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Variation in trophic status of three Karst reservoirs in the Yunnan-Guizhou Plateau, China

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Abstract — Lakes Aha, Baihua and Hongfeng are three artificial Karst reservoirs in the middle of the Yunnan-Guizhou Plateau, China. The variations in microalgal composition, chlorophyll *a* and net photosynthetic O_2 evolution rate from these Karst lakes were investigated. The relationships among total nitrogen, total phosphorus, microalgae compositions, chlorophyll *a* and net photosynthetic O_2 evolution rate in the lakes were studied. The microalgal chlorophyll *a* concentration in Lake Aha correlated with total phosphorus. In contrast, the microalgal biomass and net photosynthetic rate in Lakes Hongfeng and Baihua correlated with total nitrogen. The trophic status and the microalgal composition in the three lakes are influenced by those of water bodies in the catchments, which channel water into the lakes. The variation in the total nitrogen (TN) and total phosphorus (TP) and the ratio of TN/TP in Lakes Aha, Baihua and Hongfeng has not caused large microalgal blooms as are often symptomatic of eutrophication.

Chlorophyll *a* / eutrophication / Lake Aha / Lake Baihua / Lake Hongfeng / O_2 evolution rate / total nitrogen / total phosphorus

Résumé — Variation du statut trophique de trois réservoirs karstiques du Plateau Yunnan-Guizhou, en Chine. Les lacs Aha, Baihua et Hongfeng sont trois réservoirs karstiques artificiels situés au milieu du Plateau Yunnan-Guizhou, en Chine. Les variations de la composition en microalgues, de la chlorophylle *a* et de l'évolution de la proportion nette du dioxygène d'origine photosynthétique de ces lacs ont été suivies. Les relations entre l'azote total, le phosphore total, la composition en microalgues et l'évolution de la proportion nette du dioxygène d'origine photosynthétique ont été étudiées. La concentration en chlorophylle *a* des microalgues dans le lac Aha est corrélée avec le phosphore total. Au contraire, la biomasse microalgale et la proportion nette du dioxygène d'origine photosynthétique dans les lacs Hongfeng et Baihua sont liées à l'azote total. Le statut trophique et la composition microalgale de ces trois lacs sont influencés par ceux des eaux recueillies par les captages qui canalisent l'eau dans ces lacs. Les variations de l'azote total (TN) et du phosphore total (TP), ainsi que le rapport TN/TP dans les lacs Aha, Baihua and Hongfeng n'ont pas engendré de grandes proliférations de microalgues, souvent symptomatiques d'eutrophisation.

Chlorophylle *a* / eutrophisation / Lac Aha / Lac Baihua / Lac Hongfeng / évolution de la proportion d'O_2 / azote total / phosphore total

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INTRODUCTION

The trophic status of water bodies affects their primary productivity. Climate change and physical-chemical factors are likely to affect trophic status (Howarth *et al.,* 2000; Kangur *et al*., 2003; Sarvala *et al*., 1998; Temponeras *et al*., 2000; Wehr & Descy, 1998) and water level also influences trophic status in lakes (Nõges & Nõges, 1999). Reduction of nutrients, especially nitrogen and phosphorus, and reduction of light availability have all been shown to negatively affect phytoplankton biomass (Kangur *et al*., 2003; Seip, 1994; Wehr & Descy, 1998).

Lakes Aha, Baihua and Hongfeng are Karst reservoirs. The chemical composition of water in those lakes is dominated by HCO_3^-, Ca^{2+} and Mg^{2+}. Before 1996, blooms of Cyanophyta and Chlorophyta occurred annually in Lakes Hongfeng and Baihua in the months of May and September/October (Bai *et al*., 1995; Chen *et al*., 1999). Measures for reducing the point source pollution to improve the water quality of Lakes Hongfeng and Baihua have been taken by the government since 1997. 30 factories, which were located around the lakes, and had been releasing contaminants, were closed down; 11 sewage treatment plants were established and 20 artificial wetlands with a total area of 5 ha were constructed at the entrance of the lakes. After these steps were taken, total nitrogen and phosphorus in Lakes Hongfeng and Baihua decreased significantly. No algal bloom has been observed during the past 5 years (Wu *et al*., 2004). In contrast, no eutrophication has been found in Lake Aha for decades.

In the present research, we investigated and compared the variation in trophic status from different Karst Lakes, and studied the relationship between total nitrogen, total phosphorus, microalgae chlorophyll *a*, and O_2 evolution rate in these systems.

MATERIAL AND METHODS

Study areas

Lakes Aha, Baihua and Hongfeng (106°26'E, 26°31'N) are three multi-functional reservoirs located close to each other in the middle of the Yunnan-Guizhou Plateau (Table 1). Lake Hongfeng is an artificial riverway-reservoir and belongs to the Wujiang River water system, which is the largest tributary of the Changjiang River. Lake Baihua lies 10 km down-stream of Lake Hongfeng. Lake Aha is a medium-sized artificial reservoir. The lakes have a similar geological background and climate. The dominant mineral of these areas is trias dolomite. Shallow lime-earth and yellow-soil cover these areas, where karstification is most developed.

Sampling of surface lake water (5-10cm) at Lakes Hongfeng, Baihua and Aha was carried out monthly in 2002 and 2003. Five replicate samples in neighbouring sites were collected for each parameter and phytoplankton analyses from the same lake at the same day. 62 L surface water for each sample from each lake was immediately filtered with 270 BSS mesh fabric in order to remove coarse particles and the phytoplankton of the diameter greater than 50 μm. 2L of the surface water was used for determining total nitrogen (TN) and total phosphorus

Table 1. The hydrological characteristics of Lakes Aha, Baihua and Hongfeng

Lake name	*Altitude (m)*	*Catchment area (km^2)*	*Surface area (km^2)*	*Mean depth (m)*	*Retention time (Years)*
Aha	1147	190	3.4	13	0.44
Baihua	1108	1832	14.5	7.7	0.16
Hongfeng	1241	1915	32.2	9.3	0.32

(TP) according to standard methods (SEPAC, 1988). The sum of total Kjeldahl nitrogen and nitrate-nitrogen gave total nitrogen (TN) in water samples. Dissolved (DKN) and total Kjeldahl nitrogen (TKN) were analyzed after standard Kjeldahl wet digestion. The concentration of nitrate-nitrogen was measured using the phenyldisulphonic acid method. Total phosphorus (TP) was measured by spectrophotometry after mineralization with perchloric acid (1 ml/ 50 ml of sample). 60 L surface water was used to obtain microalgal stock solution. Surface water filtration with cellulose acetate membrane filters (1.2 μm pore size, Millipore) yielded the microalgae (of diameter between 1.2 and 50μm). Microalgae were scraped off the cellulose acetate membrane and diluted to 400 mL with final filtered subsurface water.

Ten mL microalgal suspension was centrifuged (1600 g for 10 minutes) and used to determine chlorophyll *a* (chl *a*) content. The centrifuged microalgae were soaked in 90% ethanol at 4°C in the dark for 12 hrs. The absorbance of the extract was measured at 665 and 750 nm against a 90% ethanol blank on a spectrophotometer (UV7502PC, Shanghai, China). The same extract was acidified with a drop of 1 N HCl and the steady state absorbance at 665 and 750 nm was subsequently measured within 10min. The concentration of chl *a* in the water bodies was calculated according to the spectrophotometric equations of Lorenzen (1967).

5 mL microalgal suspension fixed with a 5% formalin solution was used to identify microalgal species and analyze microalgal quantity with light microscope according to Lund *et al.* (1958).

Measurements of photosynthetic O_2 evolution

The net photosynthetic O_2 evolution rate of microalgal suspensions was measured with a Clark-type oxygen electrode (YSI-5300, USA) under a photon flux density of 150 or 500 μmol m^{-2} s^{-1} and a temperature of 25 °C. Sixty ml of microalgal stock solution were harvested by centrifugation (1600g for 10min), re-suspended in 2 ml of 25 mM HEPES-KOH (pH 8.2) and transferred to the electrode chamber. Following the addition of 2 mM bicarbonate to the chamber, the rate of O_2 evolution was measured over a period of 5 minutes (Zou *et al.*, 2004).

RESULTS

Variation of microalgal community composition

The overall composition of the microalgal community showed obvious variations during the period of the study. The microalgal community composition in the lakes fluctuated with time (Table 2). The density of Cyanophyta and the total algae in subsurface water had a similar variation range among the lakes. The variation range of the density of Chlorophyta in Lake Hongfeng subsurface water was the smallest among the lakes. The Bacillariophyta comprised the greatest average density in subsurface water, in all three lakes.

Table 2. Microalgal composition in Lakes Aha (AH), Baihua (BH) and Hongfeng (HF) during 2002-2003. (Cyano: cyanophyta; Chlor: chlorophyta; Bacil: Bacillariophyta; Total A: total algae. S.E. is shown in parentheses.)

	AH (×10⁵ cells l⁻¹)				*BH (×10⁵ cells l⁻¹)*				*HF (×10⁵ cells l⁻¹)*			
	Cyano	*Chlor*	*Bacil*	*Total A*	*Cyano*	*Chlor*	*Bacil*	*Total A*	*Cyano*	*Chlor*	*Bacil*	*Total A*
Jan-02	2.16 (0.12)	1.90 (0.14)	0.12 (0.02)	4.38 (0.21)	3.22 (0.25)	1.42 (0.19)	0.01 (0.00)	4.86 (0.31)	2.97 (0.26)	1.03 (0.07)	0.45 (0.05)	4.64 (0.27)
Feb-02	2.11 (0.14)	1.45 (0.10)	0.74 (0.05)	4.50 (0.23)	1.90 (0.12)	2.66 (0.19)	0.61 (0.08)	5.41 (0.21)	2.72 (0.18)	1.17 (0.08)	0.71 (0.04)	4.86 (0.22)
Mar-02	8.92 (0.67)	1.87 (0.14)	0.12 (0.02)	11.29 (0.71)	11.18 (0.73)	13.70 (1.65)	0.14 (0.02)	25.30 (2.01)	3.43 (0.21)	3.76 (0.28)	0.36 (0.04)	7.85 (0.41)
Apr-02	2.64 (0.25)	1.12 (0.09)	0.68 (0.05)	4.64 (0.31)	9.23 (0.63)	6.59 (0.54)	0.56 (0.04)	16.63 (0.92)	2.07 (0.16)	3.96 (0.31)	0.19 (0.03)	6.52 (0.37)
May-02	3.95 (0.40)	1.35 (0.15)	0.37 (0.04)	4.97 (0.45)	9.77 (0.72)	4.51 (0.32)	1.86 (0.17)	16.41 (1.02)	2.88 (0.19)	1.13 (0.07)	0.44 (0.04)	4.64 (0.27)
Jun-02	4.48 (0.31)	1.26 (0.08)	4.43 (0.38)	10.37 (0.51)	3.74 (0.21)	3.33 (0.21)	0.54 (0.03)	7.96 (0.35)	6.73 (0.42)	3.72 (0.21)	0.15 (0.04)	10.95 (0.60)
Jul-02	4.27 (0.27)	0.81 (0.06)	3.32 (0.27)	8.64 (0.32)	10.68 (0.86)	2.94 (0.26)	1.05 (0.08)	14.96 (0.93)	6.94 (0.38)	2.85 (0.21)	0.41 (0.03)	10.61 (0.53)
Aug-02	8.43 (0.46)	1.63 (0.11)	4.41 (0.26)	14.77 (0.76)	9.50 (0.54)	5.54 (0.46)	2.34 (0.21)	17.63 (0.85)	4.70 (0.31)	2.21 (0.17)	2.04 (0.28)	9.14 (0.50)
Sep-02	11.10 (0.91)	1.36 (0.08)	8.39 (0.42)	21.28 (1.41)	11.32 (0.90)	3.45 (0.23)	2.11 (0.17)	17.18 (1.11)	12.17 (1.01)	1.75 (0.11)	1.89 (0.14)	16.15 (1.08)
Oct-02	10.46 (1.06)	1.05 (0.08)	2.21 (0.21)	13.99 (1.25)	11.64 (1.13)	2.33 (0.17)	0.57 (0.36)	14.85 (1.02)	6.94 (0.41)	1.47 (0.09)	1.49 (0.12)	10.09 (0.53)
Nov-02	1.77 (0.13)	0.94 (0.06)	3.28 (0.24)	6.09 (0.38)	4.94 (0.35)	1.40 (0.11)	1.21 (0.10)	7.85 (0.47)	2.59 (0.17)	1.22 (0.11)	0.58 (0.04)	4.53 (0.25)
Dec-02	2.11 (0.20)	0.72 (0.06)	1.70 (0.13)	4.72 (0.34)	3.82 (0.21)	0.61 (0.07)	0.37 (0.03)	5.18 (0.24)	3.32 (0.24)	0.96 (0.07)	0.22 (0.02)	4.65 (0.23)

Table 2. Microalgal composition in Lakes Aha (AH), Baihua (BH) and Hongfeng (HF) during 2002-2003. (Cyano: cyanophyta; Chlor: chlorophyta; Bacil: Bacillariophyta; Total A: total algae. S.E. is shown in parentheses.)

	AH ($\times 10^5$ cells l^{-1})				BH ($\times 10^5$ cells l^{-1})				HF ($\times 10^5$ cells l^{-1})			
	Cyano	*Chlor*	*Bacil*	*Total A*	*Cyano*	*Chlor*	*Bacil*	*Total A*	*Cyano*	*Chlor*	*Bacil*	*Total A*
Jan-03	1.72 (0.15)	0.59 (0.05)	13.00 (1.56)	15.30 (1.59)	3.79 (0.30)	1.15 (0.08)	1.56 (0.15)	6.52 (0.32)	8.95 (0.55)	2.61 (0.17)	6.10 (0.73)	17.70 (1.09)
Feb-03	5.41 (0.38)	0.47 (0.05)	2.14 (0.21)	8.02 (0.51)	2.61 (0.19)	2.12 (0.19)	0.19 (0.03)	4.93 (0.21)	10.70 (0.72)	4.13 (0.31)	2.71 (0.24)	17.60 (1.13)
Mar-03	7.69 (0.53)	0.97 (0.09)	1.81 (0.22)	10.80 (0.71)	2.06 (0.17)	2.00 (0.17)	0.89 (0.06)	4.96 (0.25)	6.40 (0.42)	3.53 (0.26)	2.14 (0.21)	12.20 (0.75)
Apr-03	5.00 (0.41)	4.50 (0.36)	8.30 (0.71)	19.00 (1.21)	0.50 (0.31)	7.90 (0.81)	0.31 (0.04)	9.10 (0.74)	2.00 (0.13)	5.20 (0.41)	0.83 (0.06)	9.00 (0.57)
May-03	5.30 (0.39)	15.00 (2.43)	2.70 (0.23)	23.00 (2.48)	1.10 (0.09)	3.80 (0.34)	4.90 (0.38)	9.80 (0.62)	2.90 (0.18)	3.00 (0.25)	1.10 (0.13)	7.00 (0.36)
Jun-03	4.50 (0.47)	4.20 (0.34)	16.00 (2.28)	25.00 (2.53)	0.94 (0.07)	3.40 (0.18)	7.20 (0.40)	12.00 (0.51)	1.80 (0.11)	4.80 (0.32)	1.50 (0.14)	8.10 (0.47)
Jul-03	4.00 (0.29)	1.98 (0.15)	3.93 (0.46)	9.98 (0.78)	3.18 (0.23)	1.58 (0.12)	1.09 (0.06)	6.07 (0.39)	6.28 (0.41)	2.31 (0.16)	0.95 (0.07)	9.55 (0.52)
Aug-03	2.81 (0.16)	1.42 (0.14)	1.36 (0.17)	5.58 (0.34)	1.09 (0.07)	2.23 (0.16)	17.30 (1.28)	20.70 (1.30)	5.68 (0.31)	1.39 (0.09)	0.28 (0.02)	7.35 (0.37)
Sep-03	1.93 (0.12)	9.54 (0.79)	7.18 (0.66)	23.62 (1.44)	2.42 (0.18)	0.95 (0.06)	0.23 (0.03)	3.62 (0.21)	1.26 (0.07)	0.76 (0.04)	0.11 (0.02)	2.14 (0.11)
Oct-03	4.29 (0.23)	0.86 (0.10)	1.62 (0.14)	6.77 (0.32)	3.39 (0.28)	1.22 (0.08)	3.12 (0.27)	4.91 (0.31)	4.09 (0.27)	2.23 (0.16)	1.25 (0.10)	7.58 (0.36)
Nov-03	10.10 (0.89)	5.01 (0.38)	4.88 (0.49)	20.30 (1.48)	3.76 (0.21)	3.32 (0.27)	4.21 (0.37)	11.30 (0.57)	1.59 (0.19)	1.15 (0.08)	0.75 (0.05)	3.51 (0.26)
Dec-03	4.41 (0.36)	1.93 (0.14)	2.57 (0.31)	8.99 (0.61)	2.61 (0.18)	1.61 (0.11)	3.37 (0.30)	7.58 (0.47)	1.40 (0.11)	0.76 (0.05)	0.52 (0.04)	2.68 (0.18)

Variation of total nitrogen, total phosphorus, microalgal chlorophyll *a* and net photosynthetic rate in the lakes

Variation of total nitrogen, total phosphorus, microalgal chlorophyll *a* and net photosynthetic rate in the lakes fluctuated with time (Figs 1, 2, 3). The variation range of the total nitrogen in Lake Aha was the smallest among the lakes, and the average value of total nitrogen in Lake Aha was greater than those in Lakes Baihua and Hongfeng. The average value of total phosphorus in Lakes Baihua and

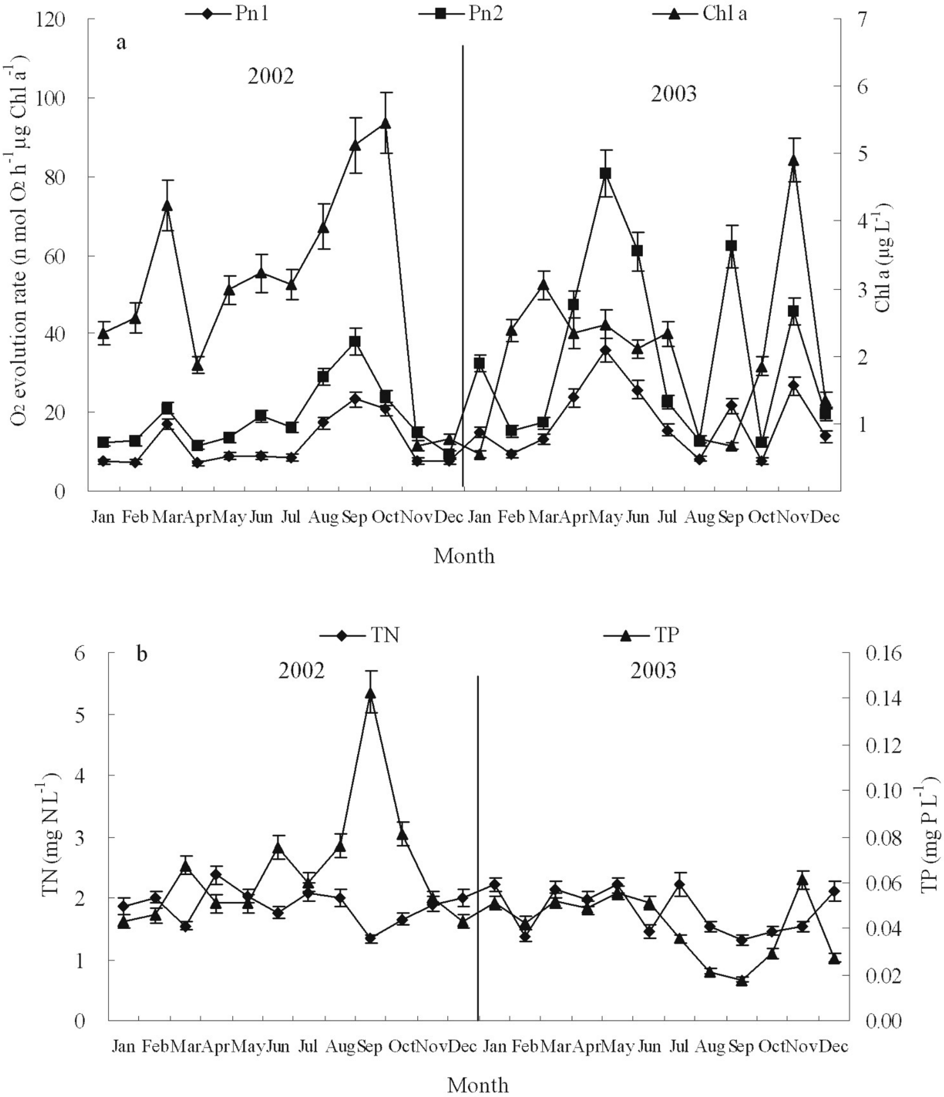

Fig. 1. Monthly changes of microalgal chlorophyll *a* and net photosynthetic rate (a), total phosphorus and total nitrogen (b) in Lake Aha (Pn1: the net photosynthetic O_2 evolution rate under a photon flux density of 150μmol m^{-2} s^{-1}; Pn2: the net photosynthetic O_2 evolution rate under a photon flux density of 500μmol m^{-2} s^{-1}).

Hongfeng was greater than that in Lake Aha. The microalgal chlorophyll *a* in water body had a similar variation range among the lakes. Net photosynthetic O_2 evolution rate under 150 μmol m^{-2} s^{-1} or under 500 μmol m^{-2} s^{-1} in the lakes varied greatly with time. Net photosynthetic O_2 evolution rate under 500μmol m^{-2} s^{-1} was greater than that under 150μmol m^{-2} s^{-1} in the same lake and month (Figs 1, 2, 3).

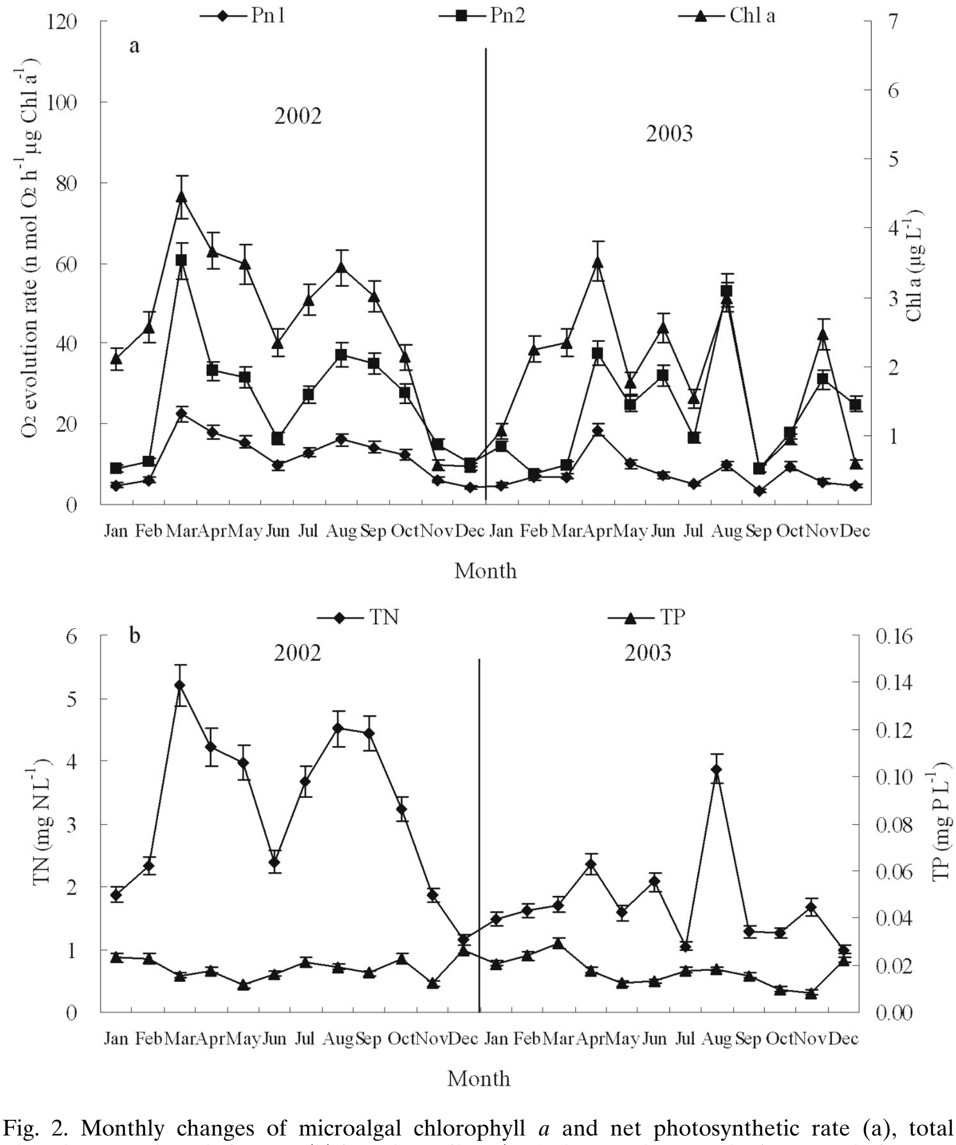

Fig. 2. Monthly changes of microalgal chlorophyll *a* and net photosynthetic rate (a), total phosphorus and total nitrogen (b) in Lake Baihua (Pn1: the net photosynthetic O_2 evolution rate under a photon flux density of 150μmol m^{-2} s^{-1}; Pn2: the net photosynthetic O_2 evolution rate under a photon flux density of 500μmol m^{-2} s^{-1}).

Variation of N/P ratio in Lakes

Variation of N: P ratios (g:g) in the lakes fluctuated with time (Fig. 4). The N: P ratio of Lake Aha was different from that of Lakes Baihua and Hongfeng. The N: P ratio ranged from 9 to 77 (average 44) in Lake Aha, from 43 to 349 (average 150) in Lake Baihua, and from 51 to 473 (average 180) in Lake Hongfeng.

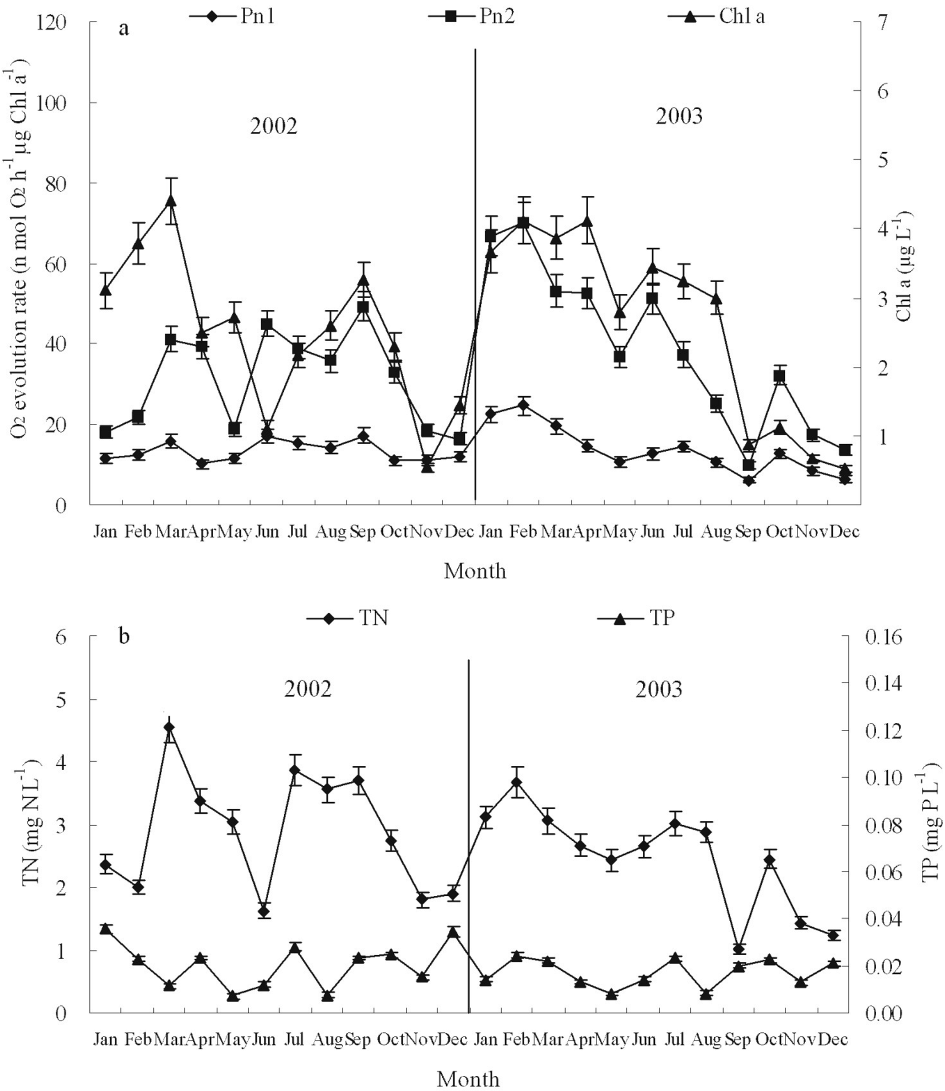

Fig. 3. Monthly changes of microalgal chlorophyll *a* and net photosynthetic rate (a), total phosphorus and total nitrogen (b) in Lake Hongfeng (Pn1: the net photosynthetic O_2 evolution rate under a photon flux density of 150μmol m^{-2} s^{-1}; Pn2: the net photosynthetic O_2 evolution rate under a photon flux density of 500μmol m^{-2} s^{-1}).

The relationship among TN, TP, microalgal chlorophyll *a*, net photosynthetic rate and compositions

The correlations among TN, TP, microalgae chlorophyll *a*, net photosynthetic rate and compositions in Lake Aha are presented in Table 3. It can be seen that microalgal chlorophyll *a*, Cyanophyta and total algal number had a significant positive correlation with total phosphorus in Lake Aha. The microalgal

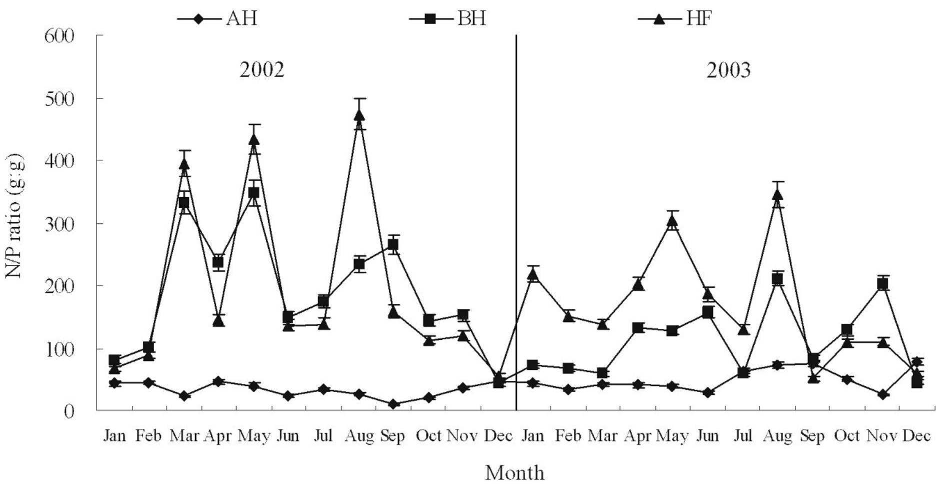

Fig. 4. Monthly variation of N/P ratio in Lakes Aha (AH), Baihua (BH) and Hongfeng (HF)

Table 3. Correlation coefficient of TN, TP, microalgal chl *a*, net photosynthetic rate and compositions in Lake Aha (n=24)

TN	1								
TP	-0.16	1							
Chl a	-0.24	0.74**	1						
Pn1	-0.18	0.30	0.37	1					
Pn2	-0.18	0.11	0.08	0.92**	1				
Cyano	-0.34	0.70**	0.90**	0.51*	0.20	1			
Chlor	-0.32	-0.14	-0.06	0.76**	0.87**	0.00	1		
Bacil	-0.20	0.19	-0.10	0.50*	0.60**	0.02	0.18	1	
Total A	-0.13	0.51*	0.45*	0.85**	0.73**	0.58**	0.41*	0.65**	1
Variables	TN	TP	Chl a	Pn1	Pn2	Cyano	Chlor	Bacil	Total A

** Correlation is significant at the 0.01 level (2-tailed). Pn1: the net photosynthetic O_2 evolution rate under a photon flux density of 150μmol m^{-2} s^{-1}; Pn2: the net photosynthetic O_2 evolution rate under a photon flux density of 500μmol m^{-2} s^{-1}; Cyano: Cyanophyta; Chlor: Chlorophyta; Bacil: Bacillariophyta; Total A: total microalgae.

chlorophyll *a* is related to the number of Cyanophyta and total microalgae. The microalgal net photosynthetic O_2 evolution rate had a significant positive correlation with total algae, Chlorophyta and Bacillariophyta in Lake Aha. Significant correlation also occurred between microalgal net photosynthetic O_2 evolution rate under a photon flux density of 150 μmol m^{-2} s^{-1} and that under a photon flux density of 500 μmol m^{-2} s^{-1}. There were no significant correlations among total nitrogen, total phosphorus and microalgal net photosynthetic rate in Lake Aha.

The correlations among TN, TP, microalgae chl *a*, net photosynthetic rate and compositions in Lake Baihua are presented in Table 4. It can be seen that significant correlation occurred among total nitrogen, the number of total microalgae, the number of Cyanophyta, the number of Chlorophyta, microalgal chlorophyll *a* and net photosynthetic rate in Lake Baihua. There were no significant correlations between total nitrogen and total phosphorus in Lake Baihua. Microalgal chlorophyll *a*, net photosynthetic O_2 evolution rate under 150 and 500 μmol $m^{-2}s^{-1}$ varied with total nitrogen. The peaks of total nitrogen, microalgal net photosynthetic O_2 evolution rate and chlorophyll *a* in Lake Baihua in 2002 appeared in March and August, while in 2003 they were evident in April and August (Fig. 2).

Table 4. Correlation coefficient of TN, TP, microalgal chl *a*, net photosynthetic rate and compositions in Lake Baihua (n=24)

TN	1								
TP	-0.09	1							
Chl a	0.83**	-0.08	1						
Pn1	0.84**	-0.20	0.82**	1					
Pn2	0.76**	-0.35	0.71**	0.76**	1				
Cyano	0.76**	-0.34	0.46*	0.63**	0.41*	1			
Chlor	0.68**	-0.22	0.79**	0.86**	0.74**	0.41*	1		
Bacil	0.12	-0.25	0.08	-0.07	0.47*	-0.30	-0.12	1	
Total A	0.91**	-0.25	0.75**	0.78**	0.92**	0.67**	0.69**	0.35	1
Variables	TN	TP	Chl a	Pn1	Pn2	Cyano	Chlor	Bacil	Total A

** Correlation is significant at the 0.01 level (2-tailed). Pn1: the net photosynthetic O_2 evolution rate under a photon flux density of 150μmol m^{-2} s^{-1}; Pn2: the net photosynthetic O_2 evolution rate under a photon flux density of 500μmol m^{-2} s^{-1}; Cyano: Cyanophyta; Chlor:Chlorophyta; Bacil: Bacillariophyta;Total A: total microalgae.

The correlations among TN, TP, microalgae chl *a*, net photosynthetic rate and algal population composition in Lake Hongfeng are presented in Table 5. It can be seen that the result of significant correlation among the total nitrogen, the total number of microalgae, the number of Cyanophyta, the number of Chlorophyta, microalgal chlorophyll *a* and net photosynthetic O_2 evolution rate was similar to that in Lake Baihua. There were also no significant correlations between the total nitrogen and the total phosphorus in Lake Hongfeng. Microalgal chlorophyll *a*, net photosynthetic O_2 evolution rate under 150 μmol $m^{-2}s^{-1}$ and 500 μmol varied with the total nitrogen (Fig. 3).

Table 5. Correlation coefficient of TN, TP, microalgal chl *a*, net photosynthetic rate and compositions in Lake Hongfeng (n=24)

TN	1								
TP	-0.06	1							
Chl a	0.71**	-0.06	1						
Pn1	0.61**	0.04	0.61**	1					
Pn2	0.62**	-0.11	0.65**	0.87**	1				
Cyano	0.53**	0.16	0.36	0.77**	0.65**	1			
Chlor	0.48*	-0.22	0.54**	0.54**	0.80**	0.15	1		
Bacil	0.31	-0.10	0.39	0.67**	0.67**	0.56**	0.20	1	
Total A	0.62**	0.02	0.54**	0.91**	0.90**	0.90**	0.50*	0.74**	1
Variables	TN	TP	Chl a	Pn1	Pn2	Cyano	Chlor	Bacil	Total A

** Correlation is significant at the 0.01 level (2-tailed). Pn1: the net photosynthetic O_2 evolution rate under a photon flux density of 150μmol m^{-2} s^{-1}; Pn2: the net photosynthetic O_2 evolution rate under a photon flux density of 500μmol m^{-2} s^{-1}; Cyano: Cyanophyta; Chlor: Chlorophyta; Bacil: Bacillariophyta; Total A: total microalgae.

DISCUSSION

Decreases of 9.0×10^4 Kg·year^{-1} in nitrogen and $4.6\text{-}6.8 \times 10^4$ Kg·year^{-1} in phosphorus were achieved after the measure of reducing point sources pollution in Lakes Hongfeng and Baihua was implemented (Li, 2001). The average total nitrogen in Lake Baihua decreased from 4.2 mg L^{-1} in 1996 to 2.5 mg L^{-1} in 2003, and from 4.7 to 2.7 mg L^{-1} in Lake Hongfeng. The average total phosphorus in Lake Baihua decreased from 0.028 mg L^{-1} in 1996 to 0.018 mg L^{-1}, and from 0.031 to 0.019 mg L^{-1} in Lake Hongfeng (Liang *et al*., 1998). In Lakes Baihua and Hongfeng, phosphorus concentration was below the critical value of mesophication (0.025 mg L^{-1}), and the concentration of nitrogen was above the critical value of eutrophication (2.00 mg L^{-1}) (Huang *et al*., 1997). In Lake Aha, the average value of total phosphorus (0.053 mg L^{-1}) was close to the critical value of eutrophication (0.050 mg L^{-1}), and the average value of total nitrogen (1.84 mg L^{-1}) was below the critical value of eutrophication (Huang *et al*., 1997). The reduction of nitrogen and phosphorus loading significantly decreased the occurrence of microalgal blooms.

Total microalgal numbers were positively correlated with microalgal net photosynthetic O_2 evolution rate in the three lakes. Microalgal net photosynthetic O_2 evolution rate under a photon flux density of 150 μmol m^{-2} s^{-1} was much lower than that under a photon flux density of 500 μmol m^{-2} s^{-1} for a given lake and month implying that the former light intensity was sub-optimal for photosynthesis. There was a significant correlation between microalgal net photosynthetic O_2 evolution rate under a photon flux density of 150 μmol m^{-2} s^{-1} and that under a photon flux density of 500 μmol m^{-2} s^{-1} in the three lakes. It was shown that microalgal net photosynthetic O_2 evolution rate and the microalgal growth rate in surface water bodies (stronger light intensities) was greater than that in subsurface water (weaker light intensities). Microalgal blooms, if they occur, may firstly appear in surface water bodies. Therefore, the growth of microalgae in the surface water body can reflect that in the subsurface water body.

Our results also indicate that the total nitrogen in Lakes Hongfeng and Baihua was correlated with microalgal chlorophyll *a* and net photosynthetic O_2 evolution rate, and that total phosphorus in Lake Aha correlated with microalgal chlorophyll *a*. The three Karst lakes can, therefore, be divided into two types according to their trophic status. One type is likely to be controlled by the total nitrogen, as is the case of Lakes Baihua and Hongfeng, and the other is supposedly controlled by total phosphorus, as is the case of Lake Aha. In fact, the trophic status and the microalgae compositions in the three lakes are not completely self-controlled. The rapid exchanges within water bodies cause fluctuations of TN, TP and microalgal compositions in the lakes with time. Therefore, the trophic status and microalgae compositions of the three lakes are not inherent.

The N:P ratio in the three lakes is significantly greater than that of the critical value of Redfield (16:1, g:g). It was therefore supposed that phosphorus was the nutrient limiting the growth of phytoplankton in the lakes. This rule, however, applies only to Lake Aha. This is because the N:P ratio of the water bodies in the lakes is affected by the input of external nutrients and the water exchange rate. The trophic status of water bodies in the catchments, which converged water into the three lakes, is the primary factor that limits the N:P ratio.

The fluctuations in the trophic status and microalgal community composition in the lakes are controlled by the erosion of the basin, loading reduction of nutrients, and climatic factors and seasonal changes. The variation in the chemical compositions of the three lakes is great because of the difference of erosion areas and magnitude (Bai & Wan, 1998). The surface water temperatures in the lakes during the study time varied seasonally between a minimum of 0.4 °C in winter and a maximum of 28.5 °C in summer. The water level of the three lakes changes greatly within one year. The wet season lasts from May to October, and the dry one from November to the end of the following April (Gu & Liu, 2001). The fluctuation during the study caused temporary eutrophication in the lakes, while the higher average value of TN and TP caused a long term of continuous eutrophication before the measures of reducing point source pollution in Lakes Hongfeng and Baihua were taken.

CONCLUSIONS

The total nitrogen in water bodies affected microalgal composition, chlorophyll *a* and net photosynthetic O_2 evolution rate in Lakes Hongfeng and Baihua, and the total phosphorus in water bodies affected the microalgal composition, chlorophyll *a* in Lake Aha. The microalgal biomass in Lakes Aha, Baihua and Hongfeng appears to be determined by the trophic status, especially levels of TN and TP. The values of TN, TP, and the ratio of TN/TP in Lakes Aha, Baihua and Hongfeng fluctuated with time. The variation of microalgal composition in the lakes also varied with time. The trophic status and the microalgal composition in the three lakes were affected by those of the water bodies in catchments, which delivered water into the lakes. The change in TN was not however accompanied by a large microalgal bloom in Lakes Baihua and Hongfeng as is often symptomatic of eutrophication. Similarly, the change in TP was not associated with a large microalgal bloom in Lake Aha. These conclusions offer a reference to the management of the hydro-environment in Karst areas.

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REFERENCES

BAI Z., WU F., WAN X., ZOU S. & WAN G., 1995 — Mechanism of water quality worsing seasonally in Lake Baihua. *Chongqing environmental science* 17:10-14.

BAI Z. & WAN G., 1998 — Variability of aquatic chemistry in central Guizhou Karst region, China. *Chinese journal of geochemistry* 17:241-248.

CHEN G., AI G., XIE Q. & YU T., 1999 — The investigation on reasons of fish in the net died in a large scale in Lake Hongfeng. *Water conservancy and fishery* 102: 47-49

GU X. & LIU X., 2001 — Analysis of Influence on Reservoir Water Capacity by Rain in Spring and Summer. *Meteorology* 26:50-53.

HUANG W.J., XU J.H. & WU Y.G., 1997 — The evaluation of eutrophication on primary reservoirs in China. *Guizhou environmental science and technology* 3:12-16.

HOWARTH R.W., SWANEY D.P., BUTLER T.J. & MARINO R., 2000 — Climatic Control on Eutrophication of the Hudson River Estuary. *Ecosystems* 3: 210-215

KANGUR K., MÖLS T., MILIUS A. & LAUGASTE R., 2003 — Phytoplankton response to decreasing nutrient level in Lake Peipsi (Estonia) in 1992-2001. *Hydrobiologia* 506-509: 265-272.

LUND J.W.G., KIPLING C. & LE CREN E.D., 1958 — The inverted microscope method of estimating algal numbers and the statistical basis of estimation by counting. *Hydrobiologia* 11: 143-170.

LI Q., 2001 — Analysis of recent eutrophication status of Hongfeng and Baihua Lakes. *Journal of Guizhou university of tchnology* (Natural Science Edition) 30: 98-102.

LIANG X., FU W., ZHANG M. & WANG A., 1998 — Investigation on Nutrient Elements and Organic Pullutants of Baihua and Hongfeng Lake. *Guizhou science* 16: 311-315.

LORENZEN C.J., 1967 — Determination of chlorophyll and phaeopigments: spectrophotometric equations. *Limnology and oceanography* 12: 343-346.

NÕGES T. & NÕGES P., 1999 — The effect of extreme water level decrease on hydrochemistry and phytoplankton in a shallow eutrophic lake. *Hydrobiologia* 409: 277-283.

SARVALA J., HELMINEN H., SAARIKARI V., SALONEN S. & VUORIO K., 1998 — Relations between planktivorous fish abundance, zooplankton and phytoplankton in three lakes of differing productivity. *Hydrobiologia* 363: 81-95.

SEIP K.L., 1994 — Phosphorus and nitrogen limitation of algal biomass across trophic gradients. *Aquatic sciences* 56: 16-28.

STATE ENVIRONMENTAL PROTECTION ADMINISTRATION OF CHINA (SEPAC), 1988 — Environmental quality standard for surface water. State standard of the People's Republic of China (GB 3838-88). Beijing, China.

TEMPONERAS M., KRISTIANSEN J. & MOUSTAKA-GOUNI M., 2000 — Seasonal variation in phytoplankton composition and physical-chemical features of the shallow Lake Doïrani, Macedonia, Greece. *Hydrobiologia* 424: 109-122.

WEHR J.D. & DESCY J.P., 1998 — Use of phytoplankton in large river management. *Journal of phycology* 34: 741-749.

WU Y.Y., LI P.P., WANG B.L., LIU C.Q., HE M. & CHEN C., 2004 — Changes of the water quality and phytoplankton in Hongfeng and Baihua Lake. *Journal of agro-environmental science* 23:745-747.

ZOU D., XIA J. & YANG Y., 2004 — Photosynthetic use of exogenous inorganic carbon in the agarophyte *Gracilaria lemaneiformis* (Rhodophyta). *Aquaculture* 237: 421-431.