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Lake sediment resuspension and caused phosphate release ——a simulation study

FAN Cheng-xin, ZHANG Lu, QU Wen-chuan

(Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China. E-mail: cxfan@niglas.ac.cn)

Abstract: Intact sediment cores and wet/dried surficial sediments sampled from the two sublakes in Taihu Lake, Meiliang Bay and Wuli Lake, were incubated in the laboratory to determine the effects of resuspension on internal phosphorus loading by simulating different resuspension events. Soluble reactive phosphorus (SRP) release from undisturbed core sediment sampled in the Meiliang Bay and Wuli Lake in July 1998 was 1.53 mg/m^2 and 2.24 mg/m^2 within 4 days, respectively. However during one hour experimental simulation of resuspension, SRP increased by 0.041 mg/L and 0.077 mg/L in the above cores, which indicate that a typical resuspension event in the lake would be accompanied by the release of 10.77 mgSRP/m^2 and 23.1 mgSRP/m^2, respectively. The internal phosphorus loading induced by resuspension is estimated to be 8 – 10 times greater than the release from undisturbed sediment. SRP release from the dried sediments during simulation of resuspension was mainly dependent on the disturbing intensity. Only when the wind strength gets to certain level, the influence of wind speed on phosphorus release appears significant, indicating that an exchangeable P pool, capable of altering equilibrium conditions in the lake areas, is built up under strongly wind-exposed resuspension events.

Keywords: sediment; resuspension simulation; phosphate release; Taihu Lake

Introduction

On interface of sediment-water, the sediment particles may resuspend up to the overlying water to form multiphase under certain hydrodynamics conditions (Lean, 1973), which can provide the habitat and nutrients for organisms. The disturbance induced by wind and water flow is easier and more intense in a shallow lake than a deep one, the interface often lies in an unstable state (Jicklls, 1998). Wind-induced sediment resuspension may influence the chemical and biological processes in the lake through effecting on turbidity, redistribution of sediment, and nutrient concentration (Gippel, 1989; Sun, 1987; Robart, 1998). Resuspension not only makes the surficial sediment move and spread around, but also greatly enlarge the action interface between sediment and water, and influence the light penetration in water column, oxygen content on the bottom and the distribution of tiny organisms. These are of importance to the phosphorus exchange across the sediment-water, form transformation and bioavailability.

The control of phytoplankton production is exerted by hydrodynamics through the proximal agents of light and (or) nutrients. The extent to which physical mixing affects these processes is determined by the force and the duration of the mixing event. High winds may resuspened bottom sediments in shallow lake basins, advecting nutrients such as phosphorus (P) or nitrogen (N) trapped in the bottom layers to the epilimnion where they can be utilized by microbial populations (Hamilton, 1988). This paper addresses the importance of resuspension to internal P-loading in the shallow and eutrophic Taihu Lake, China, and is based on in situ observations of suspended particular matter (SPM) and TP concentration during windy periods in 1997-1998, and on laboratory studies of soluble reactive phosphorus (SRP) release during simulation of sediment resuspension.

1 Materials and methods

Taihu Lake, located in south of the Changjiang delta, China, is a large, shallow and unstratified lake, with an area of 2338 km^2 and a mean depth of 2m. In its north part, there are two eutrophic sublakes, Meiliang Bay and Wuli Lake, whose mean soft sediments are 1.30m and 1.51m in depth and whose mean TP concentrations were 0.298 mg/L and 0.166 mg/L, respectively. In the summer of 1997 and 1998, the phytoplankton composition was dominated by blue-green algae.

During summer and autumn, the strong season winds are predominantly from the southeast, facing which the Meiliang Bay and Wuli Lake often are intensely exposed so that the SPM and TP concentrations in the lake water varied considerably. For example, during an increase in wind velocity (WV) from 3 to 12 m/s in the summer, surficial SPM increased from 30 to 225 mg/L. During the following days, when WV decreased to about 3.5 m/s, SPM decreased to 57 mg/L correspondingly (Fan, 1998).

Sediment in Wuli Lake is found to be very homogeneous in the accumulation areas, i.e. areas than 1.3m that constitute about 80% of the lake areas. But in the Meiliang Bay the sediment depth unevenly distributed, ranging from about 0 to 4m. In the upper 6 cm of sediment dry weight (DW), organic weight (OW), TP and the concentration of SRP in the interstitial water (SRPi) generally differed, and the values are given (Table 1). Sediment DW was low ranging from only 43.7% (37.9%) in the upper 2 cm to 63.0% (62.5%) at a depth of 28—30 cm. TP decreased from 1.33 – 1.81 mgPgDW^{-1} in the upper 2 cm to 1.24 – 1.42 mgPgDW^{-1} in 28 – 30 cm was relatively high, ranging from 42.2% – 48.8% in the

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uppermost 2 cm to 26.4% – 27.5% at a depth of 8 – 10 cm. The vertical difference of SRPi appears very different between the both lake areas, the Meiliang Bay being principally within 0.058 – 0.070 mg/L and Wuli Lake decreasing from 0.135 mg/L in the upper 0 – 2 cm to 0.090 mg/L in 28 – 30 cm. The influence of resuspension on internal phosphorus loading was investigated by laboratory experiments studying P-release from the core and experiments simulating resuspension events.

Table 1 Sediment characteristics in the accumulation (deeper than approx. 2m) in 1997

Depth, cm	Meiliang Bay				Wuli Lake			
	DW, %	OW, %	TP, $mgDW^{-1}$	SRPi, mg/L	DW, %	OW, %	TP, $mgDW^{-1}$	SRPi, mg/L
0 – 2	43.7	42.2	1.33	0.061	37.9	48.8	1.81	0.135
4 – 6	55.1	29.3	2.01	0.070	45.8	33.7	1.95	0.167
8 – 10	57.3	27.5	2.59	0.058	53.5	26.4	1.09	0.075
14 – 16	59.4	–	1.73	0.060	61.7	–	1.42	0.102
18 – 20	60.5	22.1	1.98	0.063	61.7	21.6	1.81	0.080
24 – 26	62.9	–	1.63	0.076	62.0	–	0.94	0.059
28 – 30	63.0	19.8	1.42	0.069	62.5	20.3	1.24	0.090

Water was monthly sampled during 1997 – 1998 and the wind speed and wind directions were recorded at the same time. The stratified sampling was carried contemporarily and analyzed. Some acrylic-glass tubes (Φ62 × 1000 mm) were used to sample core sediment in triplicate in Wuli Lake (31°30′55″N, 120°15′04″E) and Meiliang Bay(31°28′31″N, 120°11′39″E), whose positions were fixed by a GPS on the 23 July, 1997. The bottom water was simultaneously collected for each site and filtrated through glass fiber filters (Whatman GF/C, 0.45 μm) upon return to the laboratory. To examine the release effect under as natural a condition as possible, special care was taken to get undisturbed cores. The samples were carried to the laboratory with overlying water and with rubber stoppers tightly capped leaving no free space. The experiments were started within 6 hours after the collection. All release tests were performed at 25 ± 0.5℃ in a flowing water bath. For each sampling site, two undisturbed cores were in parallel prepared for the experiment, in which the overlying water was replaced by the filtered original bottom water.

Phosphorus release during resuspension was determined using another cores sampled in the same position. In the water column (Fig.1), a glass stirrer, which was 10 cm above the surface, stirred at about 100 revolutions per minute (r/min) for one hour. At each sampling time, 50 ml of overlying water was drawn by a syringe from 3 cm above the sediment surface and filtrated (Whatman GF/C, 0.45 μm) for analysis. The filtrated original bottom water, stored in dark at 4℃, was carefully added at the equal sampled volume followed by sampling.

To simulate the processes of the phosphorus release under different wind-induced conditions, the fresh surficial sediment was sampled in both lake areas. Fourteen flasks, each of which contained 5g fresh sediment and 100 ml filtrated water, were put on a shaker in constant temperature (25 ± 1℃). The wind speeds were simulated by means of adjusting revoluting speed of the shaker. 60 and 140 r/min represented weak and strong wind, respectively. The first stage stood for weak wind (60 r/min) effect, the second for calm, and the followed was strong wind (140 r/min) and the last was calm again. For the dried and sifted sediment experiment, the flasks were put in 1g dried sediment and 100 ml water sample, and middle wind was simulated by means of 100 r/min.

Water samples were analyzed for SRP by means of Semiflow Autoanalysis (Skalar SA1000), TP and SS according to Jin Xiangcan *et al*.(Jin, 1990). Phosphorus release was calculated as the increase in SRP during the resuspension period.

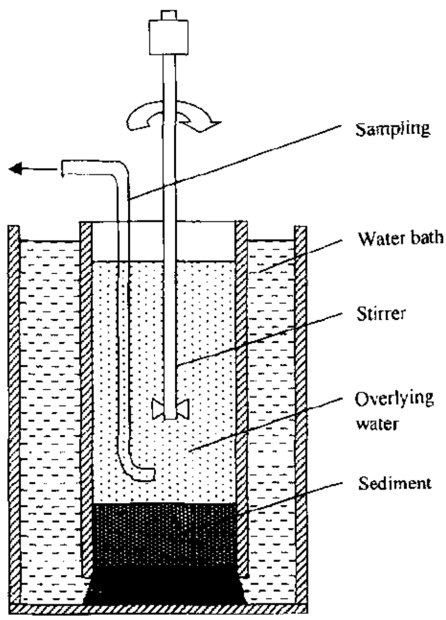

Fig.1 The layout of simulating resuspension of core sampler

2 Results and discussion

In the laboratory studies, analysis of variance revealed that the differences in nutrient release between the triplicates from one location were not significant. Thus the results obtained with the cores from the identical location were analyzed together, and most of the values given are the mean of the samples.

There was no remarkable difference in the percentage of suspended middle-sized silt particulates (0.016 – 0.004 mm) under the resuspension in the Meiliang Bay (Fig.2). But the coarse (> 0.016 mm) and fine (< 0.004mm) silt particulate contents were different, indicating that the upper was the less in the coarse and the more in the fine. However, the TP content of the fine particulate was about two orders of magnitude more than the coarse (Zhang, in press). And it was observed from energy spectrum of SPM that the fine particulate was capable to enrich a great quantity of phosphorus on and in itself, showing much higher P peak in the fine than that in the coarse.

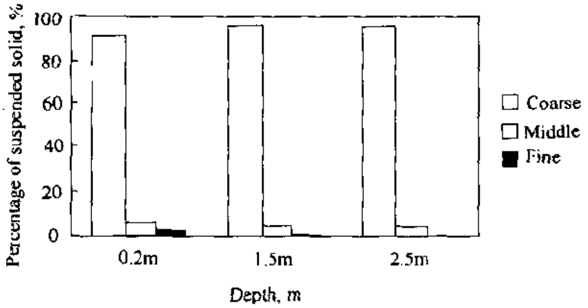

Fig.2 The percentage of the different resuspended particulates in size (%) in the Meiliang Bay

SRP release from undisturbed core sediment sampled in the Meiliang Bay and Wuli Lake in July, 1998 was 1.53 mg/m^2 and 2.24 mg/m^2 within 4 days, respectively (Table 2). However during one hour experimental simulation of resuspension, SRP release increased by 0.041 mg/L and 0.077 mg/L in the above cores, which indicate that a typical resuspension event in the lake would be accompanied by the release of 10.77 mgSRP/m^2 and 20.56 mgSRP/m^2, respectively. The lake internal phosphorus loading induced by resuspension is estimated to be 8 – 10 times greater than the release from undisturbed sediment.

Table 2 SRP concentrations prior to and following the resuspension in the cores and release increase after 1 hour disturbation

		Before resuspension	After resuspension	Increase
Meiliang Bay	mg/L	0.042	0.083	0.041
	mg/m^2	1.53	12.3	10.77
Wuli Lake	mg/L	0.067	0.144	0.077
	mg/m^2	2.24	23.1	20.86

As pore water SRP concentration is usually higher than the lake water concentration (Boström, 1982), resuspension will tend to increase lake water SRP. In order to account for the typical 0.03 – 0.10 mg/L of SRP increase observed in the resuspension experiments, the SRP concentration in the uppermost 1 – 10 mm of the sediment would have to be larger than 3 – 20 mg/L, which is unrealistic in view of the values measured in the lake areas (Fan, 1998). Furthermore, such a high porewater SRP concentration in the uppermost sediment would be expected to create a higher diffusive flux from the undisturbed sediment than was actually measured. Even though resuspension is able to cause major changes in the SRP-profile to sediment depth of several cm, despite only 1 cm actually being resuspended (Søndergaard, 1990), only a minor part of the SRP-increase can be attributed to SRP release from porewater.

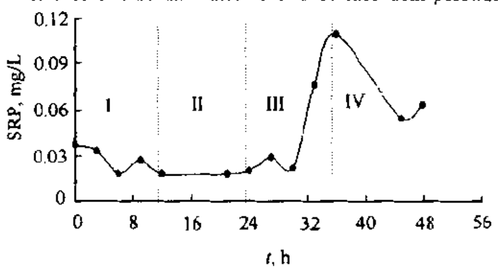

Fig.3 Phosphorus release of surficial sediments in Wuli Lake under the different wind strong periods (July 1998)

The results of both wet and dried sediment experiments showed that weak wind did not lead to a significant increase of SRP release during the simulation experiments (Fig.3 and Fig.4). Strong wind caused intense disturbation and made the deeper sediment join resuspension and scatter and deform. So much larger specific surficial space, helping sediment with P release, was got in this strong wind event than in weak one. The phosphorus in the interstitial water was free to disperse into the overlying water, in which then the internal P loading would increase because of the resuspension.

The P release from 0 – 5 cm surficial fresh and dried sediments was calculated under the great wind simulated (Table 3). After undergoing 12 – hour simulating disturbance, SRP release increased by about 3.5 – 7.5 times in contrast to the control. We also can see a more increase in SRP release of Wuli Lake's sediment than in that of Meiliang Bay's.

Wind-induced resuspension is very frequency in Taihu Lake, as qualitatively discussed by Hu Weiping *et al*. (Hu, 1998). It was predicated that wind-induced resuspension, on average, occurred about 65% of the time. The question is, how much could be released and what circumstances determine the release. In relation to the *in situ* lake water in Meiliang Bay

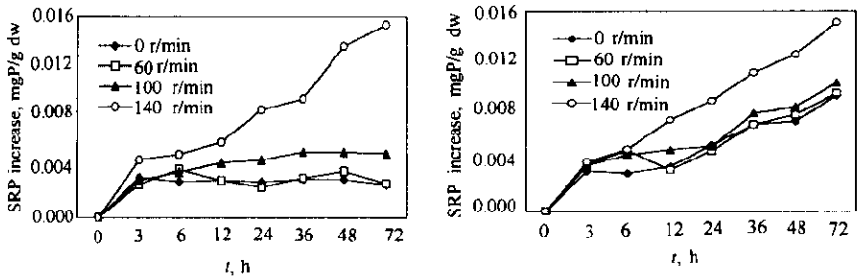

Fig.4 SRP increase of the surficial dry sediments of Meiliang Bay (left) and Wuli Lake (right) under the different simulated disturbation (25℃)

during 23 – 25 July in 1998, SRP concentration of 0.014 – 0.076 mg/L was observed at 2.8 m/s of wind speed and 0.057 – 0.127 mg/L at 4.4 m/s. The laboratory studies indicated that *in situ* resuspension would probably lead to an increase in SRP. On the basis of a typical SRP-increase of 0.050 mg/L in the experiments, it can be calculated that a single resuspension event in the lake would lead to the release of approx. 15.0 mg/m^2. So laboratory simulation of resuspension of Taihu Lake sediment revealed that *in situ* resuspension would probably lead to SRP release.

Table 3 SRP release from the surficial wet/dried sediment after 12 – hour resuspension simulation in 140 r/min (μgPg^{-1})

	Sediment	Control	After 12 – hour resuspension
Meiliang Bay	Fresh	1.1 ± 0.13	3.8 ± 0.16
	Dried	0.56 ± 0.031	6.1 ± 0.035
Wuli Lake	Fresh	1.9 ± 0.17	9.1 ± 0.21
	Dried	0.90 ± 0.023	7.2 ± 0.021

Note: for the fresh sediment, the wet weight was conversed in its dried sediment

Based on the observed changes in SPM and SRP (Fig.5), and their relationship to WV, wind can *in situ* cause SPM to increase to 40 mg/L. However, it only can do SRP to about 0.017 mg/L. Then there is a large difference between the result of laboratory simulation and that of the field observation, especially in summer. The main reason why SRP remained low in the lake water during the whole summer (June-August) is probably due to a rapid algal uptake in spite of occurrence of several resuspension events (Robarts, 1998). The combination of algal uptake and resuspension, thereby may act as mechanisms pumping P out of the sediment. Moreover, depending on the particulate properties in the lake water and sediment, resuspension may either decrease or have no effect on the lake water SRP concentration (Peters, 1984).

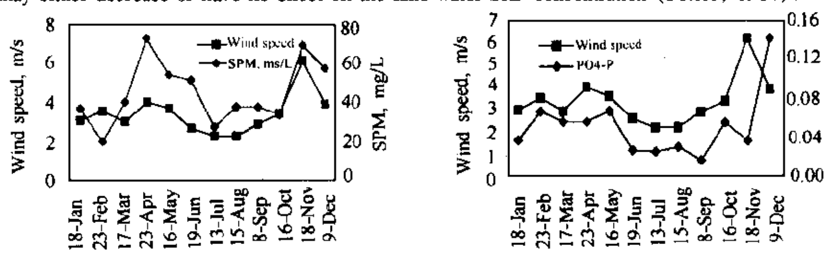

Fig.5 SPM (left) and SRP (right) at different wind speeds in the Meiliang Bay (1997)

Resuspension in shallow lakes can therefore be regarded as a mechanism that accelerates the flux of solutes between sediment and lake water. Thus shallow and wind-exposed eutrophic lakes may have a generally low Secchi depth, not only because of the high concentration of suspended matter, but also because of high nutrient generation and flux from the sediment and a consequently high algal production.

3 Conclusion

Extrapolation from laboratory and *in situ* studies indicates that phosphorus is released during the frequently occurring wind-induced resuspension of sediment in Taihu Lake. A corresponding relationship between SRP and wind speed was observed from the investigation on the Meiliang Bay and Wuli Lake. The phosphorus release caused by sediment resuspension was 8 – 10 times greater than the release from undisturbed sediment cores. Only strong wind can significantly increase P release from the surficial sediment.

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