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Issue of Cyanobacteria Blooms in Taihu Lake, China

REVIEW PAPER

ABSTRACT

Taihu Lake is an important lake located in the eastern China. As a eutrophic lake, lake-wide cyanobacteria blooms have occurred annually, damaging its natural functions and threatened the safety of drinking water resources. This paper first described the harms of cyanobacteria blooms in Taihu Lake, which are mainly manifested in effect to aquatic organisms, damage on the ecological landscape and threats to human health. The northern and western parts of lake were the most frequent area were cyanobacteria blooms occur, usually between middle June to middle October. The dominant algae during the cyanobacteria blooms were Microcystis whose abundance had correlations with water quality (i.e., pH, dissolved oxygen, permanganate index, total nitrogen and phosphorus, etc.) and bacteria quantity. Many factors impact the cyanobacteria blooms including physical, chemical and biological factors, of which high temperature (>28 °C) and nutrients loads contributed most for the cyanobacteria blooms. Further, the integrated physical (dredging sediments) and ecological methods (phytoremediation) should be utilized to control the cyanobacteria blooms in Taihu Lake.

Key words: *Cyanobacteria blooms; Taihu Lake; Microcystis; Eutrophication*

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INTRODUCTION

Cyanobacteria, also known as blue-green algae, are the simplest and most primitive algae. They are a kind of very old and tiny prokaryotes. After long-term evolution, cyanobacteria build a strong ecological competitive advantage in which is they can get the maximum growth rate at an exponential speed given appropriate environmental conditions. An earlier study have shown that cyanobacteria have ecological growth regulators for self-reinforcing to produce as many offspring as possible, resulting in the increase of toxin-producing strains (*Wang and Lu 2004*). These produced toxins are harmful and threaten human health. The main toxin-producing cyanobacteria include *Microcystis, Anabaena, Tyngbya, Aphanizomenon* and *Oscillatoria* (*Cheung et al. 2013, Gao and Meng 2009*).

In recent decades, eutrophication has been a serious problem compromising the health of freshwater systems worldwide due to excessive nutrient input, increased water abstraction and pollution (*Reichwaldt and Ghadouani 2012*). Eutrophic waters will lead to the rapid growth and reproduction of cyanobacteria, further to form cyanobacteria blooms. Since the 1990s, the main rivers (such as the Yangtze River, Yellow River, and Songhua River) and lakes (such as Taihu Lake, Poyang Lake, Chaohu Lake, Wuhan East Lake, and Dianchi Lake) were reported to experience outbreak extensive cyanobacteria blooms (*Ma et al. 2014, Wang and Lu 2004*). The cyanobacteria blooms are caused mainly by *Microcystis, Anabaena, Lyngbya, Aphanizomenon* and *Oscillatori*a (*Zhang et al. 2014*).

Taihu Lake is a large shallow lake, located in the vicinity of two large provinces. It is about 100 km west of Shanghai, the biggest city in China (*Chen et al. 2003b*). Eutrophication of Taihu Lake as a result of enhanced nutrient input from the catchment began in the 1980s (*Shi and Zai 1994*). During the last few decades, lake-wide cyanobacteria blooms have occurred annually in Taihu Lake, which have damaged lakes' natural functions and threatened the safety of drinking water resources (*Fu et al. 2015; Pan et al. 2006; Ye et al. 2011*).

The Chinese government has made a great effort to control and prevent cyanobacteria blooms in the last decade. However, to date the cyanobacteria blooms problem has not been effectively solved. This review paper analyzed the characteristics of the cyanobacteria blooms in Taihu Lake and the factors influencing the formation of cyanobacteria blooms and some suggestions to control cyanobacteria blooms.

General description of Taihu Lake

Taihu Lake is the third largest fresh water lake in China and located between 30º05'- 32º08' N and between 119º08'-121º55' E, downstream of the Yangtze River (**Figure 1**) (*Fu et al. 2013; Wang et al. 2015*). It is 68.5 km long and 56 km wide, with an average depth of 2.0 m and an area of 2,388 km^2 (*Chen et al. 2003b, Qin et al. 2007*). Taihu Lake originated from an ancient lagoon. Continental shelf extension resulted to the enclosure of the lagoon that eventually became a fresh water lake due to extreme flooding (*Qin et al. 2007; Sun 2004; Yan and Xu 1987*). The drainage basin of the lake is about 36,500 km^2, and more than 200 brooks, canals and rivers connect the lake (*Li et al. 1994*). During flooding season (spring and summer), flood runoff from the west or southwest goes through the east of the lake and empties into the East China Sea. However, during the dry season (autumn and winter), water flow can reverse (*Qin et al. 2007*). In summer, prevailing winds from the southeast or southwest generate a counter-clockwise water current in the western Taihu with the velocity being 10-30 cm s^{-1} (*Qin et al. 2000*).

In 1960, the Taihu Lake was an oligotrophic lake because of low pollution level (*Nanjing Institute of Geography 1965*). However, with the rapid economic development of the Taihu Lake basin, the pollution level has sharply increased. For example, total inorganic nitrogen increased dramatically until 1981 to about 18 times higher than that in 1960 (*Sun and Huang 1993*). Most pollutants in Taihu Lake were from the inflowing rivers, located in the west or northwest. The aquaculture in Taihu Lake has been limited to the East Taihu, a macrophyte-dominated bay in the southeast part with an area of 126 km^2. The main form of aquaculture is pen-fish-culture. Recently, fish culturing has been replaced by the more profitable freshwater crab culturing, which aggravates the deterioration of water quality and marsh development (*Qin et al. 2007*).

Harms of cyanobacteria blooms

The cyanobacteria blooms in Taihu Lake affected the health of aquatic ecosystems. Rapid growth of cyanobacteria changed the physiochemical environment of water body, particularly in reducing transparency and dissolved oxygen (DO), and in giving off stench. When the nutrients in the water were depleted, large quantities of cyanobacteria would die and many kinds of harmful gases and cyanobacteria toxins will be released, eventually resulting in the rapid collapse of aquatic ecosystems. Cyanobacteria blooms also impaired aquaculture, water supply and tourism in Taihu Lake. The harms caused by cyanobacteria blooms in Taihu Lake are mainly manifested in the following aspects (*Wu 2007*):

Figure 1. Sketch map of the Taihu Lake.

Persecuting aquatic organisms. Cyanobacteria of high density in the water surface blocked the light transmission, resulting in the reduction of photosynthetic rate and primary production of submerged plants, thereby affecting their normal growth and development. Meanwhile due to these strong ability of the cynobacteria to absorb the short-wave part of visible light, the water temperature increased, which affects the survival of biological species that are sensitive to water temperature.

Damaging the ecological landscape. Excess propagation of cyanobacteria often concentrated in the water surface and formed a layer of pellicle or foam, which made the water green and turbid. Furthermore, the dead cyanobacteria sinking to the bottom of the lake will accumulate and make the lake become shallower that accelerate marsh development and destructing the ecological landscape.

Threatening human health. Cyanobacteria blooms not only reduced the utilization efficiency of water resources, but also produced great risks to human health. Many species of cyanobacteria (e.g. *Microcystis* and *Anabaena*) can produce microcystins (MC), a class of hepatotropic cyclic polypeptide toxins, which not only directly poison fish and other aquatic animals, but also induce human liver cancer. The World Health Organization determined the tolerable daily intake (TDI) for MC as 0.04 µg/kg body weight/ day (*Gurbuz et al. 2016*). Life activities of cyanobacteria can also produce carcinogenic nitrites. In addition, large amount of cyanobacteria will increase the pH value of water body, promoting the growth and reproduction of *Vibrio cholerae* and threatening human health.

Characteristics of cyanobacteria blooms

Outbreak site and time. Based on historical data, the areas around Meilianghu, Tuoshan, and Jiaoshan had the highest incidence of cyanobacteria blooms, particularly in the eastern part of Meilianghu. The areas with the second highest incidence included Zhushanhu and the coastal zones of Yixing City and Changxing City. The eastern waters of Manshan, Xukou and Zeshan had a relatively lower incidence for outbreaks of cyanobacteria blooms. The outbreak cycles of cyanobacteria blooms varied in each year, usually appearing 2-6 large outbreaks in a year. Influenced by the meteorological and hydrological conditions, there were many cycles (i.e., outbreak-death-outbreak-death etc.) in the period of suitable conditions. Generally, the dangerous periodfor cyanobacteria outbreak blooms starts from middle June and ends in middle October (*Wang and Dou 1998*).

Unlike the cyanobacteria blooms in summer, cyanobacteria were found to concentrate in the sediments in winter, which might be an important source for the cyanobacteria blooms in the next year (*Tsujimura et al. 2000*). *Ji et al.* (*2009*) investigated the spatial variations of the over-winter cyanobacteria in different areas of the Taihu Lake by measuring the phycocyanobilin concentrations in sediment and water samples. According to the result, it is clear that the over-winter cyanobacteria were mainly distributed in western and southern areas of Taihu Lake during the winter (**Figure 2**), which may be related with the subtropical monsoon.

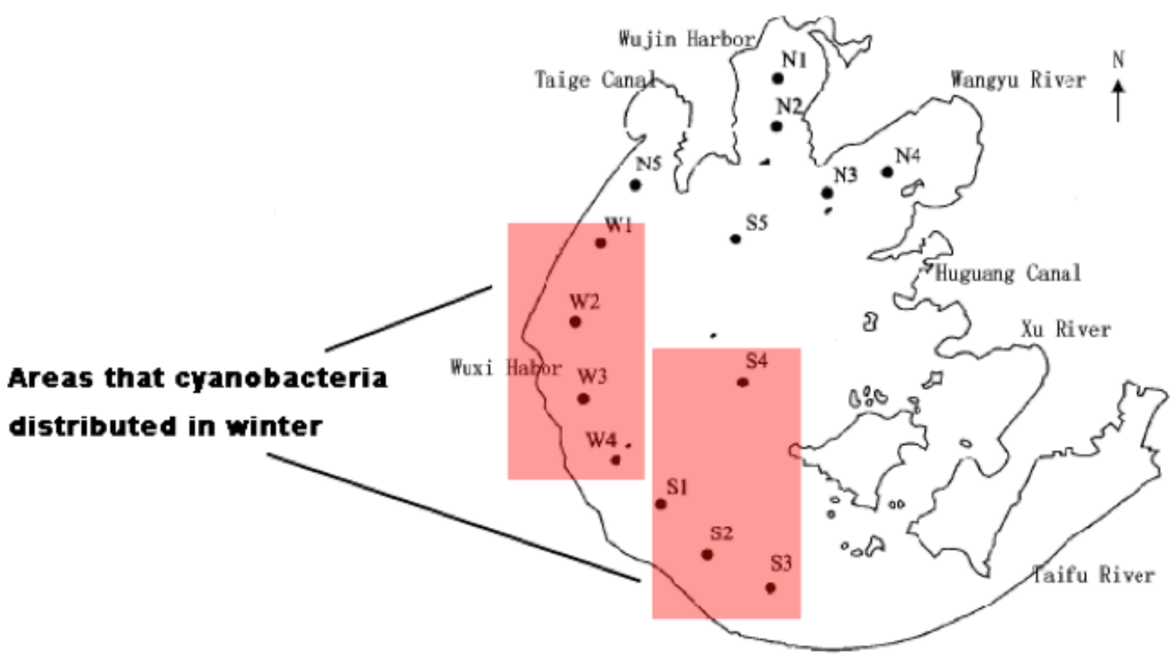

Figure 2. Cyanobacteria distributed areas in winter in the Taihu Lake (*Ji et al. 2009*).

Cyanobacteria biomass and physiochemical index. The outbreak of cyanobacteria blooms pose great impact to the aquatic environment and would worsen water pollution. It was found that during the three large-scale outbreaks of cyanobacteria blooms in the Shazhu water resource in 2007. pH and DO also rose to the highest levels, whenever cyanobacteria biomass reached the highest value (*Zhang and Li 2005*). After half or one day, other indices such as permanganate index (Im), total nitrogen (TN), total phosphorus (TP), etc. reached their maximum values. After 1-5 days, these indexes, especially DO, would decline.

Zhu (*2009*) analyzed the spatial-temporal pattern of water physiochemical indices, including Sechi Depth (SD), Im, TN, TP and chlorophyll *a* (*Chl-a*) concentration to clarify the pollution sources and their influences on cyanobacteria blooms in Taihu Lake during 2005 to 2007. After three years of monitoring, significant correlations between Chl-a concentration and other water quality indicators were observed (**Table 1**). *Chl-a* concentration was an indicator of phytoplankton biomass, which could be used as the indicator of cyanobacteria biomass in Taihu Lake in summer. The TN, TP and Im were eutrophication indicators and could indicate the eutrophication level of water body. The significant positive correlations between *Chl-a* and eutrophication indicators suggested that the severity of cyanobacteria blooms was closely related to the eutrophication level.

Cheng and Ling (*2010*) collected the water samples and analyzed chemical and biological indices quarterly in Taihu Lake from November 2007 to August 2008. They also found there were significant positive correlations between Chl-a and TN, TP and chemical oxygen demand (COD). *Cheng and Ling* (*2010*) further indicated that TP shared the largest pollution load index (34.34%-54.34%) with the average pollution index of 48.36%, and phosphorus element was most related with the cyanobacteria blooms.

Chen et al. (*2001*) tried to construct stepwise multiple regression models to predict the cyanobacteria blooms in the Meiliang Bay, Taihu Lake using related environmental factors. The total algae biomass can be calculated by the following equation:

$$\mathrm{Ln}(TB+1)=1.16\times \mathrm{Ln}(WT+1)+5.4\times \mathrm{Ln}(TP+1)-2.33 \quad (1)$$

where TB, WT and TP are total algae biomass, water temperature and total phosphorus, respectively. Specially, the biomass of Microcystis algae can be evaluated as follows:

$$\mathrm{Ln}(MB+1) = 0.95\times \mathrm{Ln}(WT+1) - 1.52\times \mathrm{Ln}(NO_3+1) + 0.89\times \mathrm{Ln}(TN+1) - 2.26 \quad (2)$$

where MB, WT, NO_3, and TP are Microcystis algae biomass, water temperature, nitrate nitrogen, and total nitrogen, respectively.

Composition of algae species. According to the monitoring results in June 2007 (*Chen et al. 2003a*), cyanobacteria remained dominant in Taihu Lake, accounting for 55.6-99.8% of total algae, followed by diatoms and green algae. However, the algae composition varied in different sampling points. In the Meiliang Lake, Tuoshan and Wuli Lake, cyanobacteria were the absolute dominant species (higher than 94%). While at the monitoring points of Shazhu and Xiaowanli, the composition of algae species changed greatly compared with 2006, and the proportion of diatoms and other algae significantly increased. For example, the algae species compositions at Shazhu were as follows: 55.6% cyanobacteria, 27.8% diatoms, 5.6% green algae, 5.6% cryptozoon, 2.8% euglenophyceae and 2.8% dinophyceae. The factors influencing for the changes of algae compositions needs further study.

Yao and Yang (*2009*) investigated the species composition, diversity and abundance distribution of phytoplankton in inlets of the South Taihu in winter (*December 2008 to February 2009*). A total of 70 phytoplankton species from seven phyla were identified, including 12 species in Cyanophyta, 24 species in Bacillarophyta, three species in Pyrrophyta, two species in Cryptophyta, six species in Euglenophyta, 21 species in Bacillariophyta, and two species in Chrysophyta. The richest algae were from Cryptophyta, Cyanophyta and Bacillarophyta.

To explore seasonal variation of *Microcystis* community in Taihu Lake, water samples were collected at four representative sampling sites (River Mouth, Meiliang Bay, lake-bay intersection, and center of Taihu Lake) in four seasons by *Kong and Zeng* (*2009*). Two methods, microscopic evaluation and Polymerase Chain Reaction-Denaturing Gradient Gel Electrophoresis (PCR-DGGE), were adopted to analyze these samples. The former method found that Microcystis biomass was dominant during the spring, summer and autumn, especially in summer (**Figure 3A**).

Table 1. Correlation analysis among Chl-a, SD, Im, TN and TP during summer (June-August) (*Zhu 2009*).

	Chl-a	SD	Im	TN	TP
Chla	1.00				
SD	-0.17*	1.00			
Im	0.92**	-0.12	1.00		
TN	0.76**	-0.14	0.76**	1.00	
TP	0.80**	-0.30**	0.80**	0.81**	1. 00

* *P* value < 0.05, ** *P* value < 0.01

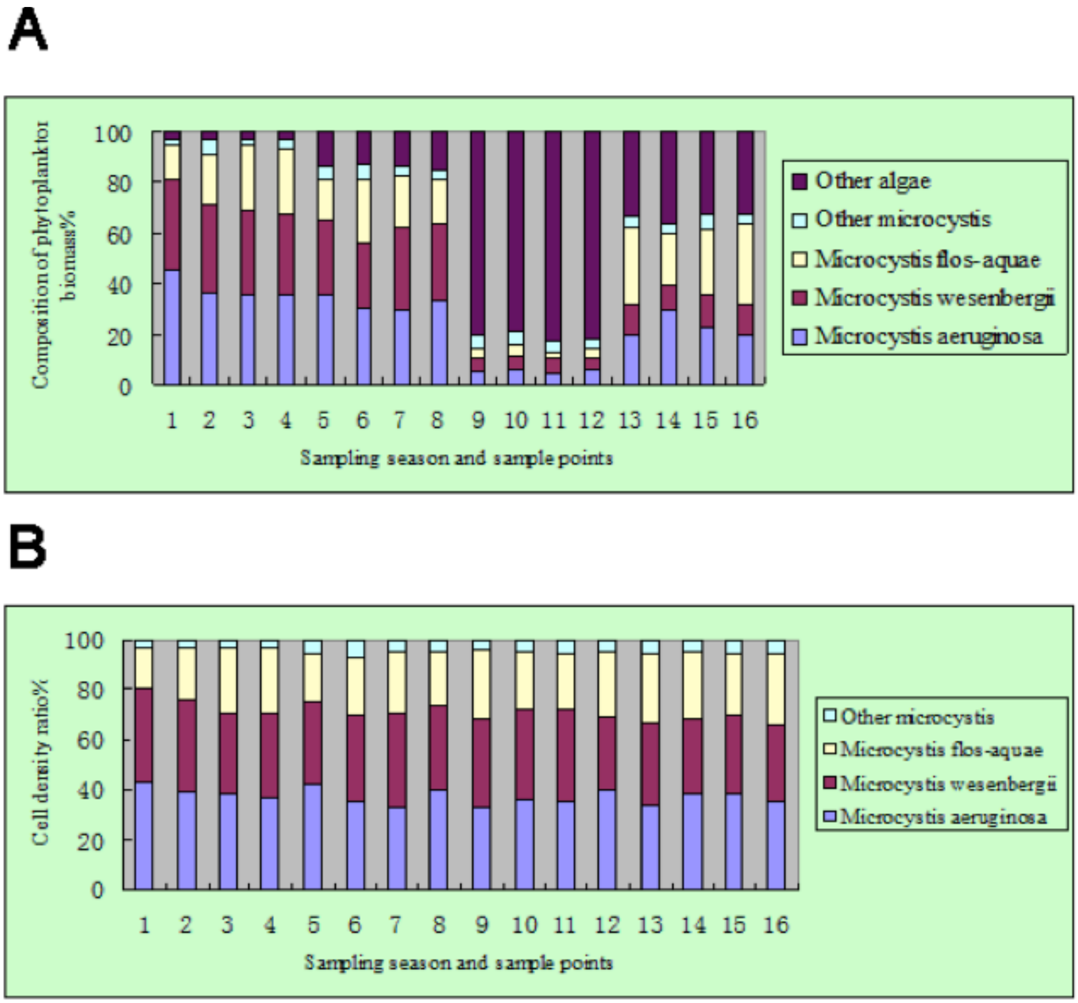

Figure 3. Composition of phytoplankton biomass (A) and cell density ratio of Micmcystis community at different sites during four seasons (B). 1-4 were summer samples, 5-8 autumn samples, 9-12 winter samples, 13-16 spring samples. Four samples of each season from the left to right are from the River Mouth, heart of Bay, intersection and center of lake (*Kong and Zeng 2009*).

Besides Microcystis algae, nearly no other algae were found among the samples collected during spring, summer and autumn. Among the samples collected in winter, there were very few *Microcystis* algae exist mainly in the form of single cells, while diatoms and green algae dominated at this time. Microscopic evaluation did not find any significant seasonal variation of the dominant species (*Microcystis aeruginosa*, *Microcystis wesenbergii* and *Microcystis flos-aquae*) in the Microeystis community ($P > 0.05$) (**Figure 3B**). However, PCR-DGGE discovered that two feature groups of *Microcystis* communities in the samples collected in summer and winter separated from each other, but those in the samples collected in spring and autumn were intermingled. Moreover, further analysis showed that genetic distance of *Microcystis* in the same season was shorter than those in different seasons (**Table 2**). Therefore, the cyanobacteria blooms of the Taihu Lake in summer mainly consisted of *Microcystis* groups.

Cyanobacteria blooms and bacterial community. *Xi and Wu* (*2007*) determined the change of bacterial diversity in the surface water of the Meiliang Bay, Taihu Lake in March and September of 2004 by 16S rRNA gene sequencing. Community compositions, especially the most dominant bacteria, were different before cyanobacteria blooms and in degraded period. Clones in the March clone library were mostly affiliated with Bacteroidetes (42.7%), β-Proteobacteria (18.4%), α-Proteobacteria (16.5%) and Actinobacteria (16.5%), while clones in the September clone library were mainly affiliated with Cyanobacteria

Table 2. Genetic distances of Microcystis within the same season and between different seasons (*Kong and Zeng 2009*).

Season	Summer	Autumn	Winter	Spring
Summer	0. 002			
Autumn	0. 033	0. 020		
Winter	0. 031	0. 028	0. 017	
Spring	0. 035	0. 024	0. 031	0. 022

(28.8%), β-Proteobacteria (18.4%), α-Proteobacteria (16.5%) and Actinobacteria (16.5%), while clones in the September clone library were mainly affiliated with Cyanobacteria (28.8%), β-Proteobacteria (25.0%), Actinobacteria (17.3%) and α-Proteobacteria (15.4%). A greater diversity in sequence composition was found in September (11 clusters) than that in March (7 clusters). Compared with related study (*Dai et al. 2005*), α-Proteobacteria, β-Proteobacteria and Actinobacteria were widely found in Taihu Lake, while γ-Proteobacteria and Firmicutes were more frequently detected in sediments and Bacteroidetes were abundant in water. Most 16S rRNA gene sequences which retrieved from the two libraries were closely related to freshwater bacteria in different aquatic ecosystems including oligotrophic, mesotrophic and eutrophic lakes (*Eiler and Bertilsson 2004*). A large number of clones were originated from the Yangtze River. The sequences represented in marine habitats were rarely found except the members of Bacteroidetes (*Warnecke et al. 2004*).

Zhu et al. (*2009*) investigated the abundances of bacteria and active bacteria of water and the attached algae, as well as the *Chl-a* and nutrient concentrations. The results indicated the bacterial abundances of water and algae attached increased as the *Chl-a* concentrations increased, although the peak values were delayed with the *Chl-a* concentration; there were significant positive relationships between the active bacterial abundances and total bacterial abundances; and the ratio of active algae attached bacteria/total algae attached bacteria was higher than that of total bacteria, and this ratio increased in the period of May to September during the cyanobacteria blooms.

Impact factors of cyanobacteria blooms

Generally, the following two conditions are needed for outbreak of cyanobacteria blooms (*Qiu 2009*): severe eutrophication of water body which means increase of the main nutrient nitrogen and phosphorus in waters leading to the overproduction of plankton; and high temperature of above 28ºC. Cyanobacteria prefer muggy, continuous rain, hot and weak wind. In such conditions, cyanobacteria will thrive and become dominant in algae community, completely inhibiting the growth of other algae.

The mechanism of cyanobacteria blooms outbreak is not very clear. Generally speaking, it may be related with environmental factors and physiological and ecological characteristics of cyanobacteria. The environmental factors include water area and volume, water residence time, degree of vertical mixing of water, light attenuation characteristics and sediment re-suspension. Physiological and ecological factors of cyanobacteria include pseudo-vacuoles, inorganic carbon concentrating mechanism, nitrogen fixation, and phycobilisomes resisting ultraviolet light damage and low-light stress, etc.

Physical factors

Temperature. *Huang et al.* (*2009*) took *Microcystis aeruginosa* as the study object, and simulated the formation and dying-off of the cyanobacteria bloom under different water temperatures with physical models. Water temperature of 28 ± 1ºC would accelerate the formation of cyanobacteria blooms with proper nutrient contents and other conditions, when the growth rate of algae would reach the highest value (**Table 3**).

The annual field observation in Taihu Lake and laboratory simulation experiments (*Wu et al. 2008, Yan et al. 2004*) showed that as the temperature decreased in the autumn, the concentrations of phycocyanin denoting cyanobacteria biomass in water gradually decreased. However, phycocyanin concentrations in surface sediments increased and reached the maximum values in the next April. In hot summer season, the concentrations of phycocyanin were low in sediments suggesting that temperature have a great impact on the distribution of cyanobacteria.

Xu (*2008*) found that cyanobacteria had a strong tolerance to low temperature of 4ºC, but adding certain intensity of light would greatly accelerated their death. Therefore, suitable lighting condition for the recovery of cyanobacteria was not suitable for their passing winter (*Xu 2008*). The condition for cyanobacteria passing winter and recovery seems to be contradicted. But in the recently published papers, pretreatment of cyanobacteria at 15ºC can induce the character of cold-light combined stress tolerance, which was called acquired chill-light tolerance (ACLT) and existed in *Synechocystis* and *Microcystis*. Under natural conditions, cyanobacteria may be induced by ACLT due to low temperature in late autumn and early winter and the winter in shallow waters of lakes (*Zhu and Xu 2013*).

Table 3. Growth rate of algae in different water temperature (*Huang et al. 2009*).

Group	Water temperature (°C)	Growth rate of algae
1	10 ± 1	0.15
2	14 ± 1	0.47
3	23 ± 1	0.90
4	28 ± 1	1.05
5	32 ± 1	1.02

Cyanobacteria recovery is closely related with temperature. When water temperature reached 14ºC, small amounts of cyanobacteria started to move into the water column; when ambient temperature rose to 18-20ºC, cyanobacteria would transfer into the water, providing the provenance for blooms. Studies have shown that the optimal recovery temperature for cyanobacteria in sediments is 18-21°C, which is higher than the optimal recovery temperature of other algae (*Tao et al. 2005*).

Light. Except for *Ch1-a*, *Microcystis* also contains phycocyanin and allophycocyanin, which make Microcystis be able to make use of green, yellow and orange bands of light that other algae can not use. Therefore, *Microcystis* can grow well in low light. Under strong light condition, the intracellular carotenoids content in *Microcystis* will increase, resulting in the enhancement of cell tolerance to strong light. By using small glass-containers to exclude the effect of fish, wave, sediment and other factors, *Wang et al.* (*2008*) focused on nutrient salts, temperature and light factors, and successfully simulated the occurrence of cyanobacteria blooms in surface water. It was found out that introducing natural water of high temperature season containing a small amount of *Anabaena* and high concentration of *Chl-a* into the transparent glass containers could form surface *Anabaena* blooms. The high temperature, strong light conditions and adding nutrient salts in glass containers made *Anabaena* get the advantage during competition.

Hydrological and meteorological factors. Wind, wave and climate have impacts on the growth of *Microcystis*. Wind and wave affect the horizontal and vertical distribution of *Microcystis*. In shallow lakes, wind and wave can make the bottom nutrient salts release. However, when the wind speed is above 3.1 m s^{-1}, the surface Microcystis blooms will be significantly inhibited. Based on field observations in the Taihu Lake, the basic vertical distribution pattern of cyanobacteria under different hydrological and meteorological conditions was identified. The variation coefficient of the algal abundance in each water layers decreased as the wind and wave increased.

Bai et al. (*2005*) carried out quantitative studies on the effect of the wind on the horizontal drift velocity of cyanobacteria blooms that had floated to the water surface through field observations and indoor air-box flume experiments. The index of wind speed and horizontal drift velocity of blooms, together with some related equations were established. The total amount of blooms drifting into specific parts of lakes under different wind strength was also established. The results showed that in Taihu Lake, when the wind speed was 0 m s^{-1}, the algae still drifted, which was caused by the free diffusion of blooms from high concentration to low concentration. When the average wind speeds were 1.4, 1.9, and 2.8 m s^{-1}, respectively, the corresponding average horizontal drift velocity of algae in water were 0.022, 0.029 and 0.114 m s^{-1}, respectively. However, when the wind speed continued increasing, blooming cyanobacteria community mixed fully with water and the horizontal drift velocity would decrease.

To elucidate the effects of climatic variables on the expansion of cyanobacteria blooms in Taihu Lake, *Zhang et al.* (*2012*) analyzed the relationships between climatic variables and bloom events which were retrieved by satellite images. They found cyanobacteria blooms occurred earlier and last longer with the increase of temperature, sunshine hours, and global radiation and the decrease of wind speed. Among these factors, sunshine hours and wind speed are the primary contributors to the onset of the blooms, explaining 84.6% of their variability over the past 23 years.

Chemical factors

Nutrients. Stumn proposed the empirical formula C:N:P = 106:16:1 on the basis of chemical analysis of algae and pointed out that phosphorus was the major limiting factor for algae growth according to the minimum law of Greece. International standards for the eutrophic lake is that TN > 0.2 mg L^{-1} and TP > 0.02 mg L^{-1}. In the Meiliang Bay of Taihu Lake average dissolved phosphorus in the water has reached 0.03-0.07 mg L^{-1}, which is no longer a limiting factor for algae growth. Except for nitrogen and phosphorus, other micronutrients (iron, molybdenum, etc.) and rare earth elements (copper, yttrium, etc.) also have some impacts on the growth of blooming algae.

Microcystis have a very high maximum uptake rate of phosphorus and they are able to store excess phosphorus in the body in the form of polyphosphate which make them resist longer when the phosphorus concentration is limited. Although *Microcystis* do not have nitrogen-fixing function like some types of Chroococcaceae, Oscillatoria, Nostoc, Siphonales, in the freshwater ecosystem nitrogen is usually not a limiting factor. Therefore, there are few reports about the impact of nitrogen on Microcystis blooms.

The latest research shows that the recovery of cyanobacteria was not primarily occurred in the sediments, but in the water column (*Cao et al. 2005*). Recently, *Xu et al.* (*2009*) studied the effect of nutrients on phytoplankton biomass by adding N, P or both to the water from the Meiliang Bay of Taihu Lake. The results showed that in spring P is the limiting factor, and N is sufficient due to plenty use of fertilizers; in summer and autumn N is the main limiting factor (**Figure 4**). Further experiments showed that the upper limit of N for biomass growth was 1.5 mg L^{-1} when P was sufficient, and the upper limit of P was 0. 2 mg L^{-1} when N was sufficient.

When the light is enough, organic compounds can not stimulate the growth of *Microcystis*. However in low light or dark conditions, organic compounds (including carbohydrates, organic acids, amino acids, etc.) can significantly accelerate the growth of *Microcystis*. Isotope labeling experiments also prove that a number of cyanobacteria in low light conditions can assimilate carbohydrates, making the content of marked organic matter accounts for 45% of the total amount of organic matter in cells. The heterotrophic growth way of *Microcystis* through fermentation and decomposition of organic matter provides a competitive advantage for growing in sediments in winter or at adverse conditions of low light intensity.

Wang and Zhu (*2009*) combined the methods of conventional filtration and tangential flow ultrafiltration (CFF) to get concentrated liquid of gel (1 nm to 1 μm). They then utilized the sterilized gel liquid to prepare culture medium for *Microcystis aeruginosa*. The result showed that the addition of natural concentrated liquid of gel can significantly promote the growth of *M. aeruginosa*. The main mechanism was that the colloidal organic phosphorus promoted the uptake of inorganic phosphorus. In addition adsorbed nutrient salts and trace elements by gel was another positive factor for *M. aeruginosa* growth.

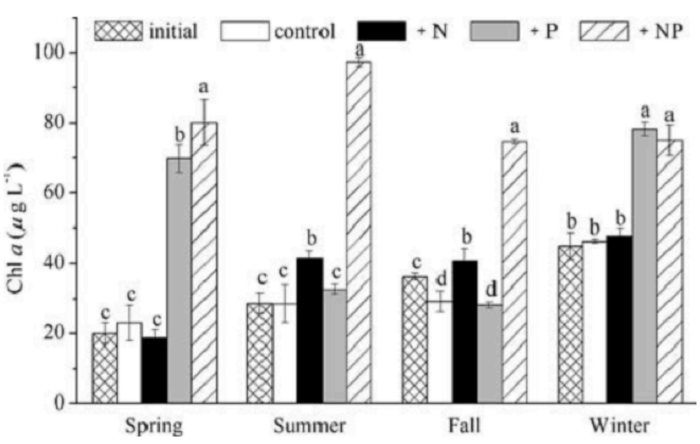

Figure 4. Initial and maximum phytoplankton biomass (Chl-a) responses in bioassays conducted in May, July, October, and December 2008 (*Xu et al. 2009*). Water samples for bioassays were collected from the surface at the Meiliang Bay of Taihu Lake. Response is 3-day Chl-a average in spring, summer, and fall and 6-day Chl-a average in winter. Error bars represent ± 1 SD of triplicate samples. Differences between treatments are shown on the basis of ANOVA post hoc tests (a > b > c; $P < 0.05$)..

pH. In the study of *Huang and Ji* (*2008*), cyanobacteria bloom was closely related to the pH of water. When the nutrients and other conditions were appropriate, pH of about 8 might promote bloom. When the pH value was not conducive to the growth of algae, algae could adjust it to alkaline range to suit growth through a series of physiological and biochemical reactions.

Allelochemicals. Allelopathy is a biological phenomenon that plants or micro-organisms release chemicals into the environments to affect the growth of other organisms and the releasing chemicals are called allelochemicals (*Zhang et al. 2014*). Many species of *Microcystis* are able to release toxins, growth inhibitors and other chemical substances to affect the growth other algae or zooplankton. Study showed that *Microcystis* would produce more toxins under the pressure of competition or predation. On the other hand, some aquatic plants, such as *Hydrilla verticillata* and *Eichhornia crassipes* can secrete anti-algae substances to inhibit the growth of algae. Therefore, these aquatic plants play an important role in improving the lake environment, reducing the eutrophication and controlling the formation of cyanobacteria blooms.

Biological factors

Gas vesicles. The bubble structure in *Microcystis* cells was first discovered by a German microbiologist Kbealln in 1895. In 1965, Bowen and Jensen found that bubble structure was mainly made up of cylindrical form of bladders. These bubble substances were called gas vesicles. The vesicle wall allows gas freely access, but water can not pass the wall because of the presence of hydrophobic amino acid chains inside the wall. Because of the small size of gas vesicles, *Microcystis* cells usually require a lot of vesicles to provide necessary buoyancy, which play important role in the floatation of *Microcystis* to form blooms. The study of *Chu et al.* (*2007*) showed that in the nitrogen restricted environment, the number of gas vesicles and buoyancy of *Microcystis* cells would significantly decreased. However, in eutrophic lakes *Microcystis* would produce more gas vesicles to regulate the buoyancy, which made *Microcystis* more competitive to grab light and inorganic carbon in the surface water. This also may be one of the mechanisms that cyanobacteria dominant in the water blooms.

Sheath. Certain types of *Microcystis* can form gel sheath by secreting polysaccharides or other viscous material, making the viscosity between cells and water increase, which affects floatation and vertical movement of cells. Usually, many cells assemble to form group through sheath, which provides a natural barrier against the outside adverse environment (*Reynolds 1984*).

Predation of zooplankton. The predation of zooplankton can induce the formation of cyanobacteria group (*Yang and Kong 2005*), which is beneficial for the formation of cyanobacteria blooms. The formation of groups in the algae can significantly reduce predating rate of zooplankton. Therefore, the phenomenon of group formation in algae induced by predation of zooplankton can be interpreted as an effective defense strategy against predation pressure, which is also the result of their co-evolution. During the inducing process, some signal molecules released by zooplankton might play an important role. Studies have shown that under laboratory conditions, zooplankton filtrate can promote the formation of *Microcystis* group.

Control of cyanobacteria blooms

There are various ways in the treatment of cyanobacteria blooms. Some main methods are listed as follows:

Biological prevention method- Cyanobacteria are the food of some freshwater fish. Therefore, putting these fish in the lakes can prevent cyanobacteria blooms.
Artificial floating rafts method- This technology uses plants to adsorb nutrients and inhibit algae growth, establishing the ecological balance.
Mechanical salvaging method- This is the most primitive and traditional method, and cyanobacteria will be salvaged out with water. Its advantage is the removal is fast and completed. However, it is still difficult to treat large areas of cyanobacteria.
Microorganisms removal method- Some bacteria in activated sludge have potent anti-algae capability. Utilizing these microorganisms can effectively remove cyanobacteria.
High-magnetic removal method- It was found that the water process with high strength magnetic field of 3700 GS could effectively eliminate the algae and improve the water quality. However, the defect of this approach was the high cost that limited its large-scale applied.
Project dredging method- This method is to introduce flowing water, such as the Yangtze River, into the Taihu Lake. Large amounts of water will wash cyanobacteria and smelly water to the sea.

Approximately 65% lakes in China have been eutrophic, and 29% lakes are turning eutrophic. The Taihu Lake is the source of drinking water for urban residents, and using a large-scale of chemical methods to control cyanobactiera blooms is not proper (*Yu and Liu 2009*). Therefore, after the outbreak of cyanobacteria blooms in the Taihu Lake, the experts tended to use physical methods and ecological restoration to deal with the crisis of water source pollution including sediment dredging and *Eichhornia crassipes* bioremediation. Sediment dredging is a kind of ecological dredging, whose main purpose is to remove the surface sludge containing organic pollutants and nutrients. *E. crassipes* bioremediation is using *E. crassipes* to absorb nitrogen, phosphorus, heavy metals and organic pollutants, and to inhibit the growth of algae, improving the water quality. Considering the complexity of water environments in Taihu Lake, integrated physical and ecological methods should be applied in the control of cyanobactteria blooms.

However, most of important measurement is the management of pollution sources, which is the essential reason for cyanobacteria. Therefore, the Chinese people should find the balance point for sustainable development.

CONCLUSIONS

Taihu Lake is the third largest fresh water lake in China, and it plays an important role in water resources, agricultural irrigation, aquaculture, and waterlogging prevention for local area. However, the water pollution and eutrophication have severely damaged the aquatic ecosystem. The frequent outbreak of cyanobacteria blooms have brought misery for the residents around the lake basin. The excess cyanobacteria biomass persecuted the aquatic organism by blocking the light transmission. Furthermore, the dead cyanobacteria will sink to the bottom of the lake, and accelerate marsh development. Moreover, the harmful cyanobacteria can produce toxins such as microcystins, which threatens human health. Generally, the outbreak cyanobacteria blooms starts from mid-June and ends in mid-October. The eastern part of Meilianghu is the area with the highest incidence of cyanobacteria blooms. *Microcystis* algae are the dominant species. The cyanobacteria biomass showed remarkably relations with various physiochemical indices including pH, DO, Im, TN, TP, *Chl-a*, etc. The outbreak of cyanobacteria blooms also increased the biodiversity of bacterial community in water. Many factors contributed to the outbreak of cyanobacteria blooms, of which high nutrients load and temperature (>28ºC) were the most critical ones. For the control of cyanobacteria blooms, sediment dredging and *E. crassipes* bioremediation are promising methods and applicable for Taihu Lake. However, to radically control the cyanobacteria blooms, more efforts are continuously needed for a long time.

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