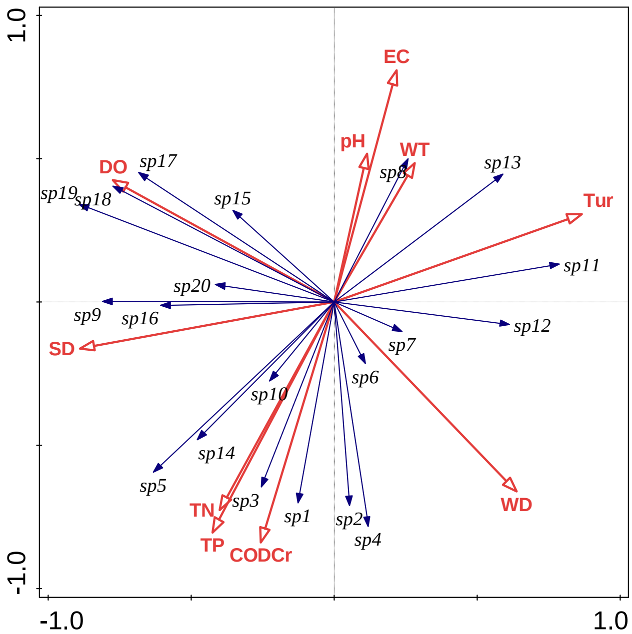

Figure 5. *Redundancy analysis (RDA) ordination diagram of the dominant species (blue lines) and environmental factors (red lines) in Wuxing Lake. The interpretation for codes of dominant phytoplankton species were shown in Table 2*

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Discussion

Spatial and seasonal variation of phytoplankton community in Wuxing Lake

Seasonal succession of phytoplankton community structure is the main content of studying dynamic change of phytoplankton community (Wei et al., 2020; Cao et al., 2018; Tian et al., 2013). However, seasonal variation of phytoplankton community in tropical area was not obvious, Cyanophyta dominated in most lakes during most seasons (Nankabirwa et al., 2019). Other scholars reported a two seasonal model (dry and rainy season) of phytoplankton succession in tropical aquatic systems while extraordinary high abundance of Cyanophyta during rainy season (Duong et al., 2012). In temperate regions, Bacillariophyta was dominant in spring with low temperature and Cyanophyta and Chlorophyta in summer and autumn (Ma et al., 2019). The main reason for the difference in phytoplankton succession between tropical and temperate regions can be explained by water temperature (Ke et al., 2008). Cyanophyta could better adapt high water temperatures compared to other phytoplankton, resulting in persistent dominance of cyanobacteria throughout the year in lakes and reservoirs in tropical areas (Nankabirwa et al., 2019; Barcante et al., 2020). While large variation of water temperature in temperate areas is beneficial to the growth and reproduction of various species of phytoplankton (Yuan et al., 2018; Zhao et al., 2017).

In our study significant seasonal succession of phytoplankton community structure was observed in Wuxing Lake. In spring phytoplankton community was dominated by Chlorophyta and Bacillariophyta which reflected the environmental characteristics of low WT and high concentration of TP (*Table 2*). During summer with the arrival of rainy season, surface runoff caused by precipitation carried large amount of sediment into the lake increased the Tur of the water, Cyanophyta with strong competitive ability proliferated rapidly and eventually predominated the phytoplankton community and led an outbreak of algae bloom. Large amounts of precipitation during autumn resulted in the highest water level and improved water quality of the lake (*Table 2*), as a result, Bacillariophyta became the dominant species.

Light condition represented by SD and Tur was the main factor influencing the abundance of phytoplankton according to the results of Pearson analysis. In addition, high correlation was observed between abundance of phytoplankton and Chlorophyta by Pearson correlation analysis ($r^2 = 0.847$, $p = 0.000$) indicating that controlling the abundance of Chlorophyta is the key to prevent the occurrence of phytoplankton blooms in Wuxing Lake. Cyanophyta is more tolerant to temperature than other algae and could grow with the optimum temperature between 30 and 35 °C (Yu et al., 2014), water temperature, light availability and nutrient are main factors influencing the competitive ability of Cyanophyta (Sekadende et al., 2005; Dalu and Wasserman, 2018). In this study, abundance of Cyanophyta may be more affected by environmental factors related to light conditions. WD, DO and EC were positive factors while WT, COD_{Cr}, and TP were negative variables of abundance of Bacillariophyta. The environmental characteristic of Wuxing Lake was low WT in spring and high WD, low WT, low nutrient (TN, TP and COD_{Cr}) in autumn, which facilitating the reproduction of Bacillariophyta (*Fig. 3c*).

Abundance of Cyanophyta showed significantly spatial difference ($p < 005$) in summer in this study. Significantly spatial variation ($p < 0.01$) of phytoplankton abundance was reported in the Lake Xingkai basin and the main reason was considered as differences in environmental factors (Yuan et al., 2018). Wuxing Lake

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is a small shallow lake which water is from precipitation and drainage of the surrounding farmland. Water entering the lake through inlet channel where distributed large number of Gramineae emergent plants, mainly cattails and reeds, however emergent plants were scarce in the lake. As a result, two areas with obvious differences were formed, including lake center (LC) with wide water surface, higher WD, less aquatic plants and inlet channel (IC) characterized by narrow, shallow in addition with large distribution of aquatic vascular plants. One-way ANOVA showed that some environmental factors (WD, WT, SD and Tur) in these two regions had significant spatial differences, which may be the main reason for the spatial variability of phytoplankton abundance.

Driving factors of phytoplankton community in Wuxing Lake

Dominant species of phytoplankton in Wuxing Lake showed obvious seasonal succession. *Merismopedia minima*, *Dictyosphaerium pulchellum*, *Ankistrodesmus falcatus*, *Cyclotella meneghiniana* and *Synedra acus* were main dominant species in spring with the dominant index (*Y*) 0.12, 0.099, 0.066, 0.060 and 0.061 respectively (*Table 3*). In summer, *Anabaena circinalis* was the most abundant dominant specie with the *Y* value 0.38, *D. pulchellum* (0.059), *M. minima* (0.060) and *Synechocystis willei* (0.064) were also dominant species with high abundance. In autumn, Bacillariophyta dominant species represented by *Melosira granulata var. angustissima* and *C. meneghiniana* became the most abundant dominant species which *Y* values 0.33 and 0.16. *M. minima* was also the main dominant species with the *Y* value 0.061.

Factors influencing phytoplankton community composition in lakes including WT, DO, ORP, SD, PH, TP, TSS, COD_{Cr} etc. (Ma et al., 2019; Jiang et al., 2014). In this study, phytoplankton community structure was mainly regulated by SD, WD and TP. Tur, DO, COD_{Cr}, TN and EC were also important environment factors influencing the phytoplankton assemblage. RDA result showed that the abundance of Chlorophyta (sp1-sp5) represented by *D. pulchellum* (sp1) and *A. falcatus* (sp3) were positive with TP and COD_{Cr}, while Cyanophyta (sp11-sp13) represented by *A. circinalis* (sp12) and *S. willei* (sp13) were positive with Tur and negative with SD and DO. Contrary, Bacillariophyta represented by *M.* var. *angustissima* (sp17), *C. meneghiniana* (sp15) and *S. acus* (sp16) were positive correlation with DO, SD and EC.

TP is the main factor stimulating the proliferation of phytoplankton (Li et al., 2021; Schindler et al., 2016), while COD_{Cr} and DO represent organic pollution in water (Kutlu et al., 2020). Large amount farmland backwater containing high concentration of nutrients flowed into the lake in spring and leading to the highest value of TP and COD_{Cr}, accelerating the reproduction of Chlorophyta. Meanwhile, high values of SD and DO in spring were also beneficial to the growth of Bacillariophyta. As a result, the abundance of Chlorophyta and Bacillariophyta dominant in spring. Some scholars reported that poor lighting condition suppressed the growth of Bacillariophyta and Chlorophyta, while facilitated the dominance of Cyanophyta (Liu et al., 2021). With the arrival of summer, precipitation carried large amount of sediment into the lake, which deteriorated the light conditions of the water (low SD, DO and high Tur, *Table 2*), which facilitating the growth of cyanobacteria. Li et al. (2019) reported that the abundance of Bacillariophyta was positive with nutritional level and EC, while negative with WT with cold temperate climate in autumn. In this study, appropriate environmental conditions such as DO, SD and EC stimulating the reproduction of Bacillariophyta and became dominant species in autumn.

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Water quality assessment and management suggestion for Wuxing Lake

Due to the sensitivity and rapid response to environmental changes, phytoplankton community can be used as indicator of aquatic health (Ni et al., 2018). Shannon-Wiener index (*H'*) and Pielou's evenness index (*J'*) based on phytoplankton community were frequently used to estimate the water quality in water body (Zhu et al., 2020). In this study, the results of *H'* and *J'* were consistent, indicating the slight to light pollution state in the lake. However, the obvious low values of *H'* and *J'* at site 3#,4# in summer indicated the risk of deterioration of water. In fact, Cyanophyta blooms already erupted in summer 2019. Wuxing Lake is a typical eutrophic small lake with water quality meeting the national water quality standard of Level Ⅴ(GB3838-2002,2002). Liu et al. (2021) suggested nutrient below the threshold ($TN \leq 1.5$ mg/L; $TP \leq 0.1$ mg/L) to sustain a good ecological status in the lake. Considering the nutritional status and the role of Wuxing Lake in maintaining ecological diversity, appropriate management measures should be taken to control the occurrence of Cyanophyta bloom in summer. Considering that SD and Tur were main factors affecting the abundance of Cyanophyta, measures to improve SD may be effective.

Conclusion

This study focused on the community structure (including species richness, abundance, biomass and dominant species), spatiotemporal change and driving factors of phytoplankton in Wuxing Lake which was a small eutrophic lake in northeast China. Meanwhile, water quality was evaluated. Chlorophyta, Bacillariophyta and Cyanophyta were main dominant species. The average abundance and biomass were 4.64×10^6 cells and 6.13 mg/L respectively with the values in summer > autumn > spring. Seasonal succession of phytoplankton dominant species (expressed by abundance) in the lake was obvious. Chlorophyta and Bacillariophyta were dominant in spring, Cyanophyta predominated the phytoplankton community in summer, while Bacillariophyta was the most abundance species in autumn. Spatial heterogeneity of phytoplankton abundance was observed in summer. 20 dominant species were selected during three seasons with 15 species in spring,8 species in summer and 6 species in autumn. RDA result showed that SD, WD and TP were most important factors influencing the abundance of dominant species. The results of Shannon-Wiener index (*H'*) and Pielou's evenness index (*J'*) indicating the slight to light pollution in the lake. However, in the lake, outbreak of cyanobacteria bloom in summer indicated that the water quality was deteriorating in recent years. In order to control the reproduction of cyanobacteria in Wuxing Lake in summer, measures should be taken to improve SD and reduce TP. Further studies should focus on long-term changes of phytoplankton community structure and relationship between phytoplankton and zooplankton to better understand the driving factors of phytoplankton community.

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