氮磷比对长江中下游地区浅水湖泊群浮游植物类群的影响

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摘 要 2003 年夏和 2004 年夏对中国长江中下游地区的 30 个浅水湖泊的浮游植物类群进行调查。为了研究不同氮磷比（TN/TP）对浮游植物组成的影响，将浮游植物的六个门，分别在 TN/TP＞30、12＜TN/TP＜30、TN/TP＜12 三个区间随总磷的变化规律进行研究。当 TN/TP 从高水平（＞30）降到中等水平（12～30）时，除蓝藻门外的其他五个浮游植物门的斜率均随总磷的升高而增加。但是当 TN/TP 从中等水平（12～30）降到低水平（＜12）时，除绿藻和隐藻门外，其他浮游植物门的斜率均随总磷的升高呈下降趋势。当 TN/TP 从高水平（＞30）降到降至低水平（＜12）时，蓝藻门的斜率不断降低，说明蓝藻在较高 TN/TP 有更好的生长潜力。同样发现，绿藻和隐藻门则随 TN/TP 的降低有更好的生长潜力。当 TN/TP 在高水平（＞30）和低水平（＜12）时，硅藻、甲藻和裸藻门的斜率均发生下降，说明这三个门的藻类在 TN/TP 为中等水平（12～30）的环境中有更好的生长潜力。

关键词 氮磷比；浮游植物；浅水湖泊；类群；长江

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Patterns of Phytoplankton Taxonomic Composition Affected by Different Nitrogen Phosphorus Ratios in Shallow Lakes of the Yangtze River Area

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Abstract The phytoplankton groups were investigated in 30 shallow Chinese lakes in the middle and lower

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reaches of the Yangtze River area in the summer of 2003 and 2004. To explore the effects of different nitrogen phosphorus ratios (TN/TP ratios) on the phytoplankton taxonomic composition of these study sites, six main taxonomic groups were studied with three TN/TP ratios intervals: TN/TP＞30, 12＜TN/TP＜30 and TN/TP＜12. The biomass curves of these taxonomic groups showed corresponding increases or decreases with different TN/TP ratios. When TN/TP ratios declined from high (＞30) to medium (12-30), the slopes of the total biomass curve increased, as did the relative abundances of all groups except Cyanophyta. But when the TN/TP declined from medium (12-30) to low (＜12) levels, the slopes of most groups decreased except Chlorophyta and Cryptophyta. The amount of Cyanophyta increased with TP when TN/TP ratios declined from above 30 to below 12, suggesting that cyanobacteria adapted to higher TN/TP ratios. However, Chlorophyta and Cryptophyta tended to be restricted by phosphorus when TN/TP ratios declined from above 30 to below 12, and these groups adapted to lower TN/TP ratios. The biomass of Bacillariophyta, Pyrrophyta and Euglenophyta tended decreased when TN/TP ratios were above 30 and below 12, suggesting that medium TN/TP ratios (12-30) favoured these groups.

Keywords nitrogen phosphorus ratio, phytoplankton, shallow lakes, taxonomic groups, the Yangtze River

1 Introduction

Transitions between nitrogen and phosphorus limitation for phytoplankton growth are common in lakes[1,2] noted that the chlorophyll in Japanese lakes was a logarithmic function of both total phosphorus (TP) and total nitrogen (TN), and concluded that over the range of 10≤TN/TP≤17, chlorophyll was very nearly balanced with respect to both TP and TN but that chlorophyll was dependent only on TN when TN/TP ratio was below 10, and only on TP when TN/TP ratio was above 17 (＞17). Dillon and Rigler[3] dealt with the problem of nitrogen limitation by restricting their analysis to lakes where TN/TP ratios were above 12. Thus, variability of the TN/TP ratios may provide an explanation for the variability in phosphorus-chlorophyll relationships.

Numerous corresponding studies have shown the TN/TP ratios were related with structure of phytoplankton community. Smith[4] found that cyanobacteria dominated when the epilimnetic TN/TP ratios had values less than 29∶1 and when TN/TP ratios had values greater than 29∶1, non-cyanobacteria became the dominated species. Bulgakow and Levich[5] reported that high TN/TP ratio (20-50) was benefit for the growth of Chlorococcales, whereas Cyanophyta dominated in the community when TN/TP ratios decreased to 5-10. Yang et al.[6] proved that Cyanophyta subjoined with the increase of nitrogen and phosphorus when TN/TP ratios had values greater than 28∶1 and Euglenophyta dominated in the community with higher content of nitrogen and phosphorus.

Several studies have described the biomass of cyanobacteria and other groups increased with the increase of total phosphorus in north temperate[7-10] and subtropical lakes[11]. And some other studies have measured the changes of the average proportions of some algal groups with TP[12-14]. Furthermore, the balance of TN, TP and SRSi-ratios was used to determine whether the phytoplankton communities are influenced by nutrient stoichiometry[15].

However, there are limited information about the quantitative comparisons of the changes of phytoplankton taxonomic groups affected by TP in different TN/TP ratios[16], especially in subtropical shallow lakes.

The purpose of this paper is to investigate six predominance phytoplankton taxonomic groups of 30 shallow Chinese lakes changed with different TN/TP ratios. So, the data of the study were divided into three groups according to three TN/TP ratios intervals: ＞30, 12-30 and ＜12.

2 Materials and Methods

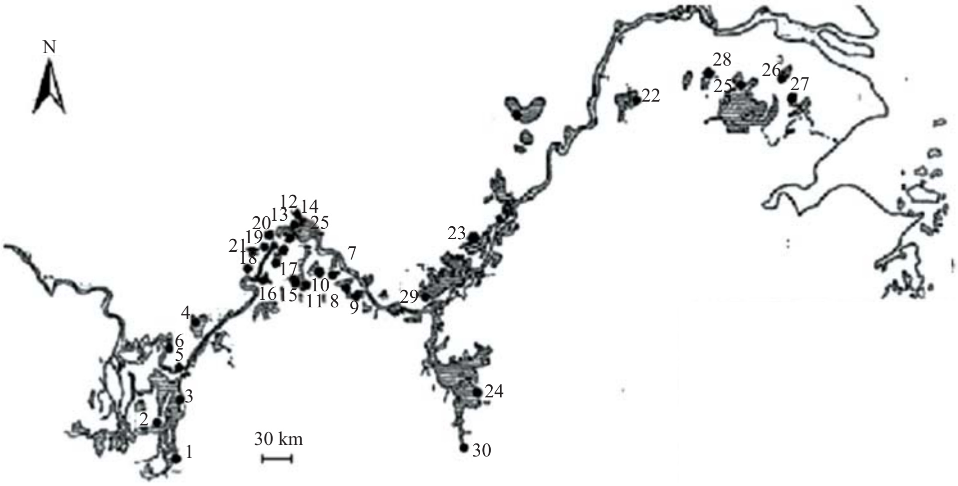
2.1 Study area

The Yangtze River is the biggest river in China and the third biggest river in the world. Thirty shallow lakes (28.5°N-32.5°N, 113.7°E-119.2°E) included in this study ranged in size from about 1 to 3 914 km^2 in the middle and lower reaches of the Yangtze River area (Fig. 1). The climate is generally subtropical monsoon, and the climate is divided into dry season (November to April) and rainy season (May to October) commonly.

All of the 30 shallow lakes are located in five provinces (Hubei, Hunan, Jiangxi, Anhui and Jiangsu) and most of these lakes are eutrophic or hypereutrophic[17] and manipulated (e.g. fertilized, dredged, acidified, stocked, etc.).

2.2 Sample collection and analysis

Considering environmental heterogeneity and surface area of the lakes, sampling sites were set from 2 to 22 in each lake. The positions were directed by a GPS system. These lakes were sampled from July to September in 2003 and 2004. Water samples in these lakes were collected each site with tygon tubing fitted with a one-way valve. Samples collected from a combination of surface, middle and bottom layers. Water samples collected were analyzed for TN, TP and phytoplankton biomass.



1.South Dongting lake; 2. West Dongting lake; 3. East Dongting lake; 4. Honghu lake; 5. Laojianghe river; 6. Tianezhou lake; 7. Huama lake; 8. Hongxing lake; 9. Sanliqi lake; 10.Qiaodun lake; 11. Baoan lake; 12. Qi lake; 13. Taojiadahu lake; 14. Zhangdu lake; 15. Niushan lake; 16. Qingling lake; 17. Nanhu lake; 18. Houguan lake; 19. Longyang lake; 20. Moshui Lake; 21. Sanjiao lake; 22. Shijiu lake; 23. Wuchang lake; 24. Poyang lake; 25. Daoshui lake; 26. Yangcheng lake; 27. Dianshan lake; 28. Gehu lake; 29. Longgan lake; 30. Junshan lake

Fig. 1 Geographic location of the lakes surveyed

Total nitrogen was determined by alkaline potassium persulfate digestion[18] with absorbance measured at 220 nm[19]. TP was analyzed by colorimetric methods after potassium persulfate digestion[20,21]. The water was filtered through a membrane filter (Ø=0.45 μm) for dissolved inorganic nitrogen and phosphorus, ammonium ion (NH_4-N) by the Nessler method[22], nitrite (NO_2-N) by the a-naphthylamine method[23], nitrate (NO_3-N) by the UV spectro photometric method[23], and orthophosphate (PO_4-P) were determined by the molybdenum blue reaction described by Koroleff [24].

Phytoplankton were preserved in Lugol's solution from the mixed water samples. Phytoplankton were identified based on descriptions of Prescott[25] and enumerated with a microscope equipped with a calibrated micrometer[26].

2.3 Statistics

Data of all sites were used to analysis. STATISTICA for Windows statistical software (version 6.0) was used for all analyses. To characterize the effects of the six taxonomic groups by TP in different TN/TP ratios, polynomial curve was used. In order to stabilize the variance for correlation and regression analysis, all the variables were log-transformed.

3 Results

The mean nutrient values were high in these lakes (Table 1). Linear correlation analyses show that over the entire TP range, the summer biomass of each phytoplankton taxonomic group and total phytoplankton biomass were significantly and positively related to TP. However, through the polynomial regression analysis, six mainly taxonomic groups increased differently with TP in different TN/TP ratios (Fig. 2 and 3). There are three growth fashions: exponential growth, logarithmic growth and linear growth.

Table 1 Nutrient characteristics for the data sets of the study lakes

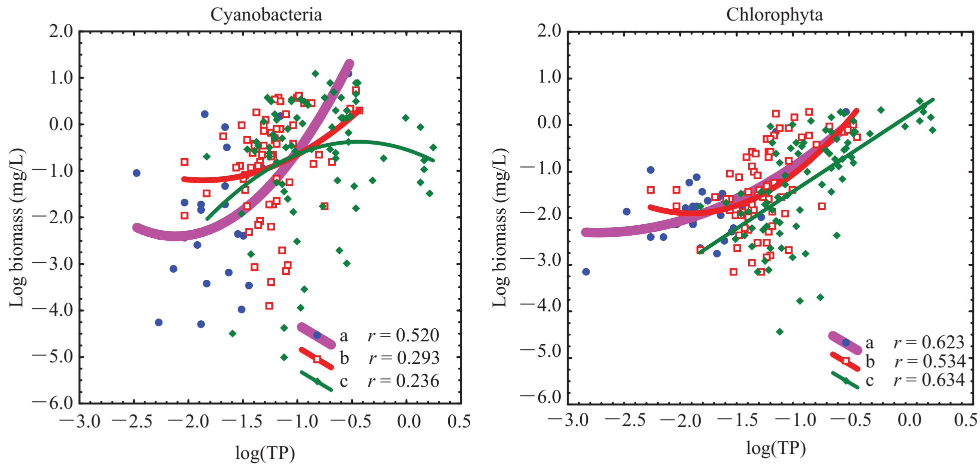
Items	Summer amount
NO_3-N	0.604 (0.046~2.063)
NH_4-N	0.358(0.004~6.541)
NO_2-N	0.052(*a*~1.205)
TN	1.604 (0.130~14.88)
PO_4-P	0.062(*b*~1.185)
TP	0.16 (*b*~1.75)
TN/TP	20.47(1.992~331.144)
Phytoplankton Biomass(PB)	2.236（0.011~21.42）

Mean and range are presented. Lake data sets as defined in the text ("*a*" means lower than 0.003 mg/L; "*b*" means lower than 0.01 mg/L; Number of samples n=219)

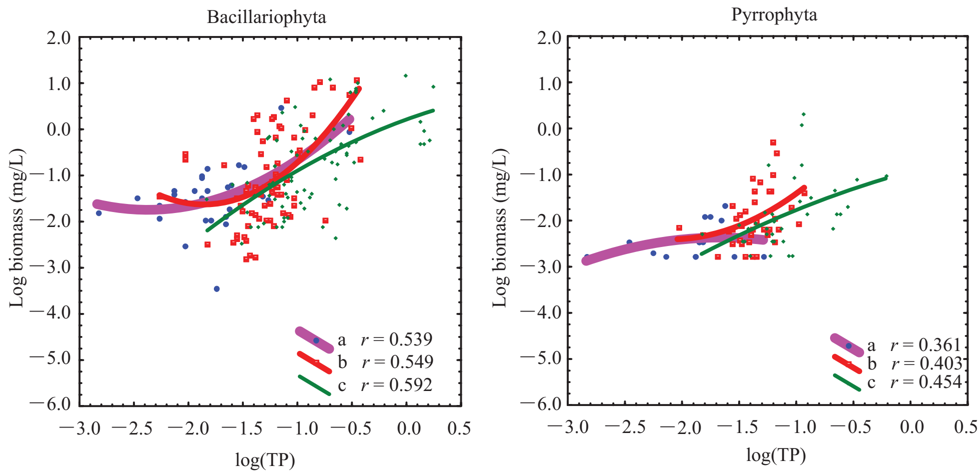
Table 2 Linear correlation between phytoplankton biomass and TP in different TN/TP

Taxonomic groups	TN/TP＞30				12＜TN/TP＜30				TN/TP＜12			
	n	*r*	*p*	slope	*n*	*r*	*p*	slope	*n*	*r*	*p*	slope
Cyanobacteria	24	0.4417	0.0307	1.6041	65	0.2705	0.0293	0.9708	78	0.1597	NS	0.4613
Chlorophyta	32	0.5801	0.0005	0.9557	72	0.5031	*	1.3407	81	0.6332	*	1.5792
Bacillariophyta	33	0.4598	0.0071	0.7577	74	0.4909	*	1.4903	81	0.5876	*	1.2149
Pyrrophyta	19	0.3097	NS	0.2929	38	0.3886	0.0159	1.0866	36	0.4524	0.0056	1.0079
Cryptophyta	21	－0.255	NS	－0.451	26	0.4133	0.0359	1.0556	49	0.7382	*	1.7115
Euglenophyta	14	0.1345	NS	0.2519	34	0.4146	0.0148	1.2621	47	0.5449	*	0.9682
Total Biomass	143	0.4942	0.0030	0.7441	309	0.5258	*	1.297	372	0.5195	*	1.0107

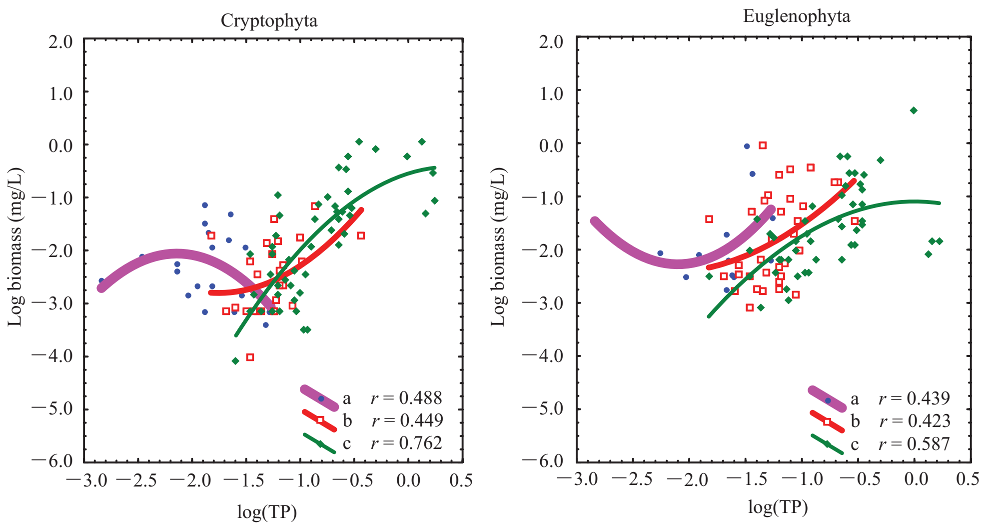
NS＝not significant; N＝number of observations; *＝P＜0.00001



(a) TN/TP>30



(b)12<TN/TP<30

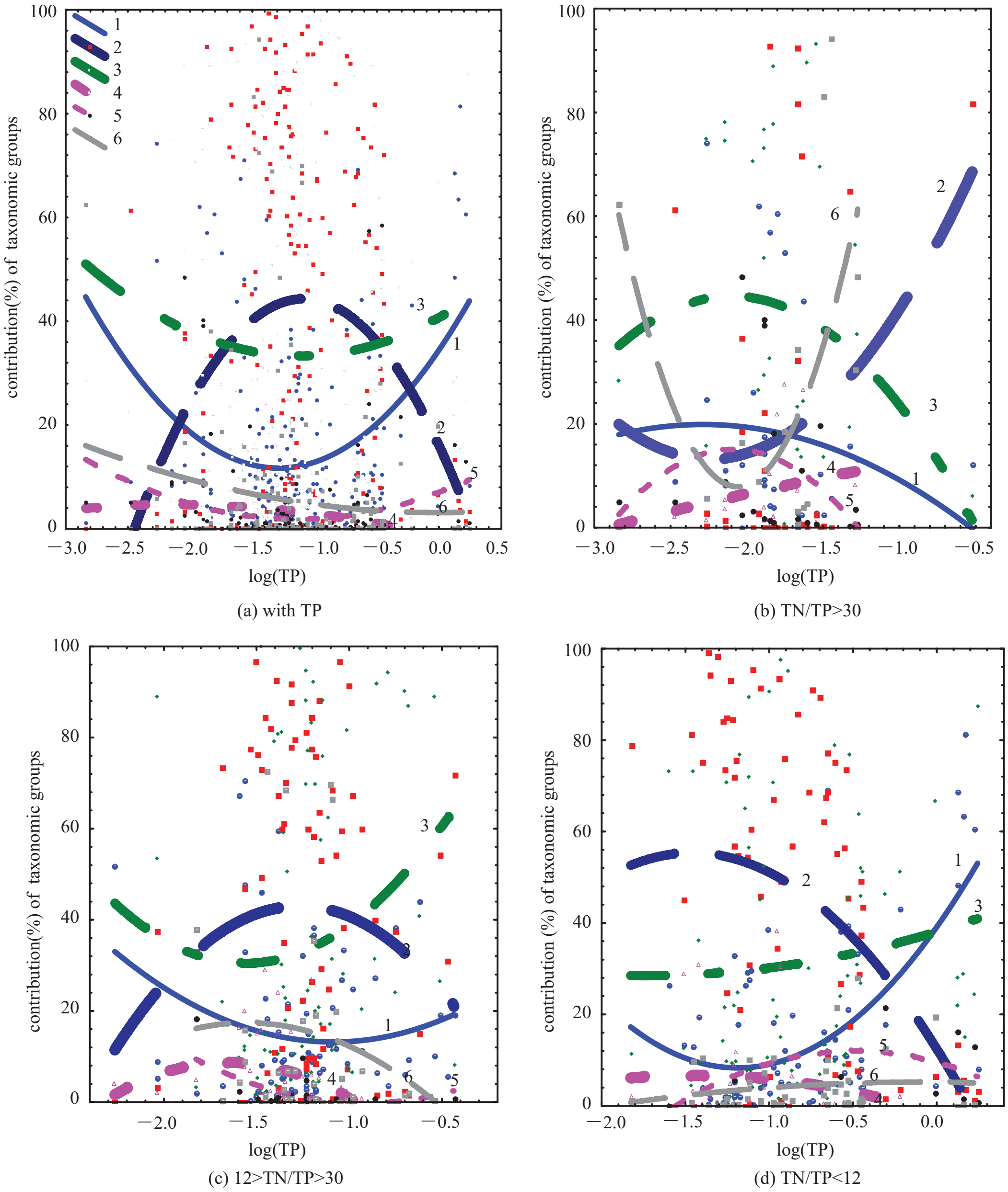


(c) TN/TP<12

Fig. 2　Ploynolmial regression analysis in six mainly taxonomic group summer biomass with total phosphorus（TP）

Cyanophyta showed lower biomass but distinctly sharp exponential growth with TP when TN/TP were above 30 (Table 2, Fig. 2). The exponential growth of Cyanophyta biomass changed more evenly with TP in the mediate TN/TP (12-30) (Fig. 2 and 3). When TN/TP ratio was below 12, the increase of Cyanophyta changed to a logarithmic growth fashion, although the change was not significant in slope (Fig. 2). Linear correlation shows similar tendency about the change of Cyanophyta with TP. The slope of cyanobacterial biomass decreases from 1.604 (TN/TP>30) to 0.971 (12<TN/TP<30) and further to 0.461 (TN/TP<12).

Bacillariophyta showed more interesting



1 = Chlorophyta; 2 = Cyanobacteria; 3 = Bacillariophyta; 4 = Pyrrophyta; 5 = Cryptophyta; 6 = Euglenophyta

Fig. 3 Contribution (%) of phytoplankton taxonomic groups to total summer biomass

change with TN/TP ratios: when TN/TP＞30, Bacillariophyta showed a quick exponential growth with TP, but when TN/TP ratios were between 12-30, the increase of Bacillariophyta biomass were faster; however, when TN/TP＜12, Bacillariophyta showed a slower logarithmic growth with TP. In contrast, the linear correlation showed a similar tendency with TP. The slope of Bacillariophyta biomass increased from 0.758 (TN/TP＞30) to 1.490 (12＜TN/TP＜30) and then decreases to 1.215 (TN/TP＜12).

However, in linear correlation mode, Chlorophyta showed a steady increase with TP from high TN/TP ratio (＞30) to low TN/TP ratio (＜12), and the biomass of Chlorophyta showed exponential growth when TN/TP ratio was above 12, and linear growth with TP when TN/TP ratio was less than 12.

As to linear correlation model, Pyrrophyta and Euglenophyta showed similar change with diatom, Cryptophyta showed similar change with Chlorophyta. However, from the polynomial curve, the three groups increased more quickly in mediate TN/TP ratios (12-30) than in high TN/TP ratios (＞30). When TN/TP ratios were less than 12, these three groups all showed exponential growth with TP.

Under different TN/TP ratios, the changes of the relative proportions about phytoplankton taxonomic groups show how summer phytoplankton community composition was relative to TP (Table 2, Fig. 3). Some groups maintained a fairly constant representation in the community. Among these, Bacillariophyta accounted for a consistently large proportion (30%-40%) of summer phytoplankton biomass from TN/TP ratios above 30 to TN/TP ratios below 12. Crytophyta and Pyrrophyta showed constant fractions of the total biomass with increasing TP in the three TN/TP intervals, although the fraction was much smaller (＜10%).

On the other hand, the relative proportion of cyanobacteria increased at first and dominated when TN/TP ratios were in mediate (12-30) and low (＜12) levels with TP, but tended to decrease in high TP concentrations. Chlorophyta maintained a constant representation in the community when TN/TP ratios were above 12, but when TN/TP ratios were below 12, Chlorophyta tended to dominate in phytoplankon groups. Euglenophyta decreased its proportion from high TN/TP ratios (＞30) to mediate TN/TP level (12-30) and showed only a smaller fraction (＜10%) when TN/TP was high (＞30).

Strongly significant relationships existed between TP and PO_4, and between TN and NH_4 in these lakes (Fig. 4).

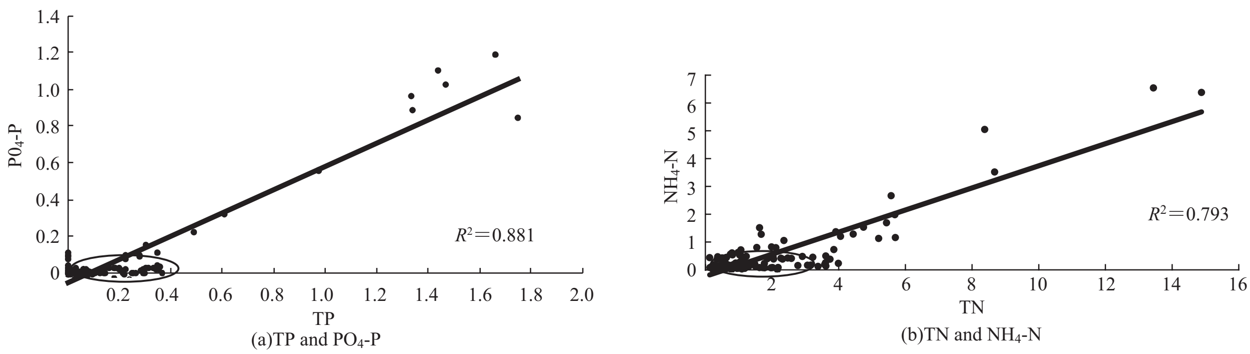


Fig. 4 Correlations between TP and PO_4-P, TN and NH_4-N. The circle area shows the low values of PO_4-P and NH_4-N

4 Discussion

The results of this study, as well as Downing and Mccauley[27], suggest that the sites with lower TN/TP ratios often have higher TP concentration. Enrichment-related changes in the taxonomic composition of summer phytoplankton communities are widely documented[9,28-31]. However, the present study shows that the biomass of taxonomic groups changed in summer with different TN/TP ratios: when TN/TP ratios were high (＞30), Cyanophyta, Bacillariophyta and Cholophyta showed positive regression with TP(Cyanophyta exhibited the most rapid increase), but Crytophyta, Pyrrophyta and Euglenophyta showed little TP-related change; in contrast, when TN/TP ratios were in mediate level (12-30), all taxonomic groups increased sharply with TP except Crytophyta; and when TN/TP ratios were below 12, Cyanophyta showed little TP-related changes, but others groups increased with TP, especially for Crytophyta (r=0.74, P＜0.001).

In the present study, the proportion of Cyanophyta showed different change with other groups in the three TN/TP ratios intervals. Species of this taxa are frequently responsible for noxious bloom in eutrophic lakes but are also an important component of phytoplankton in summer[4,5,32]. The TN/TP theory which suggests that cyanobacteria dominate in low TN/TP lakes, has been widely used to explain why cyanobacteria dominate in lakes. Also, Bulgakov and Levich[5] reported that high TN/TP ratios (20-50) favor the development of chlorococcales, while a reduction of the ratios to 5-10 frequently leads to a community dominated by Cyanophyta. Our results show that, in the mediate TN/TP ratios (12-30), cyanobacteria dominates in the phytoplankton groups, but as TN/TP ratios were below 12, proportion and increasing rate of cyanobacteria had a decrease trend. Similar results can be found in recent research by Liu, that found when N/P＝3.84, *Dactylococcopsis* sp. showed lowest growth rate than others higher N/P[33]. Therefore, our results may suggest that cyanobacteria tend to be restricted by TP as TN/TP ratios are above 30 and by nitrogen as TN/TP ratios are below 12. Although it is commonly accepted that cyanobacteria are abundant in hypereutrophic lakes, cyanobacteria are poor competitors in nutrient replete system, because of less light in hypereutrophic lakes and competition with bacteria for nutrition[34,35].

As with cyanbacteria, nutrition (especially P and Si)[36] may select for the predominant diatom morphology. Diatoms generally predominate summer phytoplankton communities at intermediate TP levels[9], and efficient nutrient uptake may favor pinnate diatoms in oligotrophic environments[37]. The experiment results show that Bacillariophyta dominate as TN/TP ratios are above 30, which also indicates that Bacillariophyta tends to dominate in lower TP values.

Chlorophyta, on the other hand, is a very diverse group[38], with a broad range of morphotypes, including both edible and inedible forms for herbivorous zooplankton. Nevertheless, this group rarely dominates in phytoplankton communities of temperate lakes, except at nutrient extremes[38], and the results also show that in low TN/TP ratio (＜12), Chlorophyta increases quickly with TP, and dominates when TP＞1.0 mg/L.

Because actual limitation of phytoplankton growth will be determined by the concentrations of available dissolved inorganic nitrogen and phosphorus, the

TN/TP ratios may be very important when the dissolved inorganic forms falls below limiting level. Although, in the present study, many values of NH_4 and PO_4 concentrations are very low in summer, probably due to active assimilation by phytoplankton and water bacteria in this season, the significant correlations between TN and NH_4, and between TP and PO_4 show that the TN/TP ratio can reflect the dissolved inorganic nutrient limitation in a sense.

In our study, Cryptophyta were abundant in oligotrophic and eutrophic waters, which in agreement with the observations of Ilmavirta[39]. Cryptophyta were found in different types of waters, with a tendency for small-sized cells to occur in less productive waters[36,40]. The result shows that Cryptophyta increases quickly as the TN/TP ratios decrease from above 30 to below 30, indicating that Cryptophyta is favoured by low TN/TP ratio(especially ＜12) and suggesting Cryptophyta prefers to live in high nutrition level if it don't be restricted by nitrogen and light intensity.

Though Euglenophyta are almost entirely restricted to eutrophic lakes[41-43], our result shows that Dinophycease and Euglenophyceae increase quickly in the mediate TN/TP ratios（12-30）, indicating that these taxa prefer to the middle TN/TP ratios.

It is beyond our scope to examine the many factors that affect individual taxonomic group dynamics. A number of these factors, however, which influence phytoplankton growth and loss rate (e.g. light, nutrition uptake, division rates, motility, sinking, and grazing losses), interact with both taxon size and morphology[44].

The ratios of TN/TP are one of the most commonly used methods to assess phytoplankton limitation in aquatic ecosystems[45]. Our study firstly applies this method in evaluating the phytoplankton taxonomic composition in different nutrient level, and the data suggest that the water column TN/TP ratio can be an effective tool for assessing the structure of phytoplankton taxonomic composition.

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