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Effects of sludge dredging on the prevention and control of algae-caused black bloom in Taihu Lake, China

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Abstract

Algae-caused black bloom (also known as black water agglomerate) has recently become a critical problem in some Chinese lakes. It has been suggested that the occurrence of algae-caused black bloom was caused by the cooperation of nutrient-rich sediment with dead algae, and sludge dredging was adopted to control black bloom in some lakes of China. In this article, based on the simulation of black bloom using a Y-shape apparatus for modeling natural conditions, both un-dredged and dredged sites in three areas of Taihu Lake, China were studied to estimate the effects of dredging on the prevention and control of black bloom. During the experiment, drained algae were added to all six sites as an additional organic load; subsequently, the dissolved oxygen decreased rapidly, dropping to 0 mg/L at the sediment-water interface. Black bloom did not occur in the dredged sites of Moon Bay and Nan Quan, whereas all three un-dredged sites at Fudu Port, Moon Bay and Nan Quan experienced black bloom. Black bloom also occurred at the dredged site of Fudu Port one day later than at the other sites, and the odor and color were lighter than at the other locations. The color and odor of the black water mainly result from the presence of sulfides such as metal sulfides and hydrogen sulfide, among other chemicals, under reductive conditions. The color and odor of the water, together with the high concentrations of nutrients, were mainly caused by the decomposition of the algae and the presence of nutrient-rich sediment. Overall, the removal of the nutrient-rich sediment by dredging can prevent the occurrence and control the degree of algae-caused black bloom in Taihu Lake.

Key words: Taihu Lake; algae-caused black bloom; sediment; sludge dredging

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Introduction

Black bloom, also known as black water agglomerate, black water or black spots, has become a critical water pollution issue in some lakes in China. In many lakes, black blooms are caused by algae. The algae decompose rapidly after aggregating in great numbers, which leads to water pollution associated with an offensive odor and black color. The black color and offensive odor are the most obvious characteristics of black bloom (Yang et al., 2008). However, black bloom is also accompanied by increased chemical oxygen demand, and elevated concentrations of ammonia and sulfide (Lu and Ma, 2009).

Taihu Lake is the third largest freshwater lake in China. It is situated in Changjiang (Yangtze) Delta, which is the most developed region in China (Qin et al., 2007). Black blooms have periodically occurred in Taihu Lake since the 1990s; however, their frequency has increased in recent years (Lu and Ma, 2009). The occurrence of black bloom poses a considerable threat to the ability of Taihu Lake to supply drinking water to the surrounding cities. A critical drinking water crisis occurred in Wuxi City on May 29, 2007, because of an offensive odor in the tap water. The Gonghu water works stopped producing, and the crisis seriously impacted the drinking water supply for 2 million people. Gonghu water works, situated in Gonghu Bay, provides 80% of Wuxi's drinking supply. The water crisis was mainly caused by the emergence of a distinct black bloom in the water that entered the Gonghu water works. This black bloom exhibited the typical characteristics of foul smell and black color. The Wuxi water crisis drew considerable domestic and foreign attention to the contamination of Taihu Lake, especially regarding the issue of algae-caused black bloom (Qin et al., 2010; Yang et al., 2008).

Several studies have investigated black water issues in lakes and on the coast. Stahl (1979) investigated a black

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water lake in Illinois and demonstrated that the blackness of the water was formed by ferrous sulfide. Duval and Ludlam (2001) found that the strong odor from Lower Mystic Lake was caused by hydrogen sulfide and that the black color of the water was due to the presence of suspended metal sulfide. A number of studies on the German Wadden Sea indicated that the odor and color of black spots were caused by hydrogen sulfide and metal sulfides and that elevated concentrations of organic matter promoted the reduction of sulfate (Böttcher et al., 1998; Freitag et al., 2003; Neira and Rackemann, 1996; Rusch et al., 1998). These previous studies focused on the features of black bloom rather than on remediation. Kong et al. (2007) noted that the black bloom in Taihu Lake in 2007 developed after cyanophyta had accumulated on the sediment and had begun to undergo anaerobic decomposition. Yang et al. (2008) emphasized that the high ammonia concentration at the site of the black bloom in Taihu Lake was beyond the range of a normal cyanophyta bloom. Sheng (2010) demonstrated that the black bloom did not occur in a simulated experiment when sediment was not included in the model. Lu and Ma (2010) investigated the entire Taihu Lake and concluded that the black bloom occurred mostly in areas with high levels of polluted sludge and accumulated algae.

The studies on black bloom in Taihu Lake showed a strong relationship between algae and nutrient-rich sediment, which led to the formation of black bloom. Sediment plays an important role in the overall nutrient dynamics of shallow lakes. Internal loading may prevent improvements in lake water quality after the elimination of external loading (Reddy et al., 2007; Søndergaard et al., 2003). Dredging can remove the nutrient-rich surface layer of sediment, and it has been widely applied to control the internal loading of shallow lakes (Gustavson et al., 2008). Because of the important role that sediment plays in the formation of black bloom in Taihu Lake, dredging was adopted to remove the nutrient-rich surface sediment (Kong et al., 2007; Lu and Ma, 2010). Dredging has been performed in some areas of Taihu Lake, which has been vulnerable to black bloom since 2007 (Lu and Ma, 2010). However, the role of dredging in improving the water quality remains controversial (Fan et al., 2004), and it is unclear whether dredging can prevent the occurrence of black bloom in Taihu Lake.

Field research on black bloom is challenging because the locations of black bloom are difficult to predict. Therefore, simulated experiments in the laboratory are particularly important for understanding the formation of black bloom (Shen et al., 2011; Liu et al., 2010b, 2010c; Lu and Ma, 2010; Lu et al., 2012). In this article, the formation of black bloom was simulated in the laboratory to evaluate the ability of dredging to prevent and control black bloom in Taihu Lake. A Y-shape apparatus was used for wind simulation. In the simulated experiment, sediment cores were collected from the dredged and undredged sites of three areas that experienced frequent algae-caused black bloom in Taihu Lake in recent years.

1 Materials and methods

1.1 Study site

Taihu Lake (30°55′40′′–31°32′58′′N, 119°52′32′′–120°36′10′′E) is a typical shallow lake in China. This lake is important for drinking and fishing, with a mean water depth of 1.9 m and a water surface area of 2338 km^2. Fudu Port, Moon Bay and Nan Quan are located along the northern portion of Taihu Lake. These areas have nutrient-rich surface sediment because most of the sewage from surrounding cities is discharged into northern Taihu Lake (Qin et al., 2007). During the summer, algal blooms mainly occur in the northern part of the lake because of the direction of the prevailing wind. These algae aggregate on the surface sediment (Lu and Ma, 2010). Moon Bay and Fudu Port have experienced several occurrences of serious black bloom in recent years (Lu and Ma, 2010). Nan Quan is located in Gonghu Bay, near the water intake of Gonghu water works facility, which suffered the 2007 Wuxi water crisis (Yang et al., 2008).

To prevent and control the occurrence of black bloom, Moon Bay and Nan Quan were dredged in 2007, and Fudu Port was dredged in 2008 (Lu and Ma, 2009; Liu et al., 2010d). In this article, we chose these three typical areas to study the effect of dredging on the prevention and control of black bloom (**Fig. 1**).

1.2 Sample collection

Two intact sediment cores were collected from each study area for the experiment. One was collected from the dredged areas, and another was collected from a nearby un-

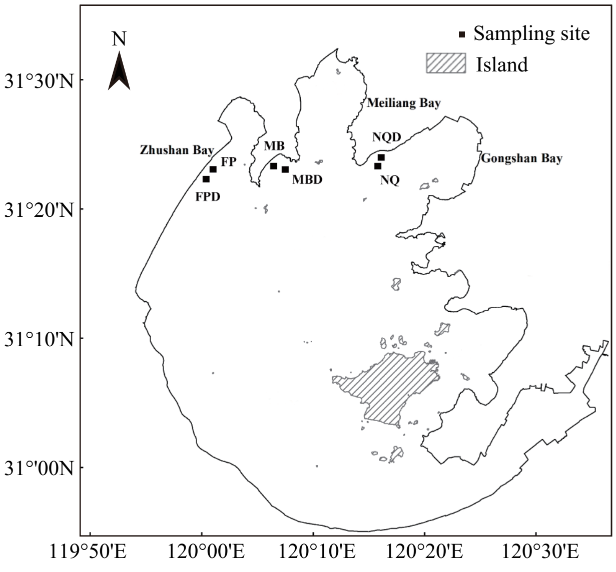

Fig. 1 Map of the sampling sites.

dredged area. Six cores were used for the experiment: Fudu Port dredged (FPD), Fudu Port un-dredged (FP), Moon Bay dredged (MBD), Moon Bay un-dredged (MB), Nan Quan dredged (NQD) and Nan Quan un-dredged (NQ).

All of the sediment cores, along with the overlaying water, were collected with a lager-caliber core sampler (Φ 110 mm, length 500 mm, Rigo Co., Japan) on January 19 and 20, 2010. The sediment cores contained 30–40 cm of sediment in a Plexiglas tube, and they were covered by overlaying water to maintain the sediment structure during sampling and transportation. The algae were collected in Moon Bay with a phytoplankton net (Φ 0.077 mm) to add to the sediment core. Lake water, which was employed as overlaying water in the experiment, was collected at each sampling site and was filtered using a phytoplankton net to remove algae (Shen et al., 2011; Liu et al., 2010a, 2010b).

1.3 Experimental design

A Y-shape apparatus was used for simulating the sediment resuspension process to reflect the natural conditions of Taihu Lake (**Fig. 2**). This Y-shape apparatus was mainly composed of six Plexiglas tubes with lengths of 2.5 m, and it contains a 1.8 m water column under experimental conditions. Two screw propellers were controlled by different motors with a frequency modulator to simulate the different sediment suspension processes under different wind conditions (Liu et al., 2010a; You et al., 2007).

The top 20 cm from the sediment cores of all six sites were carefully transplanted into the lower Plexiglas tube, and filtered water collected from each site was carefully injected over the sediment, which minimized sediment suspension; the depth of overlaying water was 1.6 m. The six Plexiglas tubes of the Y-shape apparatus contained sediment cores and overlaying water from FPD, FP, MBD, MB, NQD and NQ.

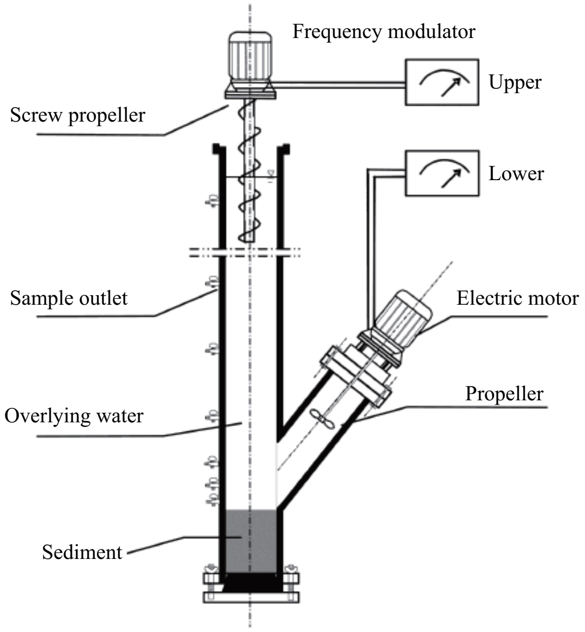

Fig. 2 Diagram of the Y-shape apparatus for "wind-simulation".

According to correlational studies (Shen et al., 2011; Liu et al., 2010b, 2010c), drained algae (at least 5000 g/m^2) could be added to the water to provide additional organic matter. Together with nutrient-rich surface sediment, an algae-caused black bloom could be simulated using the Y-shape apparatus. Therefore, 47.5 g of drained algae were added to each overlaying water column of each Plexiglas tube to simulate black bloom. In the simulated experiment, the frequency of the side and upper motors were set at 5.8 Hz from 13:00 to 17:00 each day to simulate the background wind speed in the Taihu Lake area (You et al., 2007). The surrounding temperature was maintained at (25 ± 1)°C to simulate the early summer temperature of Taihu Lake, and the room lighting provided illumination.

1.4 Sample analyses

1.4.1 Classification of water color and odor

The most salient features of algae-caused black bloom are the black color and the odor of the water. The beginning and the end of black bloom are defined as the appearance and disappearance of the blackness and odor. Rusch et al. (1998) defined three artificial levels that described the sediment surface color in black spots. In the present study, we placed a greater emphasis on the water color. The water color observed in our experiment was classified according to 4 levels, designated as 0, 1, 2 and 3, which corresponded to colorless, gray, light black and deep black, respectively. The odor was also classified according to 4 levels: odorless, slight odor, medium odor and odor. The classification of the water color and odor was recorded by one person to avoid subjective differences in classification.

1.4.2 Nutrient concentration of the overlaying water

Water samples with 50-mL volumes were taken from sample outlets on the tubes at a regular time each day. Top water samples were collected from a sample outlet 5 cm beneath the water surface, and bottom water samples were collected from 5 cm above the sediment-water interface. The water column was replenished with filtered lake water collected at the corresponding site after each sampling, and the nutrient concentration of the water samples was amended with the added lake water. The water samples were filtered using a filter membrane (GF/C, Waterman, UK) for analysis of the concentration of phosphorus (PO_4^{3-}-P) and ammonium (NH_4^+-N), and were stored at 4°C until analysis.

NH_4^+-N was analyzed via a colorimetric method using Nessler's reagent (State EPA of China, 2002), and PO_4^{3-}-P was analyzed using the molybdenum blue method (Murphy and Riley, 1962). Both colorimetric analyses were conducted using a UV-Vis spectrophotometer (Shimadzu UV-2450, Japan).

1.4.3 Sediment chemistry

The sediment cores were carefully removed from the lower Plexiglas tubes after the simulated experiments. For further measurements, the sediment cores were removed as soon as possible to avoid disturbance of the sediment-water interface microprofiles.

To test the sediment core oxygen microprofiles, a dissolved-oxygen microelectrode (PreSens, Germany) was used at all six sites, and the pH and H_2S microprofiles were measured using a microelectrode (UniSense, Denmark) at sites MB, MBD, NQ and NQD. The top 3 cm of each sediment core was sectioned at 1 cm intervals and homogenized, and the following 4 cm were sectioned at 2 cm intervals and homogenized. Half of each sediment subsample was dried at 105°C to determine the water content. The remaining subsamples were freeze-dried, ground and sieved for the analysis of organic matter (calculated as loss on ignition, LOI) at 500°C for 4 hr, total phosphorus (TP) (Ruban et al., 1999) and total nitrogen (TN) (State EPA of China, 2002). The acid-volatile sulfide in the sediment was extracted using a cold-diffusion method (Hsieh and Yang, 1989; Hsieh et al., 2002), and the sulfide was quantified using the methylene blue method (Cline et al., 1969).

2 Results

The simulated experiment was terminated on day 13, in accordance with previous studies (Qin et al., 2010; Yang et al., 2008; Shen et al., 2011). In the simulated process, the three un-dredged sites, FP, MB and NQ, exhibited black bloom on day 5. One of the dredged sites, FPD, exhibited black bloom on day 6. Over the course of the experiment, MBD and NQD samples retained their normal color and odor.

2.1 Water color and odor

No significant differences in color and odor were found at the top and bottom of the water columns from all sites during the first 4 days; however, the bottom of the water column from the three un-dredged sites (FP, MB, and MQ) became gray on day 5. Gray water also occurred in the bottom of the water column from the FPD site. The gray water from the FP, MB, NQ and FPD sites diffused to the top of the water column suddenly on day 8, and the water color became increasingly black during the course of the experiment, as presented in **Table 1**.

The changes in the odor of the water are shown in **Table 2**. On day 4, the bottom of the FP water column had a slight odor. On day 5, the gray water at the bottom of MB and NQ columns had a slight odor, and the bottom of FDP had a slight odor on day 6. On day 8, the odor of those four sites had diffused to the top of the water column and was classified as medium odor or odor, which corresponded to changes in the water color. The odor of the water was reduced in some samples, such as the top of MB and FP, later during the experiment; however, the water odor was unchanged at the end of experiment in most of the samples.

2.2 Sediment characteristics

The main characteristics of the un-dredged and dredged sediment cores are shown in **Fig. 3**. In the upper 0–6 cm of the sediment from the un-dredged and dredged samples, the water content generally decreased with increasing depth. In general, the un-dredged sediment cores contained more water than the dredged cores; however, in the samples from Moon Bay, the dredged sediment had higher water content. The organic matter content (calculated as loss on ignition, LOI) of the un-dredged sediment also decreased with increasing depth, and the dredged sediment had more stable organic matter content than the un-dredged sediment. In the sample from Moon Bay, however, the organic matter content of the un-dredged sediment was less than that of the dredged sediment. The acid volatile sulfides (AVS) concentrations at the dredged sites were less than those at the un-dredged sites in all areas.

The vertical profiles of TP and TN are shown in **Fig. 4**. Overall, the concentrations of TN and TP declined with increasing depth, and the samples from the un-dredged

Table 1 Changes in water color during the experiment

Site	Position	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13
FP	Top	0*	0	0	0	0	0	0	1	2	2	2	2	2
	Bottom	0	0	0	0	1	1	2	2	3	3	2	2	2
FPD	Top	0	0	0	0	0	0	0	1	1	1	1	1	1
	Bottom	0	0	0	0	0	1	1	2	2	2	2	2	2
MB	Top	0	0	0	0	0	0	0	1	1	2	2	2	2
	Bottom	0	0	0	0	1	1	1	2	3	3	3	3	3
MBD	Top	0	0	0	0	0	0	0	0	0	0	0	0	0
	Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0
NQ	Top	0	0	0	0	0	0	0	1	1	1	1	1	1
	Bottom	0	0	0	0	1	1	1	2	2	2	2	2	2
NQD	Top	0	0	0	0	0	0	0	0	0	0	0	0	0
	Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0

* 0, 1, 2 and 3 represent the water color and correspond to a classification of colorless, gray, light black and deep black, respectively.

FP: Fudu Port un-dredged; FPD: Fudu Port dreged; MB: Moon Bay un-dredged; MBD: Moon Bay dredged; NQ: Nan Quan un-dredged; NQD: Nan Quan dredged.

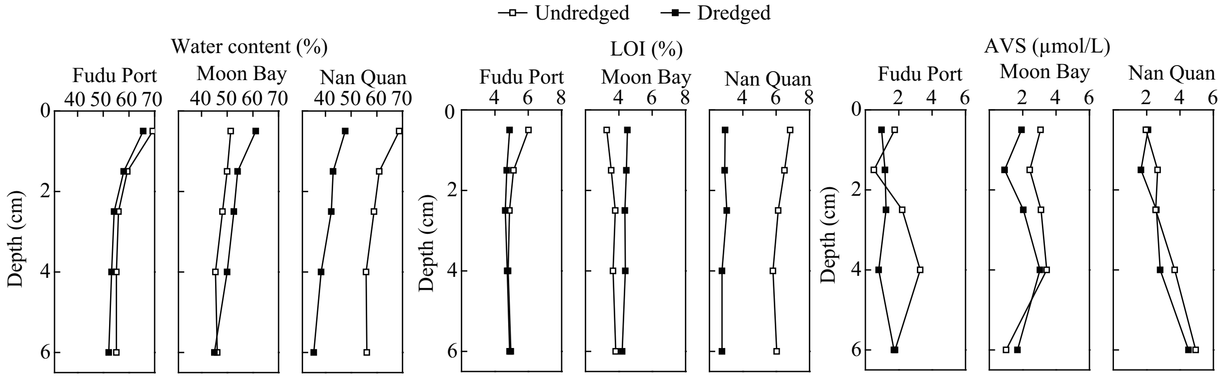

Fig. 3 Vertical profiles of the sediment characteristics after the experiment, including the water content, the organic matter content (calculated as loss on ignition, LOI), and the acid volatile sulfides (AVS) concentration.

Table 2 Changes in the odor of the water samples during the experiment

Site	Position	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13
FP	Top	0*	0	0	0	0	0	0	2	3	3	2	2	2
	Bottom	0	0	0	1	1	2	2	3	3	3	3	3	3
FPD	Top	0	0	0	0	0	0	0	2	3	2	2	2	2
	Bottom	0	0	0	0	0	1	2	2	3	3	3	2	2
MB	Top	0	0	0	0	0	0	0	2	3	3	2	2	2
	Bottom	0	0	0	0	1	1	2	3	3	3	3	3	3
MBD	Top	0	0	0	0	0	0	0	0	0	0	0	0	0
	Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0
NQ	Top	0	0	0	0	0	0	0	2	2	2	2	2	2
	Bottom	0	0	0	0	1	1	2	2	3	3	3	2	2
NQD	Top	0	0	0	0	0	0	0	0	0	0	0	0	0
	Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0

* 0, 1, 2, and 3 represent the water odor and correspond to a classification of odorless, slight odor, medium odor and odor, respectively.

sites had higher concentrations of TN and TP than the dredged sediment cores. The concentrations of TN and TP in the FP surface sediment were 401.73 and 89.19 mg/kg higher than that at the FPD site, respectively. The concentration of TP in the MBD surface sediment was 125.95 mg/kg lower than that in the MB sediment. The NQ site exhibited a marked difference in the concentrations of TN and TP; the concentrations of TN and TP in the NQ surface sediment were 1651.34 and 163.13 mg/kg higher than those at the NQD site, respectively.

2.3 Sediment-water interface

From the data shown in **Fig. 5**, the un-dredged sediment cores from the MB and NQ sites had a peak value of H_2S below the sediment-water interface. The sediment core of the MB site reached a peak value of 14.32 μmol/L at the depth of –4 mm, and the peak value of the NQ sediment occurred at a depth of –8 mm, where the concentration of H_2S was 7.32 μmol/L. The vertical profiles of H_2S in samples from the un-dredged cores were unimodal curves; however, H_2S was not detected at the MBD and NQD sites.

Based on the results in **Fig. 5**, the sediment cores in which black bloom occurred had lower pH values; i.e., the MB and NQ sites that were un-dredged generally had lower pH values than the MBD and NQD sites. The pH in the MB sediment decreased from 7.31 in the overlaying water at 4.5 mm above the interface to 7.17 at the interface. Below this depth, the pH gradually increased, reaching 7.28 at –15 mm, which was the maximum depth measured. The pH in the MBD sediment was constant in the overlaying water, and it decreased from 7.43 near the interface to 7.31 at a depth of –15 mm. The pH levels in the NQ and NQD sediments were lower than the pH of the overlaying water, and in both samples, the lowest pH value was recorded at the maximum depth measured, although the fluctuation was not high.

At the beginning of the simulated experiment, the dissolved oxygen (DO) was greater than 6 mg/L before the algae was added to the water column. After the experiment, the oxygen profiles of all six sites were measured. As shown in **Fig. 6**, the DO decreased at all sites to 0 mg/L at a depth of 1 mm above the sediment-water interface. No DO was detected below the interface at the un-dredged sites or at the dredged sites, and no difference was observed between the sites at which black bloom occurred and those at which no black bloom occurred.

2.4 Nutrients in the overlaying water

Background nutrient concentrations of lake water in each site are shown as **Table 3**. Filtered lake water was employed as overlaying water for the sediment cores in the experiment.

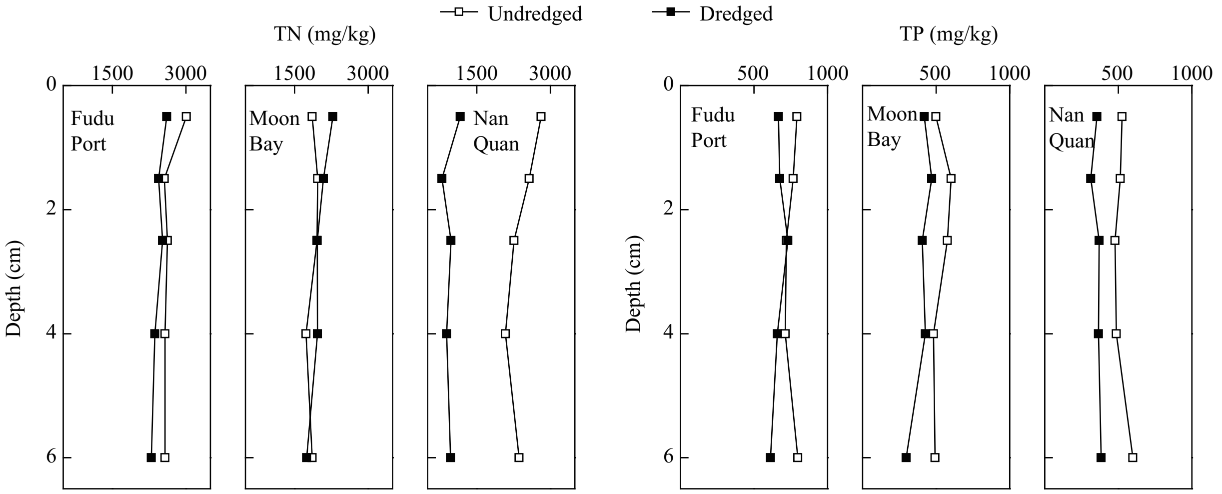

Fig. 4 Vertical profiles of TN and TP concentrations in sediment.

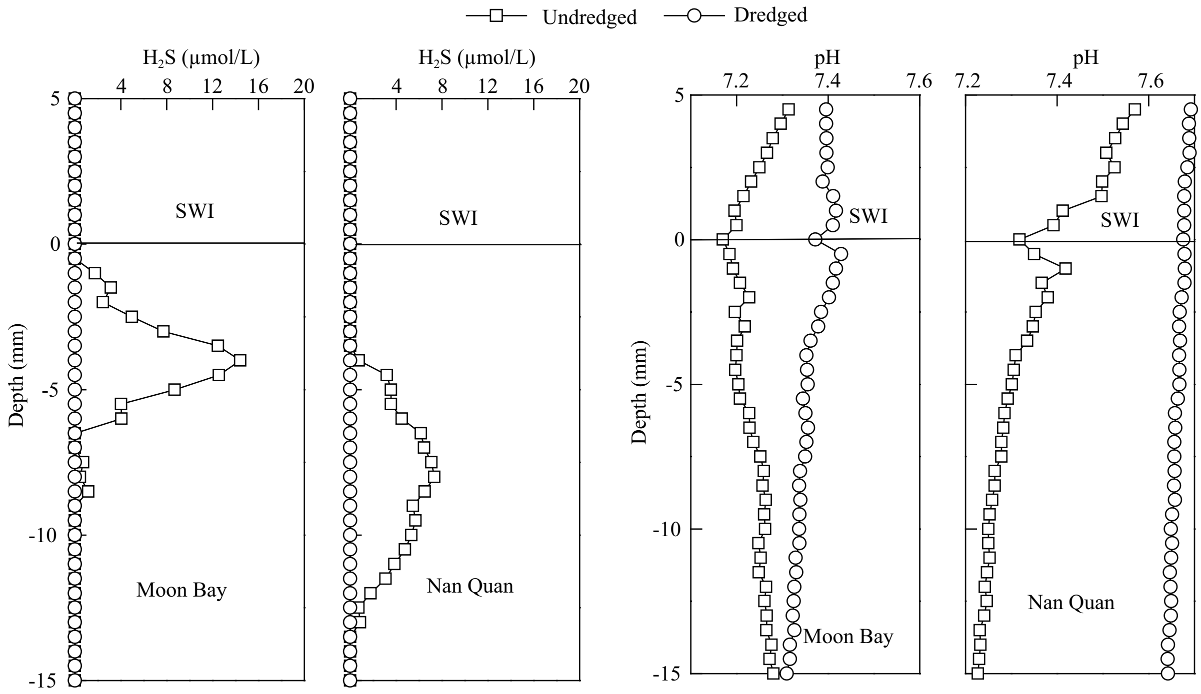

Fig. 5 Vertical profiles of H_2S and pH at the Moon Bay and Nan Quan sites. SWI: the sediment-water interface.

Table 3 Nutrient concentrations of filtered lake water, which was employed as overlaying water in the experiment

	FP	FPD	MB	MBD	NQ	NQD
PO_4^{3-}-P (mg/L)	0.03	0.02	0.02	0.02	0.02	0.02
NH_4^+-N (mg/L)	0.72	0.98	0.81	0.67	0.80	0.74

As shown in **Fig. 7**, the NH_4^+-N and PO_4^{3-}-P concentrations at day 1 were much higher than the background concentrations of lake water employed as overlaying water; the initial enhancement of nutrient concentrations was mainly due to the degradation of added algae. The NH_4^+-N concentration in the overlaying water at the Fudu Port sites increased during the experiment, especially when the black water at the bottom diffused to the top (after day 8). The PO_4^{3-}-P concentration was constant at the beginning of the experiment but increased after day 8. The PO_4^{3-}-P concentration at the FP site was higher than that at the FPD site throughout the experiment, and the PO_4^{3-}-P concentration at the bottom of the sample was initially less than that at the top; however, the concentration at the bottom of the sample had exceeded the concentration at the top of the sample by day 4, which corresponded to the occurrence of the black bloom.

The concentrations of NH_4^+-N at the top and bottom

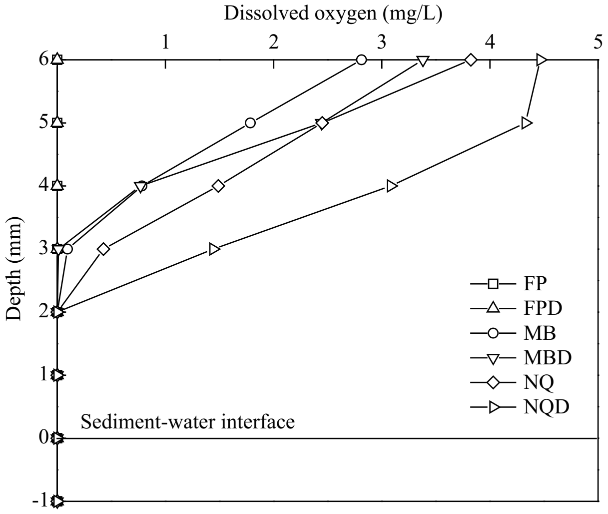

Fig. 6 Vertical profiles of dissolved oxygen at all sites.

of the samples from the MB site exceeded those from the top and bottom of the MBD site at day 8. However, the difference became smaller at the end of the experiment. The concentration of PO_4^{3-}-P at the MB site was higher than that at the MBD site throughout the study. On day 4, the PO_4^{3-}-P concentration at the bottom of the water column from the MB site increased rapidly and exceeded that at the top of the water column, which was much higher at the beginning of the experiment. The PO_4^{3-}-P concentration at the bottom of the MB site reached its peak value of 1.89 mg/L at the end of the experiment.

A larger difference was observed in the concentrations of nutrients between the NQ and NQD sites. The concentration of NH_4^+-N at the NQ site increased rapidly after the occurrence of black bloom, whereas the concentration of NH_4^+-N at the NQD site remained constant throughout the experiment. Similar to the other sites in which black bloom occurred, the PO_4^{3-}-P concentration at the NQ site increased according to the occurrence and diffusion of the black bloom. The concentration of PO_4^{3-}-P at the bottom of the sample also exceeded that at the top on day 4. The PO_4^{3-}-P concentration at the NQD site was relatively constant and fluctuated between 0.07 and 0.25 mg/L.

3 Discussion

3.1 Influence of black bloom on the sediment-water interface

The hypoxic zone in the Gulf of Mexico was formed due to the depletion of DO caused by the degradation of superabundant organic matter (Scavia et al., 2003; Díaz and Rosenberg, 2008; Díaz et al., 2009). In Taihu Lake, a large amount of DO was consumed during the decomposition of the algae, which was finally deposited on the sediment surface after the cyanobacterial bloom. The DO was mostly under 2 mg/L during the black bloom of Taihu Lake under natural conditions (Lu and Ma, 2009). The artificial addition of starch or algae into the water could also result in an oxygen deficiency (Hansen and Blackburn, 1992; Rusch et al., 1998). Liu et al. (2010c) analyzed the DO in a simulated black bloom experiment and demonstrated that the DO decreased to less than 0.5 mg/L within hours of the addition of drained algae.

To identify the vertical profile of oxygen, the DO in all of the sediment cores was measured using a microelectrode. As shown in **Fig. 6**, although the sediment cores were carefully removed from the lower Plexiglas tubes and measured as soon as possible, reoxygenation

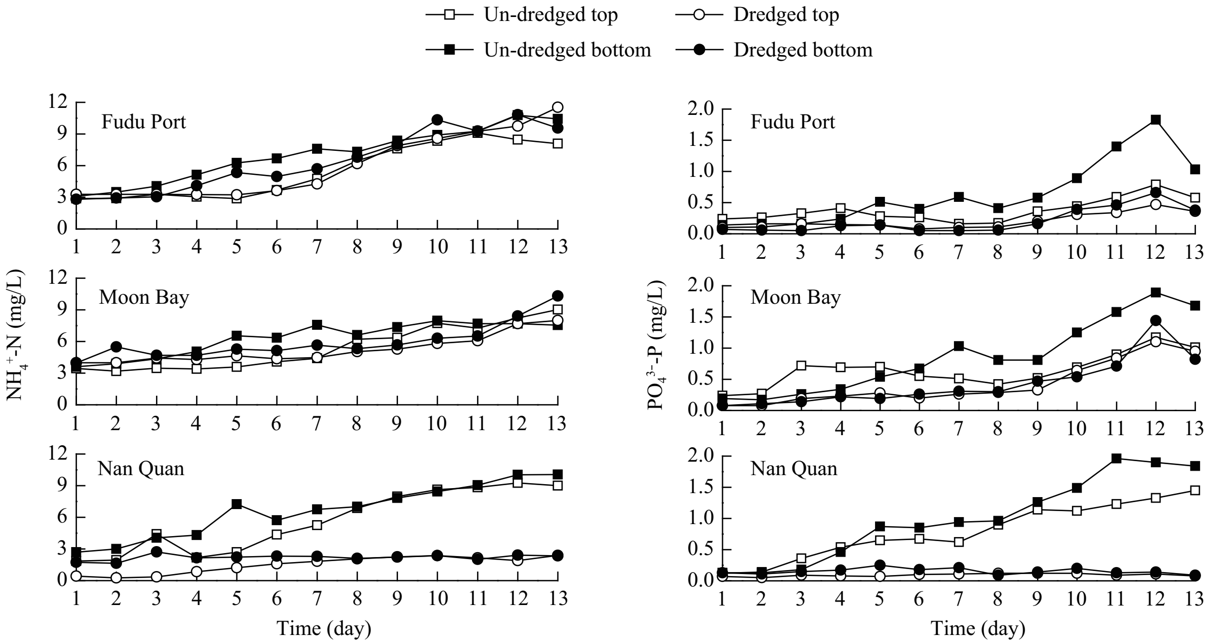

Fig. 7 Changes in the nutrient concentrations in the study areas over the course of the experiment.

still affected the DO at the surface of the overlaying water. The concentration of DO was relatively high at the top of the 5-mm-thick layer of overlaying water. However, the DO dropped to 0 mg/L at a depth of 1 mm above the interface whether black bloom occurred or not. Decaying artificially-added drained algae was decomposed into reducing substances by anaerobic microbes and caused hypoxia (Li et al., 2003). The oxygen deficiency provided the necessary conditions, but not sufficient conditions for the development of black bloom. According to the DO profiles, we inferred that the degeneration of additional algae accounted for the consumption of the DO, and the oxygen deficit was conducive to the occurrence of black bloom. In addition, the nutrient-rich sediment was essential for the occurrence of black bloom.

Hydrogen sulfide was detected at the MB and NQ sites, which developed black bloom during the experiment. Because of the emission of H_2S from the sediment to the overlaying water, the peak value of H_2S occurred at depths of –4 mm and –8 mm in the sediments from the MB and NQ sites, respectively. The maximum values of H_2S at the MB and NQ sites were 14.32 and 7.32 μmol/L, respectively. However, the maximum value detected in our experiment was significantly lower than the value measured *in situ* at Lower Mystic Lake (Duval and Ludlam, 2001). This result could be explained by the fact that our measurement was taken at the end of the experiment, and most of the H_2S generated in the black bloom had already diffused to the atmosphere. The data presented in **Table 2** also confirmed that the odor was reduced at some sites at the end of the experiment. Organic matter was mineralized primarily by sulfate reduction under conditions of oxygen deficiency (Jørgensen et al., 1982). Degeneration of the organic matter by microbial sulfate reduction led to the accumulation of H_2S and FeS (Böttcher et al., 1998). The water samples collected at the black bloom sites remained black when sealed; however, their color faded soon after the samples were exposed to air. To further study the changes in the water color, the true color of the water samples was detected after filtration through 0.45-μm acetate filter membranes; however, the filtered water color was not noticeably different between the black bloom site and the other sites. Therefore, we inferred that the blackness was mainly caused by the particulate matter that had been blocked by the filter membrane. This phenomenon of fading in air was consistent with the studies of Stahl (1979), who inferred that the blackness in a strip-mined lake was caused by metal sulfides.

Vopel et al. (2008) noted that, under natural conditions, the vertical profile of pH in the first 10 mm of sediment first decreased and then remained constant for a certain distance before increasing slightly. A significant relationship was observed between the changes in pH and the oxygen penetration depth. At the depth where the oxygen concentration decreased to 0 mg/L, the electron acceptor changed (Vopel et al., 2008). The vertical pH profiles of the four sites all decreased from the overlaying water to the sediment under reducing conditions. The fluctuations in pH at the MBD and NQD sites were slight: only 0.11 and 0.06 pH units, respectively. The pH values at the MB and NQ sites, however, were significantly lower and exhibited greater fluctuations, which coincided with our *in situ* measurements in Bafang Port, located in the northwest region of Taihu Lake, where black bloom occurred in 2011. The black spots in the Wadden Sea also had a lower pH value than the reference zone (Neira and Rackemann, 1996). We suggest that the decrease in the black bloom sediment pH value may be due to changes in the reduction conditions and in the mineralization mechanism. However, additional work is required to investigate this phenomenon.

3.2 Relationship between nutrient concentrations and black bloom

Studies on the effects of sediment dredging in Taihu Lake showed that, after the removal of nutrient-rich surface sediment, the new surface sediment contained lower levels of nutrients and the potential for nutrient release from the sediment to the water was also decreased (Zhong et al., 2008, 2010). In our research, the surface-layer sediment at the dredged sites (FPD, MBD and NQD) all contained lower concentrations of TN and TP than that of the corresponding FP, MB and NQ sites (**Fig. 4**). However, the TN concentration was similar between the un-dredged and dredged sites in Moon Bay. This result was similar to the LOI value in Moon Bay according to a study by Shen et al. (2011), and this situation most likely due to the heterogeneity of the specific area.

Overall, the concentrations of nutrients were lowered enough at the sites that did not develop black bloom in our study. After dredging, the nutrient-rich surface layer was moved, and the new surface layer contained a lower concentration of nutrients and AVS. Therefore, the potential for the formation of H_2S and metal sulfides was significantly lower than that in the original surface layer. The sediment of the new surface layer experienced early diagenesis and contained less readily degradable organic matter; the mineralization of the new surface layer was therefore weak (Zhong et al., 2010). In Moon Bay, the MBD site had a higher LOI than the MB site; however, because of the lower ratio of readily degradable organic matter in the new sediment layer, the MBD site did not develop black bloom over the course of this study. Among the three dredged sites, only the FPD site developed black bloom during the experiment, which was likely because the FPD site contained higher concentrations of nutrients than the other two dredged sites at the corresponding depth. Because of the high nutrient concentration and AVS of the new layer, the FPD site developed a black bloom with the artificial additional algae; however, both the degree of the odor and color were reduced compared with the other black bloom sites, and the beginning of the black bloom at the FPD site was also one day later than at the other sites.

According to the results of our study, we suggest that, based on the addition of organic matter, such as drained algae, the occurrence of black bloom is associated with the concentrations of nutrients and AVS. The external organic matter results in an oxygen deficiency in the water, and the reduction of sulfates and the formation of H_2S and metal sulfides cause the odor and black color of the water. The nutrient concentration in the sediment plays an important role in the generation of black bloom.

The concentrations of nutrients in the black bloom zones were approximately ten times higher than normal values in Taihu Lake when black bloom occurred in the summer of 2007 (Qin et al., 2010). The concentration of NH_4^+-N observed in the black bloom zone was significantly higher than the concentration observed in an algae bloom (Zhang et al., 2011). Therefore, it is possible that the higher concentration of NH_4^+-N was due to its release from the sediment and from decomposing algae (Sheng et al., 2010). Because of the oxygen deficiency in the black bloom water, the redox potential is relatively low, and the ferric iron will become ferrous sulfide because of the reduction of sulfides under this condition. Therefore, phosphate which was bonded to ferric iron before is released to the overlaying water. The decomposition of algae simultaneously increases the concentrations of nutrients in the water (Böttcher et al., 1998; Geurts et al., 2010; Graca et al., 2004; Hansen and Blackburn, 1992). Overall, this situation results in the enhancement of concentrations of nutrients during black bloom and deterioration of the water quality. In our simulated experiment, the observed enhancement of nutrient concentration at black bloom sites could be attributed to the different characteristics of sediment samples, because the artificial additional drained algae at each site were the same.

The enhanced nutrient concentration was evidenced by the changes in the NH_4^+-N concentration in the water column, which indicated that NH_4^+-N levels at the black bloom sites increased stably before the occurrence of black bloom. However, they increased rapidly when the black bloom began and remained stable for the rest of the experiment. Despite the wind simulation provided by the side-position and upper-position motors, the NH_4^+-N concentration at the bottom of the sample was higher than at the top in almost every water column. One possible explanation for this difference might be the artificial additional algae, which was deposited on the sediment and increased the release of NH_4^+-N to the bottom water (Sheng et al., 2010). Another possible explanation may be the remineralization of labile organic matter in or on the surface sediments (Graca et al., 2004). Because of the wind simulation in the experiment, the difference in the NH_4^+-N concentrations between the top and bottom of the water columns was smaller at the end of the experiment.

The PO_4^{3-}-P concentration at the black bloom sites was higher than that at the other sites, because phosphate in the sediment mainly exists in the form of Fe-P (Graca et al., 2004). The phosphate is released from the sediment when ferric iron is reduced to ferrous iron under relatively low redox potentials, and the mechanism by which redox potentials control the PO_4^{3-}-P concentration is complex (Li et al., 2007). The dredged sites also have less potential for releasing phosphate from the sediment to the overlaying water (Zhong et al., 2008). The most interesting finding was that all the water samples from the black bloom sites, particularly the un-dredged sites, contained higher PO_4^{3-}-P concentrations at the tops of the samples compared with the bottoms of the water samples at the beginning of the experiment. However, the PO_4^{3-}-P concentration at the bottom exceeded that at the top after the occurrence of black bloom. This also demonstrated that the unusually high concentrations of nutrients in black bloom were mainly derived from the sediment and that the removal of the nutrient-rich sediment by dredging could prevent and control the black bloom.

4 Conclusions

Based on the results of our simulated experiments on black bloom at un-dredged and dredged sites with the addition of drained algae, in which we measured the changes in the sediment characteristics, the sediment-water interface and the nutrient concentrations in the overlaying water, we conclude that:

(1) With the removal of nutrient-rich sediment, dredging could prevent and control black bloom. In our experiments, all three un-dredged sites developed black bloom, whereas only the FPD site developed black bloom among the dredged sites. However, the black bloom at the FPD site developed one day later than the black blooms at the un-dredged sites, and the bloom was also less severe based on the water color, the odor and the concentrations of nutrients in the water.

(2) The cause of black bloom was nutrient-rich sediment rather than the accumulation and degeneration of algae. Furthermore, the oxygen deficit was not caused by black bloom, but rather by the decomposition of algae. Black bloom occurred as a result of the combination of algae decomposition and the presence of nutrient-rich sediment.

(3) The substantial enhancement of the nutrient concentrations in the water was predominantly the result of the release of nutrients from the sediment to the overlaying water because of the changes in conditions caused by the occurrence of black bloom.

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References

Böttcher M E, Oelschläger B, Höpner T, Brumsack H J, Rullkötter J, 1998. Sulfate reduction related to the early diagenetic degradation of organic matter and "black spot" formation in tidal sandflats of the German Wadden Sea (southern North Sea): stable isotope (^{13}C, ^{34}S, ^{18}O) and other geochemical results. *Organic Geochemistry*, 29(5-7): 1517–1530.

Cline J D, 1969. Spectrophotometric determination of hydrogen sulfide in natural waters. *Limnology and Oceanography*, 14(3): 454–458.

Díaz R J, Rosenberg R, 2008. Spreading dead zones and consequences for marine ecosystems. *Science*, 321(5891): 926–929.

Díaz R J, Rosenberg R, Rabalais N N, Levin L A, 2009. Dead zone dilemma. *Marine Pollution Bulletin*, 58(12): 1767–1768.

Duval B, Ludlam S D, 2001. The black water chemocline of meromictic Lower Mystic Lake, Massachusetts, USA. *International Review of Hydrobiology*, 86(2): 165–181.

Fan C X, Zhang L, Wang J J, Zheng C H, Gao G, Wang S M, 2004. Processes and mechanism of effects of sludge dredging on internal source release in lakes. *Chinese Science Bulletin*, 49(17): 1853–1859.

Freitag T E, Klenke T, Krumbein W E, Gerdes G, Prosser J I, 2003. Effect of anoxia and high sulphide concentrations on heterotrophic microbial communities in reduced surface sediments (Black Spots) in sandy intertidal flats of the German Wadden Sea. *FEMS Microbiology Ecology*, 44(3): 291–301.

Geurts J J M, Smolders A J P, Banach A M, van de Graaf J P M, Roelofs J G M, Lamers L P M, 2010. The interaction between decomposition, net N and P mineralization and their mobilization to the surface water in fens. *Water Research*, 44(11): 3487–3495.

Graca B, Burska D, Matuszewska K, 2004. The impact of dredging deep pits on organic matter decomposition in sediments. *Water, Air, & Soil Pollution*, 158(1): 237–259.

Gustavson K E, Burton G A, Francingues N R, Reible D D, Vorhees D J, Wolfe J R, 2008. Evaluating the effectiveness of contaminated-sediment dredging. *Environmental Science & Technology*, 42(14): 5042–5047.

Hansen L S, Blackburn T H, 1992. Effect of algal bloom deposition on sediment respiration and fluxes. *Marine Biology*, 112(1): 147–152.

Hsieh Y P, Yang C H, 1989. Diffusion methods for the determination of reduced inorganic sulfur species in sediments. *Limnology and Oceanography*, 34(6): 1126–1130.

Hsieh Y P, Chung S W, Tsau Y J, Sue C T, 2002. Analysis of sulfides in the presence of ferric minerals by diffusion methods. *Chemical Geology*, 182(2-4): 195–201.

Jørgensen B B, 1982. Mineralization of organic matter in the sea bed -the role of sulphate reduction. *Nature*, 296(5858): 643–645.

Kong F X, Hu W P, Gu X H, Yang G S, Fan C X, Chen K N, 2007. On the cause of cyanophyta bloom and pollution in water intake area and emergency measures in Meiliang Bay, Lake Taihu in 2007. *Journal of Lake Sciences*, 19(4): 357–358.

Li Q M, Bi S P, Ji G L, 2003. Determination of strongly reducing substances in sediment. *Environmental Science & Technology*, 37(24): 5727–5731.

Li Q M, Zhang W, Wang X X, Zhou Y Y, Yang H, Ji G L, 2007. Phosphorus in interstitial water induced by redox potential in sediment of Dianchi Lake, China. *Pedosphere*, 17(6): 739–746.

Liu G F, Fan C X, Zhong J C, Zhang L, Ding S M, Yan S H et al., 2010a. Using hexadecyl trimethyl ammonium bromide (CTAB) modified clays to clean the *Microcystis aeruginosa* blooms in Lake Taihu, China. *Harmful Algae*, 9(4): 413–418.

Liu G F, He J, Fan C X, Zhang L, Shen Q S, Zhong J C et al., 2010b. Environment effects of algae-caused black spots: impacts on Fe-Mn-S cycles in water-sediment interface. *Environmental Science*, 31(11): 2652–2660.

Liu G F, Shen Q S, Zhang L, Fan C X, Yan S H, 2010c. Environment effects of algae-caused black spots: driving effects on the N, P changes in the water-sediment interface. *Environmental Science*, 31(12): 2917–2924.

Liu G F, Zhang Z Y, Liu H Q, Zhong J C, Yan S H, Fan C X, 2010d. Effects of sediment dredging on benthos community structure and water quality in Zhushan bay. *Environmental Science*, 31(11): 2645–2651.

Lu G H, Ma Q, 2009. Analysis on the causes of forming black water cluster in Taihu Lake. *Advances in Water Science*, 20(3): 438–442.

Lu G H, Ma Q, 2010. Monitoring and analysis on "Black Water Aggregation" in Lake Taihu, 2009. *Journal of Lake Sciences*, 22(4): 481–487.

Lu X, Fan C X, Shang J G, Deng J C, Yin H B, 2012. Headspace solid-phase microextraction for the determination of volatile sulfur compounds in odorous hypereutrophic freshwater lakes using gas chromatography with flame photometric detection. *Microchemical Journal*, 104: 26–32.

Murphy J, Riley J P, 1962. A modified single solution method for determination of phosphate in natural waters. *Analytica Chimica Acta*, 26(1): 31–36.

Neira C, Rackemann M, 1996. Black spots produced by buried macroalgae in intertidal sandy sediments of the Wadden Sea: Effects on the meiobenthos. *Journal of Sea Research*, 36(3-4): 153–170.

Qin B Q, Xu P Z, Wu Q L, Luo L C, Zhang Y L, 2007. Environmental issues of Lake Taihu, China. *Hydrobiologia*, 581(1): 3–14.

Qin B Q, Zhu G W, Gao G, Zhang Y L, Li W, Paerl H W et al., 2010. A drinking water crisis in Lake Taihu, China: linkage to climatic variability and lake management. *Environmental Management*, 45(1): 105–112.

Reddy K R, Fisher M M, Wang Y, White J R, James R T, 2007. Potential effects of sediment dredging on internal phosphorus loading in a shallow, subtropical lake. *Lake and Reservoir Management*, 23(1): 27–38.

Ruban V, López-Sánchez J F, Pardo P, Rauret G, Muntau H, Quevauviller P, 1999. Selection and evaluation of sequential extraction procedures for the determination of phosphorus forms in lake sediment. *Journal of Environmental Monitoring*, 1(1): 51–56.

Rusch A, Töpken H, Böttcher M E, Höpner T, 1998. Recovery from black spots: results of a loading experiment in the Wadden Sea. *Journal of Sea Research*, 40(3-4): 205–219.

Scavia D, Rabalais N N, Turner R E, Justić D, Wiseman W J, 2003. Predicting the response of Gulf of Mexico hypoxia to variations in Mississippi River nitrogen load. *Limnology and Oceanography*, 48(3): 951–956.

Shen Q S, Shao S G, Wang Z D, Fan C X, 2011. Simulation of black bloom in Moon Bay of Lake Taihu and physical and chemical responses of water and sediment. *Advances in Water Science*, 22(5): 710–719.

Sheng D, Xu Z A, Gao Y, 2010. Cause and impact analysis of black water cluster in Taihu Lake. *Water Resources Protection*, 26(3): 41–44, 52.

Søndergaard M, Jensen J P, Jeppesen E, 2003. Role of sediment and internal loading of phosphorus in shallow lakes. *Hydrobiologia*, 506-509(1-3): 135–145.

Stahl J B, 1979. Black water and two peculiar types of stratification in an organically loaded strip-mine lake. *Water Research*, 13(5): 467–471.

State EPA of China, 2002. Monitoring and Determination Methods for Water and Wastewater (4th ed). China Environmental Science Press, Beijing. 254–257, 435–438.

Vopel K, Gibbs M, Hickey C W, Quinn J, 2008. Modification of sediment-water solute exchange by sediment-capping materials: effects on O_2 and pH. *Marine and Freshwater Research*, 59(12): 1101–1110.

Yang M, Yu J W, Li Z L, Guo Z H, Burch M, Lin T F, 2008. Taihu Lake not to blame for Wuxi's woes. *Science*, 319(5860): 158–158.

You B S, Zhong J C, Fan C X, Wang T C, Zhang L, Ding S M, 2007. Effects of hydrodynamics processes on phosphorus fluxes from sediment in large, shallow Taihu Lake. *Journal of Environmental Sciences*, 19(9): 1055–1060.

Zhang L, Shen Q S, Hu H Y, Shao S G, Fan C X, 2011. Impacts of *Corbicula fluminea* on oxygen uptake and nutrient fluxes across the sediment-water interface. *Water, Air, & Soil Pollution*, 220(1-4): 399–411.

Zhang X J, Chen C, Lin P F, Hou A X, Niu Z B, Wang J, 2011. Emergency drinking water treatment during source water pollution accidents in China: origin analysis, framework and technologies. *Environmental Science & Technology*, 45(1): 161–167.

Zhong J C, You B S, Fan C X, Li B, Zhang L, Ding S M, 2008. Influence of sediment dredging on chemical forms and release of phosphorus. *Pedosphere*, 18(1): 34–44.

Zhong J C, Fan C X, Zhang L, Hall E, Ding S M, Li B et al., 2010. Significance of dredging on sediment denitrification in Meiliang Bay, China: A year long simulation study. *Journal of Environmental Sciences*, 22(1): 68–75.

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