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ORIGINAL ARTICLE

Historical eutrophication in Lake Taihu: evidence from biogenic silica and total phosphorus accumulation in sediments from northern part of Lake Taihu

Jun Li · Cong-Qiang Liu · Zhaozhou Zhu

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Abstract Sediment and water from the Meiliang Bay of Lake Taihu were analyzed to examine the historical relation between the accumulation of biogenic silica (BSi) and total phosphorus (TP). The results indicate that BSi accumulation in the northern part of Lake Taihu had been controlled by diatom production and phosphorus loading since the 1950s. BSi accumulation increased with the growing agricultural activity since the 1950s, up to a maximum level in the 1960s. After that, BSi accumulation decreased due to the diatom dissolution till the 1980s, and then the diatom biomass decreased with BSi accumulation increased. Lake Taihu came into an accelerated eutrophication periods since the 1990s, while BSi accumulation began to increase but the proportion of diatom decreased. Although the onset of silica depletion cannot be confirmed in the present work, it is clear that BSi accumulation was restrained by the input of TP.

Keywords Lake Taihu · Eutrophicaton · BSi accumulation · TP loading · Total organic carbon · Total nitrogen

Introduction

Eutrophication is the process of enhanced trophic status due to increased nutrient inputs (Moss et al. 1997). This process can induce abnormal phytoplankton increase, rapid decrease in water transparency, gradual decline in the macrophyte, quick deterioration of water quality, and even final forfeiture of water function. Although nitrogen (N) and phosphorus (P) have been assumed to be primarily responsible, phosphorus is the vital factor for freshwater systems (Aminot and Andrieux 1996). Silica (Si) is an important nutrient for certain biota; especially for the diatoms that require silica for cell division (Brzezinski 1992). Therefore, the composition of phytoplankton population is controlled largely by the availability of P and Si. Surplus anthropogenic P loading into the lake causes increase in diatom production. Such a factor promoted the uptake and the subsequent sedimentation of Si, which led ultimately to long-term reduction of Si stored in the lake water column. Many previous studies have accepted that increased biogenic silica (BSi) accumulations in Laurentian Great Lake sediments were associated with increased P inputs from human activities in the surrounding watershed (Schelske and Stoermer 1971; Conley and Schelske 1993; Schelske et al. 2006).

Lake Taihu, located in the lower Yangtze River delta (Fig. 1), is a large (2,338 km^2), shallow (average depth 1.9 m) freshwater lake in eastern China (Qin et al. 2007). The lake provides water supply, irrigation water and culture fisheries to the surrounding areas. In the recent decades, water consumption increased with the rapid industrial and agricultural development, population growth and urbanization. As a result, Lake Taihu has suffered from eutrophication since the 1950s, due to increasing amounts of nutrient sources (Chang 1996; Guo et al. 2004), and has been influenced by intensive blooms of blue-green algae during the summer (Wu et al. 2006; Qin et al. 2007). It is known that P limits phytoplankton productivity in Lake Taihu; however, there are few reports on the relationship

J. Li · C.-Q. Liu (✉)
State Key Laboratory of Environmental Geochemistry,
Institute of Geochemistry, Chinese Academy of Sciences,
Guiyang 550002, China
e-mail: liucongqiang@vip.skleg.cn; lijun5931@163.com

Z. Zhu
Key Laboratory of Water Resource and Aquatic Environment,
Tianjin Normal University, Tianjin 300387, China

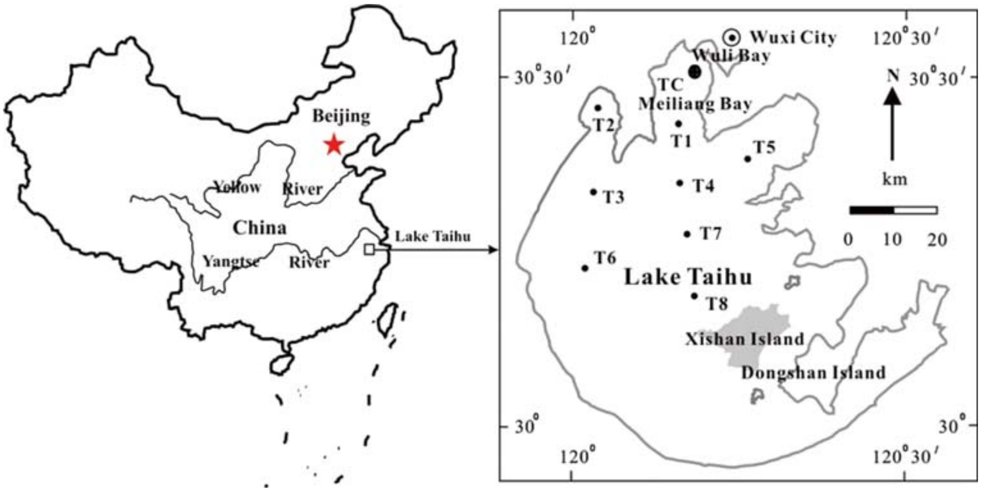

Fig. 1 Map of the sampling sites in Lake Taihu

among the total phosphorus (TP) inputs, diatom production and BSi accumulation. Atomic ratios of dissolved nutrients in the water column of Taihu Lake show that for phytoplankton, the nutrient that is limited is P during the winter and Si during the summer (Li et al. 2005).

Geochemical records preserved in sediments can serve as archives of detailed information on anthropogenic influence and environmental changes, which occurred at the time of their deposition (Ratnayake et al. 2005). Therefore, two short sediment cores collected from Lake Taihu were investigated to determine the historical relation among accumulation of BSi, TP, biologically available phosphorus (AVP), total organic carbon (TOC) and total nitrogen (TN) in the sediments.

In this paper, data on TP loading and BSi accumulation are used to show the (1) responses of Lake Taihu to increased TP loading since the 1950s, (2) changes in the biogeochemistry of Si and P, and (3) evolutions in the community structure of phytoplankton since the 1950s.

Materials and methods

Study area and sampling

Based on the hydrological characteristics and the eutrophication extent of different locations, sediment cores were collected at station TC from Meiliang Bay in the northern part of Lake Taihu, in 2002, using a gravity corer (Fig. 1). TC station abuts Wuxi City, which is not only an industrialized city, but also an impacted area. A large amount of industrial and urban pollutants from Wuxi City are discharged into Wuli Bay, where water currents can take such pollutants into the Taihu Lake via the Wuli Bay during the winter and spring (Zou et al. 1996). The cores were immediately sliced into 1-cm sized sections using a plastic slicer in situ. The sections were kept in the polythene centrifuging tubes, which had been washed with diluted acid and deionized water successively. The samples were stored at 4°C for further solid-phase analysis.

In addition, water samples for phytoplankton and nutrients analysis were also collected from 0.5 m below the water surface at the monitored sites (T1–T8, including TC) from the northern part of Lake Taihu in 2004 (Fig. 1). Two samples were collected at each sampling site, one sample for phytoplankton analysis was preserved immediately with Lugol’s iodine solution, and the other sample was stored at 4°C in darkness for TN and TP analysis.

Analytical methods

Samples for BSi were freeze-dried and crushed, and then homogenized for 24 h. Approximately, 50 mg of sediment was weighed into polycarbonate containers and digested with 5 ml H_2O_2 (10%) for 30 min to remove organic material, then 5 ml HCl (1 M) was added and the sample was subjected to ultrasonic bath for 30 min to remove carbonates. Quantification of BSi was carried out with a slightly modified Na_2CO_3 extraction method following Mortlock and Froelich (1989). After drying at 60°C, 40 ml of 2 M Na_2CO_3 solution was added into the residual biogenic and terrigenous Si and oscillated for 5 h to extract BSi. BSi was analyzed using the spectrophotometric techniques. Duplicate analysis of the same sample suggests that the precision of this extraction procedure is better than ± 5%.

Sediment samples were freeze-dried using the freeze-dryer and then ground as fine as to be < 125 μm in the agate mortar. A modified extraction procedure based on the methods of Aspila et al. (1976) and Kenney et al. (2001) was used to separate different forms of P in the sediments. In this procedure, the original sample was divided into three subsamples. One was oven-ashed at 550°C for 2 h

Table 1 Evaluating criteria of the trophic status indexes (Jin and Tu 1990)

	Oligotrophic	Mesotrophic	Eutrophic
TP (mg l^{-1})	0.003–0.019	0.019–0.065	0.065–1.415
TN (mg l^{-1})	0.04–0.24	0.24–0.77	0.77–14.64

and then extracted with 1 M HCl for 16 h to determine TP. Another subsample, designated to determine AVP, was extracted with 0.1 M NaOH for 17 h. In the same way as BSi, P forms were analyzed, and the precision of analysis was within ±5%.

The third subsample was used in determining TOC and TN concentrations by combustion using the elemental analyzer (PE2400-II). First, the sample was acidified with 1 M HCl for 24 h, to remove inorganic carbon, and then washed with deionized water to remove excess acid, followed by freeze-drying.

TN and TP concentrations of water samples followed Chinese standard methods for lake eutrophication surveys (Jin and Tu 1990). TN of water samples was determined as NO_3^- after oxidation with NaOH and K_2SO_4, and TP of water samples was converted into PO_4^{3-} with H_2SO_4 and K_2SO_4. The phytoplankton samples were concentrated to 30 ml after sedimentation for 2 days. After mixing, 0.1 ml concentrated sample was counted directly using the microscope at 8 × 40 magnification. Phytoplankton species were identified according to Hu et al. (1979).

The concentration of nutrient is a potent parameter, which can be used to define the trophic levels (Vollenweider 1969). Based on it, the trophic classification standard that suited the Chinese lake was proposed by the research group of the lake and reservoir eutrophication in China (Jin and Tu 1990). To reflect the status of lake eutrophication, the concentrations of TN and TP were selected as the evaluating parameters (Table 1).

In addition, sediment age was estimated from available dates determined by ^{210}Pb (Zhou 2006). ^{210}Pb activity was measured by direct gamma spectrometry using S-100 Series 16384 Multi-Channel Energy Spectrometer manufactured by U.S. Canberra Co. (Wan et al. 1987).

Results and discussion

The sediment accumulation rates and sedimentation rates were calculated from ^{210}Pb profiles and physical properties. Mean accumulation rate of the core was 3×10^4 μg cm^{-2} a^{-1}, and average sedimentation rate was 0.32 cm a^{-1}. The ages for the core are shown in Figs. 2 and 4. Based on the results of ^{210}Pb dating, the nutrient accumulation rates were estimated according to

$$AR = SR \times BD \times CN \quad (1)$$

where AR is the accumulation rate of nutrient in μg cm^{-2} a^{-1}, SR is sedimentation rate in cm a^{-1}, BD is bulk dry density in μg cm^{-3} and CN is the concentration of nutrient in μg g^{-1}. The nutrient accumulation rates of the TC core are shown in Table 2 and Fig. 2.

Nutrient accumulation rates

The nutrient accumulation rates present significant variation with depth in the TC core (Table 3, Fig. 2), which could be related with the changes of nutrients loading. In general, most of TOC, TP, AVP and TN show positive significant correlations in the TC core (Table 4). TOC show an obviously positive correlation with TP, AVP and TN, suggesting that the accumulation of P and N could be regulated by organic sources. Moreover, the excellent correlations between TP and AVP indicated that the concentrations of AVP in the sediments were controlled by the concentrations of TP. On the other hand, the distinct

Fig. 2 Profiles of nutrient accumulation rates versus depth in the TC core

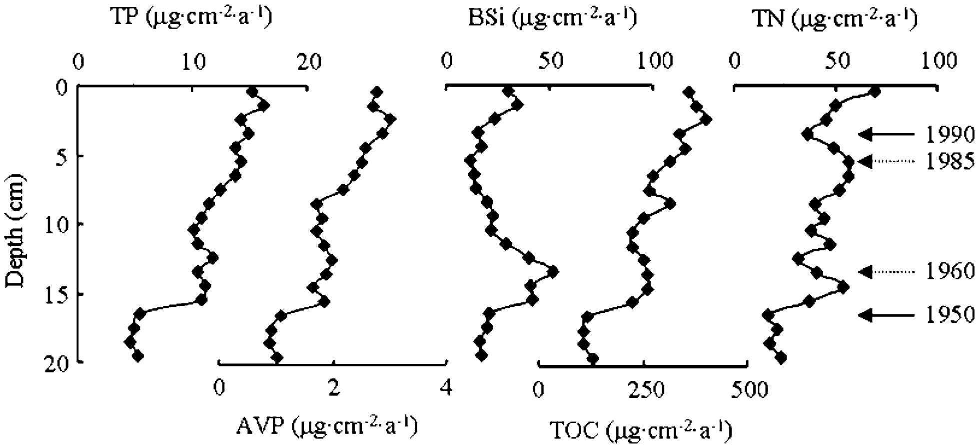

Table 2 Nutrient accumulation rates and atomic nutrient ratios in TC core

Depth (cm)	Nutrient accumulation rates (μg $\mathrm{cm^{-2}\ a^{-1}}$)					Atomic nutrient ratios				
	TP	AVP	BSi	TOC	TN	BSi/TP	AVP/TP	TOC/TN	TOC/TP	TOC/BSi
0–1	15.32	2.77	30.32	359.90	69.44	0.96	0.18	6.05	60.68	63.31
1–2	16.30	2.71	34.56	379.46	49.55	1.03	0.16	8.93	60.14	58.57
2–3	14.34	3.00	23.47	399.35	44.99	0.79	0.21	10.36	71.92	90.74
3–4	15.00	2.87	15.32	339.04	36.51	0.49	0.19	10.83	58.41	118.01
4–5	13.69	2.58	17.60	350.45	48.90	0.62	0.19	8.36	66.12	106.17
5–6	14.34	2.51	11.74	314.92	56.40	0.40	0.17	6.51	56.72	143.11
6–7	13.69	2.38	13.69	276.12	56.40	0.48	0.17	5.71	52.10	107.56
7–8	12.39	2.18	14.67	263.73	52.16	0.57	0.17	5.90	55.00	95.88
8–9	11.41	1.73	20.21	317.20	40.10	0.86	0.15	9.23	71.82	83.70
9–10	10.76	1.83	23.15	251.35	44.34	1.04	0.17	6.61	60.36	57.92
10–11	10.11	1.73	21.84	226.24	37.82	1.05	0.17	6.98	57.83	55.24
11–12	10.43	1.86	28.69	222.98	46.94	1.33	0.18	5.54	55.22	41.45
12–13	11.74	1.99	39.77	251.67	31.62	1.64	0.17	9.29	55.40	33.75
13–14	10.43	1.89	51.51	259.82	40.75	2.39	0.18	7.44	64.34	26.90
14–15	11.08	1.66	41.08	262.43	54.12	1.80	0.15	5.66	61.16	34.07
15–16	10.76	1.86	41.40	225.92	37.49	1.86	0.17	7.03	54.25	29.10
16–17	5.41	1.10	20.60	118.73	16.94	1.84	0.20	8.18	56.67	30.73
17–18	4.88	0.93	20.30	109.68	21.56	2.02	0.19	5.94	58.08	28.82
18–19	4.57	0.90	16.34	105.92	17.31	1.73	0.19	7.14	59.89	34.58
19–20	5.19	1.02	17.69	129.66	23.04	1.65	0.19	6.56	64.50	39.09

correlations between TP and TN suggested that these nutrients probably had similar sources.

TP accumulation is relatively constant (5 μg $\mathrm{cm^{-2}\ a^{-1}}$) at the bottom of the core, from 20 to 17 cm in 1950, and then increases rapidly to 11 μg $\mathrm{cm^{-2}\ a^{-1}}$ at 16 cm of the core (Fig. 2). Subsequently, TP shows a trend of gradual increase above 16 cm, and at the top 3 cm has a maximal accumulation of approximately 16 μg $\mathrm{cm^{-2}\ a^{-1}}$. The AVP pattern is similar to that of TP, except in the top 3 cm, which may be related to the increase in biological assimilation with the increase in phytoplankton biomass. TOC shows a pattern similar to that of TP toward the top of the core, which suggests that P is a controlling factor for the primary productivity in the lake. The pattern in TN accumulation is similar to that of TOC from 20 to 13 cm, but displays almost a mirror image increase as that of TOC in the rest of the core.

BSi accumulation is about 16 μg $\mathrm{cm^{-2}\ a^{-1}}$ at the bottom of the core, and then increases sharply to the highest accumulation of 51 μg $\mathrm{cm^{-2}\ a^{-1}}$ at 14 cm in 1960 of the core (Fig. 2). After the peak period, BSi accumulation in the core decreases to one-third of the peak period at 6 cm in 1985, and then increases to a secondary peak at the top 4 cm in 1990. An increase in TP and AVP accumulation accompanied with a decreased accumulation of BSi between 14 and 4 cm is quite obvious, which may indicate that diatom production is limited by Si (Schelske et al. 2006).

Atomic nutrient ratios

Table 2 and Fig. 4 show the vertical changes in atomic ratios of nutrients. BSi/TP ratios can be used as proxy for quality of nutrient enrichment or silica depletion. BSi/TP ratios

Table 3 The mean, range and standard deviation (SD) of nutrient concentrations ($\mathrm{mg\ l^{-1}}$) and nutrient accumulation rates (μg $\mathrm{cm^{-2}\ a^{-1}}$)

	Water samples (n = 9)				Sediment samples (n = 20)			
	Mean	Minimum	Maximum	SD	Mean	Minimum	Maximum	SD
TP	0.19	0.05	0.79	0.24	11.09	4.57	16.30	3.61
AVP					1.98	0.90	3.00	0.65
BSi					25.20	11.74	51.51	11.12
TOC					258.23	105.92	399.35	89.35
TN	5.79	2.12	21.13	6.21	41.32	16.94	69.44	14.04

Table 4 Pearson correlation of nutrients in TC core

Nutrients	TP	AVP	BSi	TOC	TN
TP	–	0.97*	0.08	0.96*	0.83*
AVP		–	0.00	0.94*	0.75*
BSi			–	0.09	0.10
TOC				–	0.77*
TN					–

* Significant at the 0.001 probability level

increase slightly from the bottom of the core to 14 cm and then decrease gradually. The major peak occurs at 13–15 cm, which corresponds to the maximum accumulation of BSi. In sediments deposited after the major peak, ratios of BSi/TP decrease, and then increase to a secondary peak at the top 4 cm of the core. AVP/TP ratios can reflect not only the AVP proportion of TP, but also the AVP contribution from anthropogenic sources. AVP/TP ratios decrease from the base of the core to 9 cm in 1975, and then increase to the peak value of 0.2 at 3 cm, which may suggest that there was increased loading of nutrients derived from urban sewage and industrial waste since the 1975s (Fan 1996). The decrease in AVP/TP at the top 3 cm is consistent with the decrease in AVP accumulation at the top 3 cm.

TOC/TN ratios are often used to trace the source of organic matter and the extent of organic matter degradation in the sediments (Meyers 1997). TOC/TN ratios are low (5.5–10.8) in the entire core (Fig. 4), suggesting that the organic matter was mainly derived from lacustrine authigenesis. Moreover, TOC/TN ratios with slight variation do not show specific variation trends, which could be related to the selective degradation of organic matter during early diagenesis, so TOC/BSi ratios can be used to reflect factually the changes of phytoplankton assemblage and primary production of the lake. TOC/BSi ratios increase from the bottom of the core to 6 cm, and then decrease at the top of the core (Fig. 4). To sum up, TOC/BSi ratios are greater in the surface sediments (in the upper 10 cm) than at the depth. This result may indicate that increased deposition of organic matter in surface sediments could be resulted from increased production of non-siliceous phytoplankton, provided the bulk of organic matter was derived from phytoplankton.

Water sample analysis

The concentrations of TN and TP were very high at all of the sampling sites during the study period (Table 3) and very close to the nutrient indexes of the eutrophic level (Table 1). From the nearshore to the offshore sites, the spatial distributions of TN and TP concentrations tended to decrease (Li et al. 2006), which indicated that anthropologic activities and lake characteristics had a strong impact on the water quality of Lake Taihu. TN concentrations varied between 2.12 and 21.13 mg l^{-1}, and with an average value of 5.79 mg l^{-1}. Compared to the other sites, the sampling sites TC and T1 had a significantly higher TN concentration. TP concentrations ranged from 0.05 to 0.79 mg l^{-1}, and with an average value of 0.19 mg l^{-1}. The concentration gradient of TP was similar to that of TN. Although the concentration of nutrients is significantly different, the trophic status of lake water is mostly at the eutrophic level, according to Chinese trophic classification standard (Jin and Tu 1990), and the different areas do not show any significant difference (Fig. 3).

The density of phytoplankton was also very high at all of the sampling sites, ranging from 2.54×10^7 individuals l^{-1} to 8.53×10^8 individuals l^{-1}, and with an average value of 2.87×10^8 individuals l^{-1} (Li et al. 2006). There were six main phytoplankton assemblages including Cyanophyta, Cryptophyta, Bacillariophyta, Chlorophyta, Euglenophyta and Pyrrophyta, among which the predominant species was *Microcystis* spp., accounting for 90% of total phytoplankton biomass. Bacillariophyta merely accounted for 4% of the total phytoplankton biomass. Although the diatom is still one of the dominant algae with high nutrient inputs, its proportion in phytoplankton species composition is gradually decreasing (Fig. 5).

The quantities of phytoplankton and the concentration of nutrients have increased since the 1950s (Fan 1996). TP concentrations have been increased 10-fold since the 1980s, and TN concentrations have been augmented to 8-fold as well (Fig. 5). In addition, the density of phytoplankton has increased from tens of thousands per liter to tens of millions per liter since the 1960s (Li et al. 2006).

Historical eutrophication in Lake Taihu

TOC accumulation is directly related to the primary production (Qiu et al. 1993), and the BSi accumulation can be

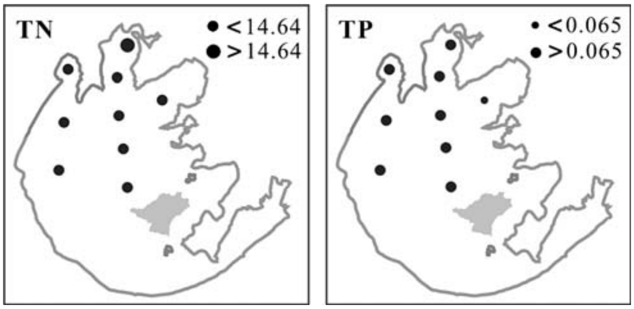

Fig. 3 Spatial distributions of TN and TP (mg l^{-1}) in the water column of Lake Taihu

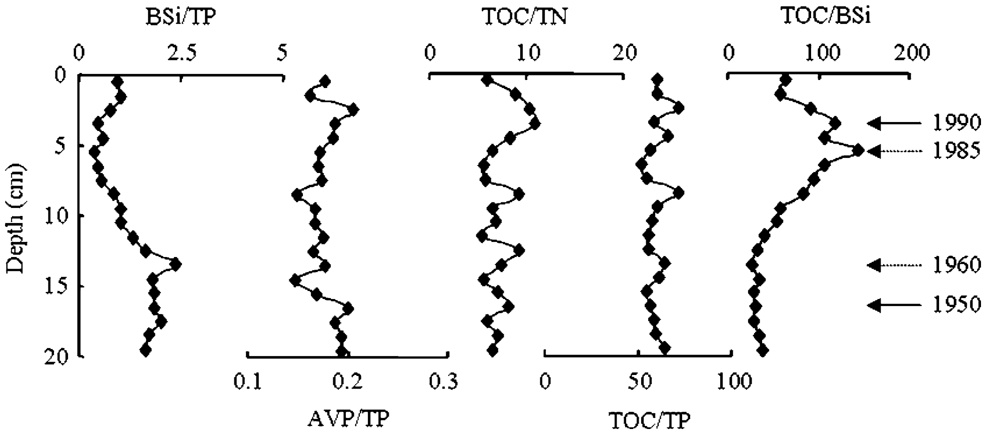

Fig. 4 Profiles of atomic nutrient rates versus depth in the TC core

used to reflect diatom production as well (Peinerud et al. 2001). Although enough data are not available for historical rates of phytoplankton and diatom production, we can assume that the rates of phytoplankton degradation and diatom dissolution did not change prior to permanent burial. We can, therefore, realize how overall primary productivity impacted on the accumulation of BSi through a comparison of TOC and BSi accumulation records.

The higher accumulation of nutrients (Fig. 2) since the 1950s reflects the beginning of an increase in the intensity of agricultural activity associated with soil erosion and land use in Lake Taihu basin (Chen and wang 1999). During this period, terrestrial organic matter was washed into the lake via surface runoff, as evidenced by the rapid decrease of AVP/TP values (Fig. 4). At the top 4 cm of the core, i.e., since the 1990s (Fig. 2), the highest accumulation of nutrients are the result of enhanced primary productivity from the lake itself related to increased nutrient loadings from urban sewage and industrial waste.

Meiliang Bay has undergone two major events during past decades in primary productivity and BSi accumulation and those resulted from anthropogenic activities: (1) The intensity of agricultural activity since the 1950s: The earliest event, the intensity of agricultural activity, occurred in 1950 due to population explosion, which caused an increase in soil erosion. Due to the high input of terrestrial organic matter, the accumulation of nutrients shows a trend towards rapid increase, but aquatic productivity also plays a larger role in this shift, because the TOC/TN values (6.9–10.8) are within the acceptable range for modern aquatic vegetation from Lake Taihu (Wu et al. 2007). The BSi accumulation had been up to a maximal value, with the TOC increase at this stage mainly resulting from diatom bloom due to an increased input of TP. In 1960, there were 91 species of phytoplankton in Lake Taihu, and the dominant species belonged to Cyanophyta with the density of the algae individuals being tens of thousands per liter (Fan 1996). The nutrient concentrations of TN and TP increased rapidly in the 1975s, and Taihu Lake came into the mesotrophic level. Natural water plant had disappeared in Wuli Bay. In 1980, there were 79 species of phytoplankton in Lake Taihu, of which the dominant species belonged to Bacillariophyta and Cyanophyta, with the density of alga individuals being hundreds of thousands per liter (Fan 1996). Subsequently, the nutrient concentration continued to increase, the nutrient level was enhanced and the water quality continued to deteriorate. Although the BSi accumulation continued to decrease from the 1960s to the 1985s with the increase of TP accumulation (Fig. 2), we consider that Si was not the limiting factor for diatom production, based on the evolutions of phytoplankton species composition (Fig. 5). Therefore, the response relation between BSi and TP (AVP) could be attributed to the Cyanophyta bloom and the diatom dissolution (Peinerud 2000). (2) The accelerated eutrophication since the 1990s: At the beginning of the 1985s, the water quality continued to deteriorate. The dominant species of phytoplankton belonged to Cyanophyta and Bacillariophyta. Compared with the 1980s, the diatom proportion of phytoplankton

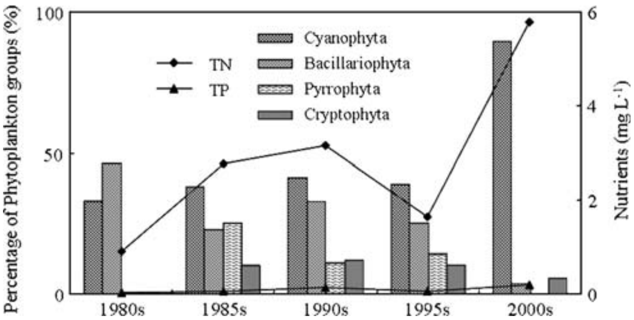

Fig. 5 Summary variations of phytoplankton species composition with TN and TP increase in the water column of Lake Taihu since the 1980s (Fan 1996; Li et al. 2006)

composition decreased, but the BSi accumulation began to increase (Figs. 2, 5). At the beginning of the 1990s, Lake Taihu roundly entered into the eutrophic level, and the aquatic vegetation degenerated seriously. There were only 17 species of residual hydrophytes, and submerged macrophytes almost vanished. The species of phytoplankton increased to 86, and the density of alga individuals was tens of millions per liter with the dominant species belonging to Cyanophyta and Bacillariophyta in 1993 (Fan 1996). Subsequently, the deterioration of water quality was still in progress, Lake Taihu gradually came into the hypertrophic level. The proportion of diatom in phytoplankton species composition rapidly decreased, and the Cyanophyta almost became the exclusively dominant phytoplankton species in 2004 (Li et al. 2006). The BSi accumulation increased with the decrease of diatom proportion at this stage and may be related to the longer regeneration cycle of silica in the sediments (Lewin 1961). This result also indicates that the sediments are an important sink for BSi, even though under disadvantageous environmental and biotic condition.

Conclusions

BSi accumulation in the northern part of Lake Taihu since the 1950s has been controlled by primary productivity and anthropogenic activity. The record of BSi accumulation provides a general index that can be used to assess the historical impacts of P enrichment. Although Si is not a limiting factor for phytoplankton production, so far, this trend is very obvious since the 1990s, especially at the beginning of the 2000s. The sharp decrease in diatom production is accompanied by the decrease of BSi accumulation. Simultaneously, a rapid increase of Microcystis biomass has occurred. The Microcystis bloom is a serious environmental and ecological problem and will be a remarkable and watchful event.

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References

Aminot A, Andrieux F (1996) Concept and determination of exchangeable phosphate in aquatic sediments. Water Res 30:2805–2811

Brzezinski MA (1992) Cell-cycle effects on the kinetics of silicic acid uptake and resource competition among diatoms. Plankton Res 14:1511–1539

Chang WYB (1996) Major in environmental changes since 1950 and the onset of accelerated eutrophication in Lake Taihu, China. Acta Palaeontologica Sinica 35:155–174 (in Chinese)

Chen ZY, Wang ZH (1999) Yangtze Delta, China: Taihu lake-level variation since the 1950s, response to sea-level rise and human impact. Environ Geol 37:333–339

Conley D, Schelske CL (1993) Potential role of sponge spicules in influencing the silicon biogeochemistry of Florida Lakes. Can J Fish Aquat Sci 50:296–302

Fan CX (1996) Historical evolution of water ecological setting in Taihu Lake. J Lake Sci 8:297–304 (in Chinese)

Guo HY, Wang XR, Zhu GJ (2004) Quantification and index of non-point source pollution in Lake Taihu region with GIS. Environ Geochem Health 26:147–156

Hu H, Li R, Wei Y, Zhu C, Chen J, Shi Z (1979) Freshwater algae in China. Science Press, Beijing (in Chinese)

Lewin J (1961) The dissolution of silica from diatom wall. Geochim Cosmochim Acta 21:182–198

Li J, Liu C-Q, Wang SL, Zhou ZH, Zhu ZZ, Xiao HY (2005) Seasonal variations in compositions and distribution of dissolved nutrients in the water column of Taihu Lake, China. Earth Environ 33:63–67 (in Chinese)

Li J, Liu C-Q, Xiao HY, Liu XY, Li YY, Wang SL (2006) Summer phytoplankton diversity and water quality evaluation in northern part of Taihu Lake, China. Ecol Environ 15:453–456 (in Chinese)

Jin XC, Tu QY (1990) Survey criteria of lake eutrophication. China Environmental Science Press, Beijing (in Chinese)

Meyers PA (1997) Organic geochemical proxies of paleocenographic, paleolimnologic, and paleoclimatic processes. Org Geochem 27:213–250

Mortlock RA, Froelich PN (1989) A simple method for the rapid determination of biogenic opal in pelagic marine sediments. Deep Sea Res 36:1415–1426

Moss B, Madgwick J, Phillips GA (1997) A guide to the restoration of nutrient-enriched shallow lakes. Hawes, London

Peinerud EK (2000) Interpretation of Si concentrations in lake sediments: three case studies. Environ Geol 40:64–72

Peinerud EK, Ingri J, Pontér C (2001) Non-detrital Si concentrations as an estimate of diatom concentrations in lake sediments and suspended material. Chem Geol 177:229–239

Qin BQ, Xu PZ, Wu QL, Luo LC (2007) Environmental issues of Lake Taihu, China. Hydrobiologia 581:3–14

Qiu LQ, Williams DF, Gvorzdkov A, Karabanov E, Schimaraeva M (1993) Biogenic silica accumulation and paleoproductivity in the northern basin of Lake Baikal during the Holocene. Geology 21:25–28

Ratnayake NP, Sampei Y, Tokuoka T, Suzuki N, Ishida H (2005) Anthropogenic impacts records in the sediments of Lunawa, a small tropical estuary, Sri Lanka. Environ Geol 48:139–148

Schelske CL, Stoermer EF, Kenny WF (2006) Historic low-level phosphorus enrichment in the Great Lakes inferred from biogenic silica accumulation in sediments. Limnol Oceanogr 51:728–748

Schelske CL, Strermer EF (1971) Eutrophication, silica depletion and predicted changes in algal quality in Lake Michigan. Science 173:423–424

Vollenweider RA (1969) Möglichkeiten und Grenzen elementarer Modelle der Stoffbilanz von Seen. Arch Hydrobiol 66:1–36

Wan GJ, Santschi PH, Sturm M, Farrenkothen K, Lueck A, Werth E, Schuler C (1987) Natural (^{210}Pb, ^{7}Be) and fallout (^{137}Cs, ^{239,}

^{240}Pu, ^{90}Sr) radionuclides as geochemical tracers of sedimentation in Greifensee, Switzerland. Chem Geol 63:181–196

Wu JL, Huang CM, Zeng HA, Schleser GH, Battarbee R (2007) Sedimentary evidence for recent eutrophication in the northern basin of Lake Taihu, China: human impacts on a large shallow lake. J Paleolimnol. 10.1007/s10933-006-9058-x

Wu JL, Lin L, Gagan MK, Schleser GH, Wang SM (2006) Organic matter stable isotope (δ^{13}C, δ^{15}N) response to historical eutrophication of Lake Taihu, China. Hydrobiologia 563:19–29

Zhou ZH (2006) Paleo-environmental change of the lakes in the Middle and Lower Reaches of the Yangtze River, China: study on carbon and nitrogen records of the lake sediments. Institute of Geochemistry, Chinese Academy of Sciences, Guiyang (in Chinese)

Zou HX, Sheng GY, Sun C, Xu OY (1996) Distribution of organic contamnants in Lake Taihu. Water Res 30:2003–2008