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ScienceDirect
Journal of Environmental Sciences 2010, 22(1) 32–39

JOURNAL OF ENVIRONMENTAL SCIENCES
ISSN 1001-0742
CN 11-2629/X
www.jesc.ac.cn

Effect of nutrient level on phytoplankton community structure in different water bodies

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Received 11 February 2009; revised 25 May 2009; accepted 28 July 2009

Abstract

Increasing levels of pollution within water bodies can cause eutrophication and an associated rapid growth in and reproduction of phytoplankton. Although most frequently occurring in bodies of water such as lakes and dams, in recent years an increasing number of river systems in China have suffered serious algal blooms. The community structure of phytoplankton may differ, however, dependent on the hydrodynamic conditions and nutrient levels within the water body. The field investigation results obtained from a stagnant river in Suzhou City and Taihu Lake, China, showed that in water with higher concentrations of nitrogen and phosphorus, Chlorophyta became the predominant species and in water with lower concentrations of nitrogen and phosphorus, Cyanobacteria became the predominant species. Growth experiments with competitive species, *Microcystis aeruginosa* Kütz and *Scenedesmus* quadricauda (Turp.), were conducted at three different nutrient levels. The biomass of algae in pure and mixed cultures was measured under conditions of different N/P ratios at oligotrophic, eutrophic and hypertrophic nutrient levels. The results indicated that the most suitable state for the growth and reproduction of *M. aeruginosa* and *S. quadricauda* were eutrophic conditions in both pure and mixed cultures. Under competition, however, the lower medium nutrient levels favoured *M. aeruginosa*, while the higher medium nutrient levels better suited *S. quadricauda*. Under similar hydrodynamic conditions, the community structure of phytoplankton in the water body was determined by the dominant species in competition for nutrients.

Key words: phytoplankton; community structure; nutrients level; N/P ratio

DOI: 10.1016/S1001-0742(09)60071-1

Introduction

As water pollution intensifies in various water bodies, the problem of eutrophication becomes ever more serious and leads to an increase in the frequency of algae blooms. These problems have influenced the ecosystem, human health and local economy (Wang and Lu, 2004). In analysing the causes of algae blooms, we considered three types of factors: physical, chemical and biological. Recently, in an attempt to control algae blooms, researchers have predominately concentrated on studying chemical factors. In particular, such research has focussed on establishing the relationship between algae growth and concentrations of nitrogen and phosphorus, and determining the limiting factors of algae growth. For example, Liu et al. (2003) analysed the distribution characteristics of nutrients in a water body and the relationship of nutrient distributions with chlorophyll *a*. From the analyses, they concluded that phosphorus was the main limiting factor for the growth of phytoplankton in the Fuxian Lake in China. In addition, based on long-term observations, Lau and Lane (2002) found that the phytoplankton biomass in the Broad Lake (Norfolk, UK) had a high correlation with the concentration of P and N in spring, summer and autumn.

The community structure of phytoplankton depends on the morphology of the water body, hydrodynamic characteristics, sunlight intensity, temperature, nutrient concentration and the biological characteristics of algae and zooplankton. Previously, in the process of improving water quality of city waterways, we have found that in some water bodies with low velocity and very high nutrient levels, Cyanobacteria blooms do not occur. In contrast, Cyanobacteria blooms have been observed in some water bodies with very low nutrient levels. Moreover, after wastewater interception around some heavily polluted water bodies, Cyanobacteria bloom outbreaks have occurred after water quality improvement. In relation to these phenomena, we investigated the community structure of phytoplankton in a river with very low flow velocities in Suzhou City and from around Taihu Lake, China. Through comparing Taihu Lake and the relatively stagnant Suzhou City river, we investigated whether different nutrient concentrations cause or influence different phytoplankton community structures. In order to identify the formation mechanism of predominant species under different nutrient levels, we selected *Microcystis aeruginosa* Kütz

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and *Scenedesmus quadricauda* (Turp.) to study the algae species competition relationships and interactions using laboratory experiments. Understanding the characteristics and formation mechanisms of phytoplankton population is of vital significance to the development of measures for controlling eutrophication.

A number of studies about the specific relationships between different species of algae, typically *Prochlorococcus* and *Synechococcus*, in the coastal oceans have been conducted. Results showed that *Prochlorococcus* abundance was recorded in oceanic warm currents, while *Synechococcus* was most abundant in the coastal areas associated with high nutrient levels (Jiao et al., 2002, 2005). Fresh water studies on the competition relationship of algae have also been conducted. Hyenstrand et al. (2000), for example, studied the competition between *S. quadricauda* and *Synechococcus* under different modes of inorganic nitrogen supply. This research, however, focussed on the effects of inorganic nitrogen form on the competition relationship of algae, not the nutrient level specifically. Chen et al. (1999) studied the competition relationship of *M. aeruginosa* and *S. obliquus* under specific nitrogen and phosphorus concentrations, which initially promulgated the reason why Cyanobacteria became the dominant species under different kinds of algal competition conditions. Their research, however, only examined the relationship of competition under fixed HGZ medium and 1/2HGZ medium and did not examine the relationship of competition under different nitrogen and phosphorus concentrations. Additionally, their results were from laboratory experiments only, and did not include field experiments in natural water bodies. Consequently, the aim of our study was to determine why particular species of algae become dominant under certain nutrient conditions (specifically, nutrient levels and N/P ratios).

1 Materials and methods

1.1 Study area and sampling sites

In order to disclose the succession rule and community structure of phytoplankton in a stagnant water body in Suzhou City, Jiangsu Province, China. Water quality and phytoplankton conditions were monitored from July 2004 to May 2005. Suzhou City is one of the most developed cities in China. Located in the downstream basin area of Yangtze River. The city has a relatively flat topography with a dense mesh of waterways and rivers. The conditions of these waterways are complex and characterised by very low flow velocities. There are six main waterways in the southeast ancient part of the city: three of them flow from north to south and the other three from east to west, perpendicular direction. There was one fixed sampling site in every river, as shown in Fig. 1.

Taihu Lake is a good example of a eutrophic shallow lake system (Bai et al., 2006), and has been studied extensively. The phytoplankton community structure in Taihu Lake is described in following sections.

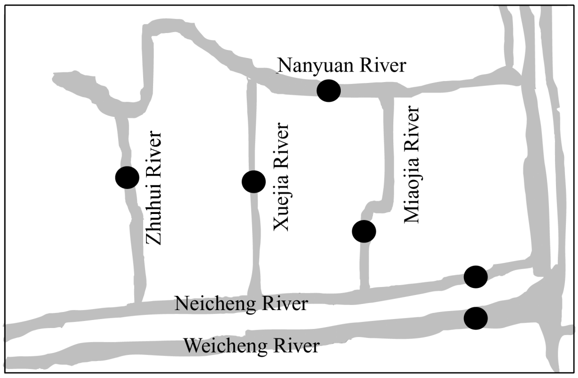

Fig. 1 Sketch map of riverways in Archaic Zone, Suzhou City, Jiangsu Provience, China.

1.2 Sample analysis

Surface water (0–0.5 m) was collected at each site every month, and temperature, water transparency (Trans), dissolved oxygen (DO) and pH were measured in the field. Chemical oxygen demand (COD), total nitrogen (TN), ammonium nitrogen (NH_4^+-N) and total phosphorus (TP) were determined in the laboratory following the standard methods of Ministry of Environmental Protection Administration of China. Chlorophyll-*a* (Chl-*a*) was measured after extraction in 90% acetone by a freeze-thaw method.

1.3 Experimental methods

The experiment was carried out using two species of algae, *M. aeruginosa* (obtained from the Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan, China) and *S. quadricauda* (separated from samples collected from the Miaojia River in Suzhou). Of these two species, *M. aeruginosa* is the most familiar water bloom algae in China and *S. quadricauda* is the most commom algae in rivers in Suzhou. The algae were grown in the laboratory using BG11 medium, which is considered suitable for both *M. aeruginosa* and *S. quadricauda* (Hu et al., 2004). A series of experiments were conducted with different concentrations of nitrogen and phosphorus and N/P ratios.

The experiments were carried out in a 250-mL Erlenmeyer flask with 100 mL BG11 medium. The algae samples were washed using 15 mg/L $NaHCO_3$ solution and then separated by centrifuge (Jin and Tu, 1990). In order to maintain a relatively constant nutrient level in the culture medium, the experiments used perfusion culture such that the culture was replaced half by half every two to three days, which was similar to chemostat. The algae number in the supernatant fluid could be ignored, since it was less than 2% of the number in the flask. The experiment was carried out in an illuminated incubation box at (24 ± 1)°C. A light intensity of 2500–3000 lx was applied on a 12-hr light-dark cycle. The flasks were shaken manually every 2 to 4 hr. For each experimental condition, two parallel experiments were conducted.

In order to study systematically the growth and competition of *M. aeruginosa* and *S. quadricauda*, under different nutrient conditions, representing the nutrient levels of

Table 1 Concentrations of N and P and N/P ratios used in the experiments

N/P	Oligotrophic condition		Eutrophic condition		Hypertrophic condition	
	N (mg/L)	P (mg/L)	N (mg/L)	P (mg/L)	N (mg/L)	P (mg/L)
10	0.1	0.01	2	0.2	10	1
15	0.15	0.01	3	0.2	15	1
20	0.2	0.01	4	0.2	20	1

Qiandao Lake (Zhejiang Province, China), Taihu Lake and Suzhou urban waterways respectively, we used different concentrations of nitrogen and phosphorus as listed in Table 1. Water quality of Qiandao Lake is very good and the nutrient level is low. It is considered to be a typical oligotrophic water body, with healthy stands of macrophytes, dominated by submerged species (Hilton et al., 2006). Taihu Lake is a typical eutrophic water body, with concentrations of TN > 0.2 mg/L, TP > 0.02 mg/L in 1991, and mean values of TN = 1.89 mg/L, TP = 0.051 mg/L (Huang and Zhu, 1995). The Suzhou urban waterways are typical hypertrophic waters, and the concentration of nitrogen and phosphorus is significantly higher than Taihu Lake. As there is currently no unified standard for hypertrophic levels, we referred to nutrient levels in natural water bodies and defined TP > 0.5 mg/L, TN > 6.0 mg/L as the hypertrophic level standard temporarily.

2 Results

2.1 Characteristics of phytoplankton population at the field sites in Suzhou City

Our measurements showed that the annual concentrations of TN in these rivers were in the range of 3.48–12.97 mg/L and TP in the range of 0.23–1.01 mg/L. The main component (65%–93%) of the total nitrogen was ammonia and the N/P ratio varied between 14 and 23. All these figures significantly exceed the thresholds of local water quality standards, putting the rivers into the fifth category (the worst quality of environmental quality standards for surface water, China) of water bodies.

Seventy-four species of phytoplankton belonging to six phyla were detected in the waterways of Suzhou City during our monitoring from 2004 to 2005: 13 Cyanophyta species, 2 Cryptophyta species, 4 Pyrrophyta species, 17 Bacillariophyta species, 4 Euglenophyta species and 34 Chlorophyta species. The number of species and total biomass varied seasonally and such variability was characterised by a decreasing trend from summer to autumn to spring and to winter. In spring, the phytoplankton population was dominated by Chlorophyta, while the population of Cyanobacteria (Cyanophyta) increased significantly in summer. In autumn and winter, the populations of Chlorophyta again became the dominating species, along with the diatoms. The overall population of phytoplankton was generally low from October to February of the next year and reached a relatively high level in July. Seven Chlorophyta including *Crucigenia*, *Coelastrum*, *S. quadricauda*, *Cyclotella*, *Melosira*, *Navicula*, *Chroococcus* were commonly observed. The average phytoplankton population and biomass over the whole year were relatively low. Except for summer, when the high temperature favoured the Cyanophyta populations, the biomass of Chlorophyta was the highest throughout the year. For example, the measured biomass of *Pandorina* in the Miaojia River in July reached 22.28 mg/L, which accounted for 78.9% of the total biomass. The results obtained from this study showed that the phytoplankton community was clearly characterised by a mixed form of Chlorophyta and diatoms (Wan et al., 2006).

2.2 Phytoplankton community characteristics of Taihu Lake

Cyanophyta can be seen throughout the year, spreading over the entire lake. A small-scale belt-shaped algal bloom became evident in May. The bloom continued to expand and reached its maximum extent in July and August, which lasted until November. In the peak period, the quantity of *M. aeruginosa* can be as high as 8×10^7 cell/L as reported by Sun and Huang (1993). Over such events, Yang (1996) have stated that *M. aeruginosa* and *Microcystis flos-aquae* were the dominant species; and *Anabaena spiroides* Klebahn, *Anabaena flos-aquae* and *Ch. limneticus* Lemm. also existed in a relatively large amount.

2.3 Laboratory experiments on competition characteristics of the two algae species

2.3.1 Competitions under oligotrophic conditions

The algae growth curves at different concentrations of nitrogen and phosphorus are shown in Fig. 2. Under the oligotrophic conditions, as N/P ratio increased from 10 to 20, the maximum biomass of *M. aeruginosa* increased by a factor of 7.4. The growth of *M. aeruginosa* in the mixed culture behaved differently depending on the N/P ratio. For N/P ratios were 10 and 15, the maximum biomass of *M. aeruginosa* in the mixed culture was found to be greater than that in the pure culture. In particular, when N/P = 10, the maximum biomass of *M. aeruginosa* in the mixed culture was nearly five times larger than that in the pure culture. However, as the ratio increased to N/P = 20, the maximum biomass of *M. aeruginosa* in the mixed culture became less than that in the pure culture. The maximum biomass of *S. quadricauda* was higher in the mixed culture for all N/P ratios, by factors of 1.6–2.6.

The competition results were analysed further through the inhibition rate calculated as follows:

$$R_I = (M_M - M_P)/M_P \times 100\% \quad (1)$$

where, R_I is inhibition rate; M_M is maximum biomass in the mixed culture; M_P is maximum biomass in the pure culture.

As shown in Table 2, based on the calculated inhibition

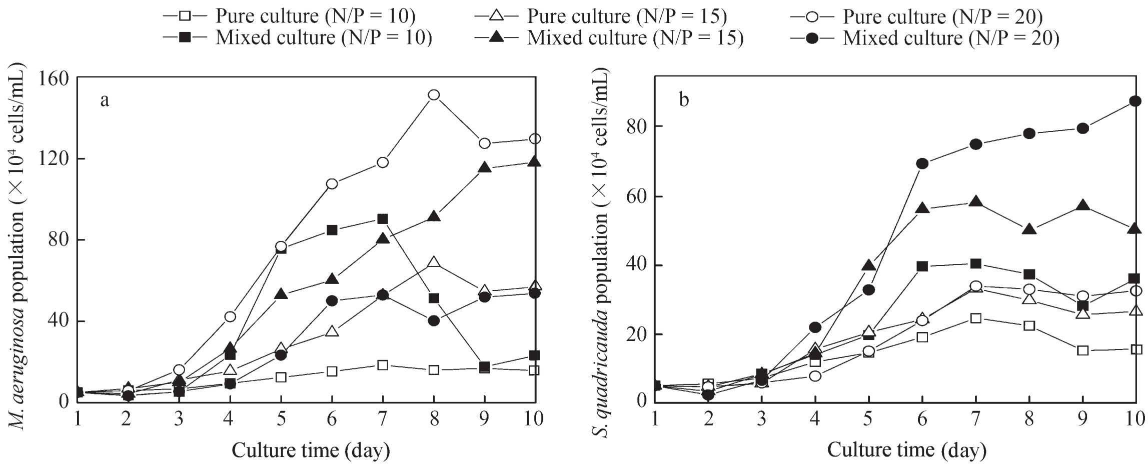

Fig. 2 Growth curve of *M. aeruginosa* (a) and *S. quadricauda* (b) under oligotrophic conditions.

Table 2 Inhibition or stimulation rate (%) based on comparison of the growth in mixed and pure cultures

Condition	*M. aeruginosa*				*S. quadricauda*			
	N/P=10	N/P=15	N/P=20	Average	N/P=10	N/P=15	N/P=20	Average
Oligotrophic	+390.12	+67.92	–64.53	+131.13	+64.31	+72.10	+157.83	+98.08
Eutrophic	–11.50	–45.78	–43.47	–30.25	–8.28	–15.79	–52.11	–25.40
Hypertrophic	–55.11	–65.71	–66.99	–62.60	–34.25	–26.62	–43.65	–34.84

"+" means stimulation and "–" means inhibition.

rates, *M. aeruginosa* did not inhibit the growth of *S. quadricauda* under oligotrophic conditions. On the contrary, *M. aeruginosa* stimulated the growth of *S. quadricauda*. The stimulation effect became more profound as the N/P ratio increased. Conversely, *S. quadricauda* stimulated the growth of *M. aeruginosa* when the N/P ratio was relatively small. This stimulation effect, however, weakened as N/P increased and when N/P = 20, *S. quadricauda* actually became inhibiting for the growth of *M. aeruginosa*. Overall, the stimulation effect of *S. quadricauda* on *M. aeruginosa* was found to be more significant than that of *M. aeruginosa* on *S. quadricauda* under oligotrophic conditions.

2.3.2 Competitions under eutrophic conditions

The algae growth curves under eutrophic conditions are shown in Fig. 3. This nutrient level is representative of many water bodies in China. The experiments were run for a longer time to obtain a more complete trend of algal growth. The results showed that under eutrophic conditions, the maximum biomass of *M. aeruginosa* in the pure culture increased mildly with the N/P ratio. The opposite trend was evident in the mixed culture. The maximum value merely increased by about 10% from the minimum. When N/P = 10, the population of *S. quadricauda* in the mixed culture was higher than that in the pure culture during the early growth period. The population difference between the mixed culture and pure culture was reduced,

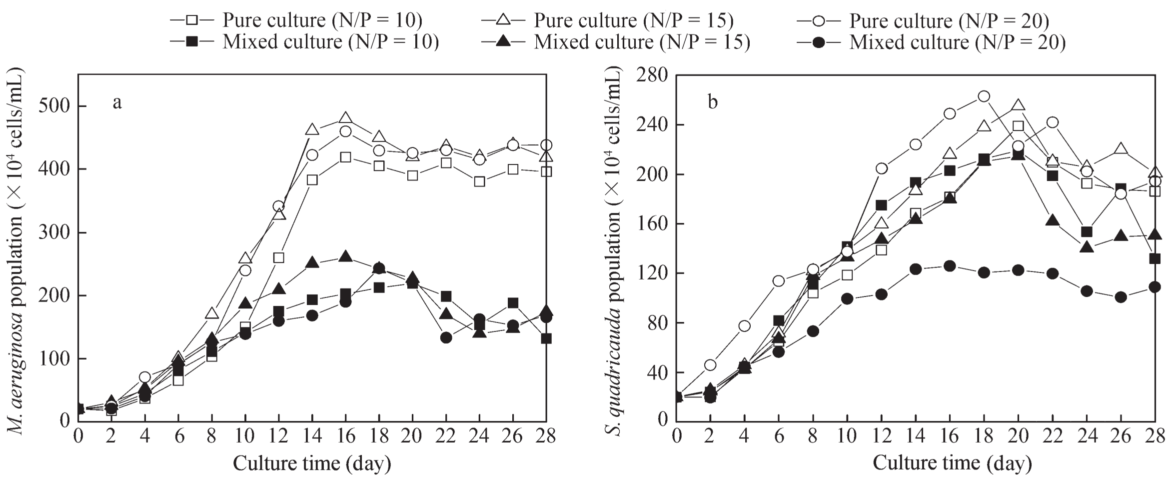

Fig. 3 Growth curve of *M. aeruginosa* (a) and *S. quadricauda* (b) under eutrophic conditions.

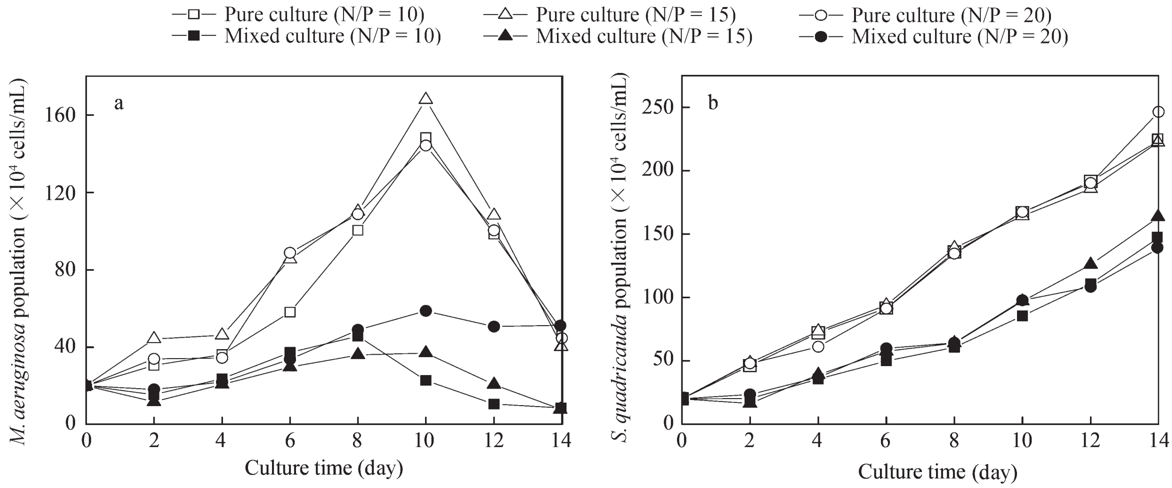

Fig. 4 Growth curve of *M. aeruginosa* (a) and *S. quadricauda* (b) under hypertrophic conditions.

however, after 18 days had elapsed. As the N/P increased further, the maximum biomass of *S. quadricauda* in the mixed culture became less than that in the pure culture.

The competition between the two species under eutrophication conditions was also examined based on the inhibition rate (calculated as before). The results are shown in Table 2. When N/P = 10, the inhibition effect of *M. aeruginosa* on *S. quadricauda* was not obvious. The inhibition effect was enhanced, however, by increasing N/P ratios and became the most profound when N/P = 15, after which, as N/P increased further, the inhibition effect diminished. Results showed, therefore, that the inhibition effect of *M. aeruginosa* and *S. quadricauda* on each other was weak under these experimental conditions and that these two species may co-exist for a long time.

2.3.3 Competitions under hypertrophic conditions

The algae growth curves under hypertrophic conditions are shown in Fig. 4. Because other algae appeared in the *M. aeruginosa* incubator on day 14, the experiment was stopped. The results show that *M. aeruginosa* achieved the maximum biomass within 10 days. After this time, the appearance of mixed algae affected the growth of *M. aeruginosa*, which also explained why *M. aeruginosa* did not grow well at high nutrient concentrations. Based on the data from the experimental period (data of the first 10 days), the maximum biomass of *M. aeruginosa* in the pure culture was at the highest level when N/P = 15, with the maximum biomass at N/P = 10 slightly larger than that at N/P = 20. The population of *M. aeruginosa* was significantly reduced in the mixed culture compared with the pure culture results. In contrast, the growth of *S. quadricauda* was better than that of *M. aeruginosa* when the concentrations of nitrogen and phosphorus were high. The maximum biomasses of *S. quadricauda* for N/P = 10 and 15 were similar. As the ratio increased to N/P = 20, the maximum biomass became slightly larger (by a factor of 1.11) than those at N/P = 10 and 15. The inhibition results are shown in Table 2. When the concentrations of nitrogen and phosphorus were high, the inhibition effect of *S. quadricauda* on *M. aeruginosa* was considerably more significant than the effect of *M. aeruginosa* on *S. quadricauda* regardless of the N/P ratio.

3 Discussion

3.1 Characteristics of phytoplankton communities

Previous research on phytoplankton in different water bodies has revealed some common features of the water systems, including that the phytoplankton community in lakes is mostly in a mixed form of Cyanobacteria and diatoms. In reservoirs, the phytoplankton community is typically in a form of diatoms and Chlorophyta under the condition of large flow exchange and switches to the Cyanobacteria and diatoms form under low flow exchange rates. Most rivers have a mixed form of diatoms and Chlorophyta. According to statistical results obtained during the 1970s, the total quantity of Cyanobacteria and diatoms comprised more than 65% of the annual average biomass in 20 of main lakes in China, including Dongting Lake, Taihu Lake and Hongze Lake (Nanjing Institute of Geography and Limnology, 1989). In rivers such as the Yangtze River, Heilongjiang, Yellow River and Haihe River, diatoms accounted for the greatest quantity (Hong and Chen, 2002). Such results indicated that the hydrodynamic conditions of a water body are a critical factor for phytoplankton communities. In general, the biomass of Cyanobacteria tends to be higher in lake systems than in river systems. Conversely, however, the quantity of diatoms is greater in rivers than lakes because of the special physiological structure of river systems (Jan, 1994). Some researchers also believe that the survival strategy of phytoplankton in unstable systems differs from that in stable systems. In particular, phytoplankton in a stable system is an *r*-strategist and a *K*-strategist in an unstable system (Dos Santos and Calijuri, 1998). An *r*-strategist is an exploiter of new habitat, but its survival is contingent upon opportunity. In other words, they are opportunists and can experience a very sudden and dramatic increase and a just as sudden and dramatic decrease. The maintenance *K*-strategist depends upon a stable environment. In a sense, they are conservative and when the survival environment changes, it is difficult for them to restore (Li, 2000).

The condition of Suzhou City riverways is complex and characterised by very low flow velocities. Based on the hydrodynamic conditions, one would assume that Cyanobacteria would be the predominant species. The monitoring results obtained from this study, however, showed that Chlorophyta is generally the predominant species. Which other factors can significantly influence the form of phytoplankton communities besides hydrodynamic conditions? At present, the nitrogen concentration in most fresh water bodies around the world is largely below 2 mg/L and the phosphorus concentration is below 0.25 mg/L. In contrast, the TN concentration in waterways of Suzhou is mostly above 7 mg/L and TP above 0.5 mg/L. The phytoplankton population is also dominated by Chlorophyta and diatoms. The result that the phytoplankton community and nutrient concentration are related.

3.2 Influence of nitrogen, phosphorus and N/P on the growth of *M. aeruginosa* and *S. quadricauda*

Previous work has indicated that when Cyanobacteria bloom outbreaks occurred, N/P in water was not fixed but changed greatly (Chen, 2006). That is to say, the suitable N/P for growth of Cyanobacteria is not stable, which conflicted with the empirical formula of algae. From the experimental results obtained in this study, we found that under low nutrient conditions, the biomass of algae increased with increasing N/P. This tendency was more pronounced for *M. aeruginosa* than for *S. quadricauda*. Under eutrophic conditions, the maximum biomass of *M. aeruginosa* was greater for smaller N/P. The maximum biomass of *S. quadricauda* was larger for a higher N/P in the pure culture. Under hypertrophic conditions, the maximum biomasses of *S. quadricauda* and *M. aeruginosa* did not show significant change with the N/P ratio. The results suggest that when the concentrations of nitrogen and phosphorus were very low, the N/P ratio strongly influenced the growth and reproduction of algae, any nutrient element can stimulate the growth of algae. Once the concentrations of nitrogen and phosphorus increased to a certain level, and thus nutrients were very abundant, the influence of N/P on the growth and reproduction of algae diminished.

3.3 Symbiosis and competition between *M. aeruginosa* and *S. quadricauda*

The experimental results showed that under eutrophic and hypertrophic conditions, the maximum biomasses of M. *aeruginosa* and *S. quadricauda* were lower in the mixed culture than in the pure culture. This indicates that mutual competition and inhibition might exist between *M. aeruginosa* and *S. quadricauda*. Under low nutrient conditions, the maximum biomasses of *M. aeruginosa* and *S. quadricauda* were higher in the mixed culture than in the pure culture, suggesting that a symbiosis relationship existed between *M. aeruginosa* and *S. quadricauda*. Such a symbiosis relationship was also implicated by the microscopic photo (Fig. 5). Physically smaller *M. aeruginosa* was found to parasitize in *S. quadricauda* under oligotrophic conditions, such that *S. quadricauda*'s bigger shell became *M. aeruginosa*'s habitat. This phenomenon was not found under eutrophic or hypertrophic conditions. Under oligotrophic conditions, algae might reduce demand for nutrients through autoeciousness. Previous research has shown similar symbiosis relationship: for example, microcystin could accelerate the growth of *S. quadricauda*, depending on the concentration of microcystin, category of algae and density of species (Hu et al., 2006).

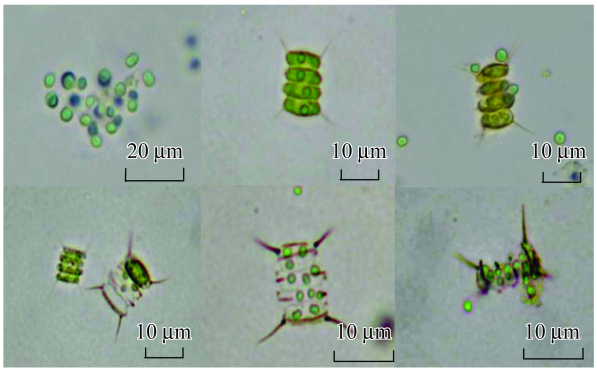

Fig. 5 Photo of *M. aeruginosa* eroded *S. quadricauda*.

Under oligotrophic and eutrophic conditions, the maximum biomass of *M. aeruginosa* was close to that of *S. quadricauda* and *M. aeruginosa* had some advantage in the mixed culture. Under hypertrophic conditions, the maximum biomass of *S. quadricauda* increased, which explains why *S. quadricauda* became the dominant species when concentrations of nitrogen and phosphorus were high.

The competitive relationship between *M. aeruginosa* and *S.* quadricauda can be explained by the resource-ratio hypothesis. According to the resource-ratio hypothesis (Tilman, 1982), the resource regimes corresponding to the decline, growth and steady state of Cyanobacteria and Chlorophyta under conditions of limited nitrogen and phosphorus are illustrated in Fig. 6. Generally speaking, the Cyanobacteria is fitted to lower N/P and hence its resource regime is leaning to left-up (Fig. 6a); the Chlorophyte is fitted to higher N/P and thus its resource regime is leaning to right-down (Fig. 6b). In theory, when competition exists between two species, their resource regimes may be superimposed (Fig. 7a). However, the results from this study showed that in the presence of competition, the resource regimes of the Cyanobacteria and Chlorophyte changed. The demands for nitrogen and phosphorus by the Cyanobacteria and Chlorophyte varied, which resulted in modifications of the resource regimes (Fig. 7b). As demonstrated in Fig. 7b, the dashed line (1) denotes the resource regimes of the Cyanobacteria and dashed line (2) denotes the resource regimes of the Chlorophyte in pure culture. In area A of Fig.7b, the Chlorophyte has no chance to win against the Cyanobacteria, and vice versa in area C. In area B, however, the Chlorophyte and the Cyanobacteria can co-exist for an extended period of time. This explanation is only qualitative not quantitative.

The experiments conducted in this study used the

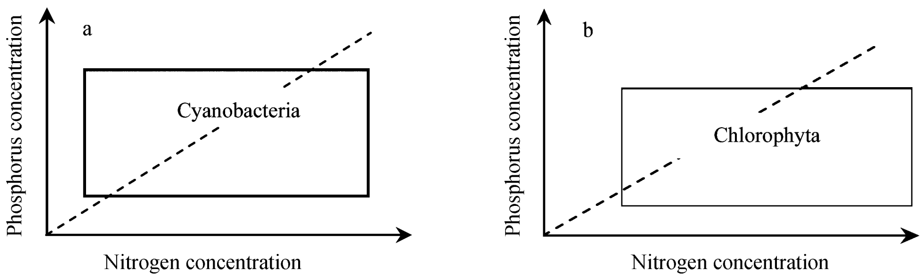

Fig. 6 Resource regime of Cyanobacteria (a) and Chlorophyta (b).

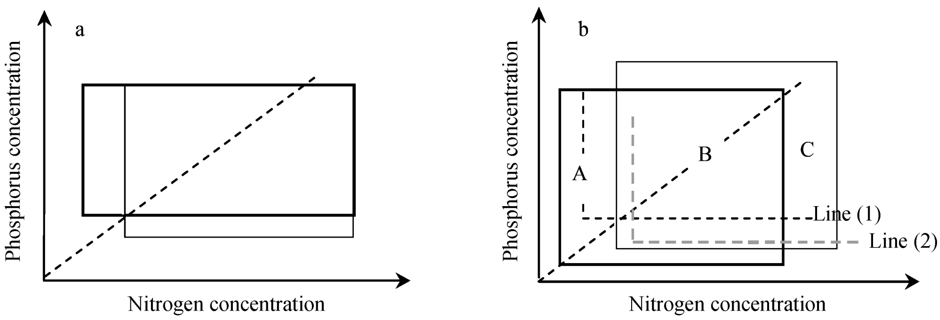

Fig. 7 Superimposed (a) and moved (b) resource regimes of Cyanobacteria and Chlorophyta.

perfusion cultivation method; and the effects of nutrient supply frequency and pulse were not considered. In addition, given the difference between the experimental set-up in the laboratory and field conditions, the results obtained here may not be directly transferable to the field. For example, in the natural water body, *M. aeruginosa* can capture light using vacuoles, which created an advantage to becoming the dominant species. Nevertheless, these experiments simulated similar light conditions and aimed to examine the influence of nutrients on the competitive relationship between two different algae species that dominated the waterways in Suzhou City.

3.4 Implications of the experimental results for solving the eutrophication problem

The community structure of phytoplankton is different in different eutrophic water bodies. Qin (1998, 2002) pointed out that prior to eutrophication, the main species found in most water bodies are typically Pyrrophyta and Chlorophyta. After the occurrence of eutrophication, the population of Cyanobacteria can increase rapidly. However, if the water pollution worsens with further elevated concentrations of nitrogen and phosphorus, the previously competitive Cyanobacteria may gradually lose dominance. The experimental results presented in current study help to determine the mechanisms of competitive processes in the formation of algae community structures. If only *M. aeruginosa* and *S. quadricauda* are considered, a *M. aeruginosa* bloom is more likely to occur under poor nutrients conditions, while nutrient rich conditions favour a *S. quadricauda* bloom. This may explain why Cyanobacteria blooms do not occur in some heavily polluted water bodies. In controlling the pollution and ecosystem restoration of a heavily polluted water body, measures must be taken against the blooming of Cyanobacteria, especially *M. aeruginosa*, after the initial improvement of water quality when nitrogen and phosphorus concentrations are reduced. For example, improvements in the hydrodynamic conditions and increases in the fluidity of a water body can control the growth of Cyanobacteria.

Most previous research on Cyanobacteria blooms have focussed on the relationship between the growth of *M. aeruginosa* and N, P and/or the N/P ratio. The results of such single species studies have had limited implications. Our investigation has shown that the optimal growth and reproduction of *M. aeruginosa* and *S. quadricauda* separately in pure culture occurs under medium level nutrient conditions. However, under competitive conditions, lower medium nutrient levels are more suitable for *M. aeruginosa* while higher medium nutrient levels promote the growth of *S. quadricauda*. In fact, the suitable growth regime of N, P and/or N/P for algae is likely to change in a complex fashion along with the competition relationship among different algae. In reality, the community structure and dominant species of phytoplankton result from mutual competition among various algae.

4 Conclusions

This article introduced community structure of phytoplankton in the waterways of Suzhou City and did laboratory experiments on competition characteristics of *M. aeruginosa* and *S. quadricauda* . The main conclusions from this study are:

(1) In water bodies of similar hydrodynamic conditions, the community structure of phytoplankton depends on concentrations of nitrogen and phosphorus to a large extent. In water with higher concentrations of nitrogen and phosphorus, the Chlorophyta became the dominant species, while in water with lower concentrations of nitrogen and

phosphorus, the Cyanobacteria became the predominant species. Although high temperature stimulated the growth of Cyanobacteria in summer and Cyanobacteria biomass increased, Cyanobacteria blooms did not easily occur in water with higher concentrations of nitrogen and phosphorus.

(2) In both pure and mixed cultures, the suitable conditions for growth and reproduction of *S. quadricauda* and *M. aeruginosa* was under eutrophic conditions, as shown in our experiment when N was in the range of 2–4 mg/L and P was 0.2 mg/L. Under competitive conditions, however, *M. aeruginosa* has the advantage under the lower medium nutrients level and *S. quadricauda* has the advantage under the higher medium nutrient levels. These results explain the observed different community structures in water bodies subjected to different degrees of pollution. The tolerance of Chlorophyta against pollution is higher than that of Cyanobacteria.

(3) Competition and inhibition likely occurs between *M. aeruginosa* and *S. quadricauda* under high nutrients conditions. Under low nutrients and small N/P conditions, there may be symbiosis and stimulation between these two species.

(4) The suitable conditions for survival and reproduction of phytoplankton can change depending on the mutual competition among algae species. Experiments based on single algae species in pure culture are not able to explain fully the growth conditions of multiple algae species in real water bodies. Therefore, the research on the mechanisms of algal bloom needs to consider the mutually competitive relationships of different algae species.

Acknowledgments

This work was supported by the Natural Science Foundation of Jiangsu Province (No. BK2006710) and the Hi-Tech Research and Development Program (863) of China (No: 2003AA601100). We extend our special thanks to Prof. L. Li for his continued support and encouragement.

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