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Processes and mechanism of effects of sludge dredging on internal source release in lakes

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Abstract **Simulated research of internal loading and collecting and analyzing the samples from the lakes were carried out before and after dredging in polluted suburb lakes, Wuli Lake (Wuxi City) and Xuanwu Lake (Nanjing City). The research results showed that dredging can inhibit internal loadings in a certain degree in a short term. The discrepancy of dredging effect and technical level, namely dredging quality, by different dredging methods will result in a difference of control of lake internal loadings. The internal loadings' reversion will gradually appear along with the biogeochemical processes, including suspended particle precipitation, hydrodynamic disturbance and microbio-transformation. The reversion rate mainly depends on the dredging method and the change of interfacial processes on the newborn surface layer. The higher nutrient contents and organic matter in the sediment will enhance water-sediment interfacial processes and nutrients regeneration. It is very important to study the physicochemical and biological character of lacustrine sediments before dredging for determining the dredging methods and predicting their environmental effect.**

Keywords: lake sediment, dredging, internal source, release, pollution reversion, interface process.

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The severe pollution of lake water in East China becomes an important environment problem, and sludge dredging, as a significant method, has been used to control the internal loading of lakes, but up to date, there is still a drastic disputation about the environmental effect of sludge dredging. Some dredging projects make the water pollution be controlled effectively[1,2]; meanwhile, it is found that a good water quality after dredging cannot maintain for a long time, and in some cases even worse than before dredging[3]. In 1982, one year after partly dredging deeply in Lake Suwa (dredging depth about 45—120 cm), the water quality did not improve as expected in the dredging area[4]. The West Lake in Hangzhou City is one of the lakes which were dredged earliest and more frequently. But the good water quality after dredging could only maintain for a short time. It is difficult to finally decide both home and abroad whether the internal pollution reversion after dredging exists or not and how much internal loading can be controlled by dredging[2,3,5,6]. The Xuanwu Lake and the Wuli Lake are city lakes in Nanjing and Wuxi, Jiangsu Province, respectively. After the late 1980s, the two lakes were suffering from severe eutrophication and serious siltation. The sediments in the two lakes contain high organic contents[7, 8] and have an obvious internal loading release[9, 10]. To improve the lake water quality, these two lakes were extensively dredged with drying and then hydraulic purged flushing dredge method as well as cutterhead suction method from Nov. 1997 to Mar. 1998 and from Jun. 2002 to Mar. 2003, respectively, whereas corresponding dredging depth is 30 and 60 cm, separately. The internal releasing rates were tracked and simulated for different dredging depths and time after dredging in the lakes. The water-sediment interface process and nutrient transformation mechanism were analyzed. The research results can provide scientific base for internal loadings harness in polluted lakes.

1 Materials and methods

(i) Sample collection and analysis. (1) Sediment samples. Two sample sites were set in the northwest of Xuanwu Lake, with a distance of 100—150 m away from the bank of the Peninsula Huanzhou (X1, X2). Two sites, with a spatial interval of 20 m, represent dredging area (X1) and reference (X2), respectively. Samely, two sample sites are located in the west of the Baojie Bridge of the Wuli Lake (W1) and near the sluice of the east Wuli Lake (W2), the latter is undredged reference site for control. All the sediment samples were collected under orientation of GPS (with a precision of 10—33 m). The sediment cores were collected by a core sampler (Rigo Co., Japan) made of Plexiglass with a dimension of $\Phi 62\times 1000$ mm. The sediment cores stood vertically and were sealed by rubber stopper at the two ends, and carefully taken back to the laboratory for processes and experiments. (2) Water samples. The water samples were collected in the depth of 0.5 m in the center of the north Xuanwu Lake and east Wuli Lake before and right, after the dredging guided by GPS. After taking back to the laboratory, the water samples were filtered by glass fiber membranes (Whatman GF/F) and stored under 4℃ till analysis of DTN and DTP. (3) Pore water collection. Bamboo tripod was set up in the center of east Wuli Lake (W3) and undredged area for control (W2) after 11 months of dredging. Pore water samples were collected by peeper (Dialysis Pore Water Sampler)[11]. The chambers of peeper lain on table were filled with deionized water, and the two sides of the peeper were covered with biologically inert polysulphone membrane, then immersed in a bucket filled with deionized water, and deaerated with nitrogen for 1 h. The peeper with 36 chambers was deployed vertically into the sediment with self-made launcher for 30 d equilibrium.

After the peeper was taken out, E_h was measured instantly on board and 1 mL pore water was fixed by adding 1 mL 1,10-phenanthroline solution with 10% concentration and 1 mL buffer solution, then taken back to the laboratory for measuring ferrous. The left pore water in the chamber was taken up and stored in an icebox filled with blue ice. Ammonia and phosphate were analyzed by a Continuous Flow Analyzer (Skalar-SA100).

(ii) Experiment methods of effect of dredging on releasing of ammonia and phosphate. Exp.1. Several sediment cores were collected in the undredged area of Xuanwu Lake X2 and Wuli Lake W2 on May 24, 1998 and May 31, 2001, respectively. In the laboratory, the top sediments of several sediment cores were cut for simulating the effect of different dredging depths (0, 10, 20, 30 and 40 cm). The filtered overlying water was carefully dropped onto the sediment cores with 30 cm height without disturbation. The water surface was marked. All the sediment cores were vertically put into the circulated water bath machine (Colora WK100, ±0.1℃) under the appointed temperature and incubated without light. 35 mL water samples were taken out from the columns at 5 cm above the sediment surface by a syringe in every 0, 3, 6, 12, 24, 36, 48, 72 h, respectively. After collection, the preserved filtered water was recharged into the columns to the original mark. The water samples were filtered with a glass fiber membrane with the pore size of 0.45 μm and frozenly stored till next analysis. PO_4^{3-}-P, NH_4^+-N and dissolved COD_{Mn} (DCOD) were analyzed by molybdate spectro-photometric method, Nessler's reagent colorimetric method and Acidic Potassium Permanganate method[12], respectively. The calculation method of releasing rate refers to ref. [10]. Exp. 2. According to Exp. 1, the same procedure was preceded to test dredging effect using the cores taken from the Xuanwu Lake and Wuli Lake. The samples from Xuanwu Lake (X1) were collected after dredging for 3 d on Mar. 7, 1998 and for 7 months' undredged site X2 the samples were collected on Oct. 8, 1998, whereas the samples from Wuli Lake were taken before and during dredging on May 31, 2001, after 2 d dredging (W1) on Jun. 29, 2002, after 11 months' dredging in W1 on May 23, 2003, and undredged site was 20 m away from W1. PO_4^{3-}-P, NH_4^+-N were analyzed for the above water samples in experiment process.

2 Result and discussion

(i) The short term effects of phosphorus and ammonia release by different dredging depths. Figs. 1 and 2 represent the change of simulated releasing rate of PO_4^{3-}-P, NH_4^+-N and DCOD in post-dredging for different dredging depths in Xuanwu Lake (X1) and Wuli Lake (W1). Generally, most curves tended to stable after 2 d, which means that the simulated releasing rates are close to the actual ones. The control effect of phosphorus release was rather obvious within short-term after dredging by means of the simulation experiment for Xuanwu Lake and Wuli Lake. Compared with the releasing rate of 1.0 $mg \cdot m^{-2} \cdot d^{-1}$ of undredged sediment, the releasing rate after dredging was immediately controlled near zero, and even negative value (namely the sediment showed as a "sink"). In the site of X1, the phosphorus releasing rate was diminished along with the increase of dredging depth. When the dredging depth is deeper than 20 cm, the releasing rate changed to a negative value. The reason is that the sediment surface was removed after dredging and the newborn surface directly contacted the overlying water containing abundant oxygen. The redox of the newborn surface rose to a high value which made the Fe^{2+} change to Fe^{3+}. The Fe^{3+} easily combined with the free PO_4^{3-} to

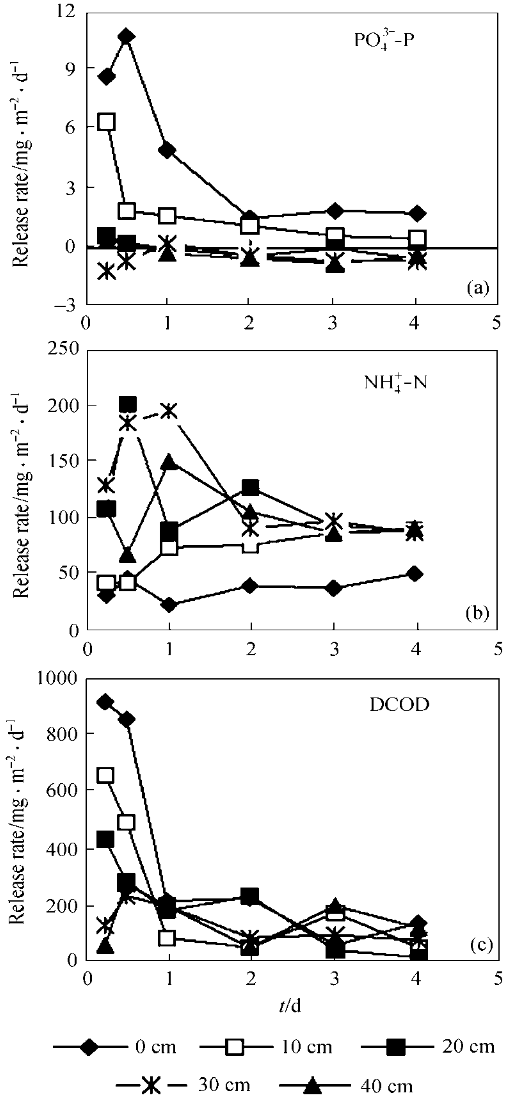

Fig. 1. The short term effect of sediment releasing with different dredging depths in Xuanwu Lake (X1) at temperature of 15℃.

form the precipitation of $FePO_4$. There will be a new oxidizing zone in the newborn surface because of the existence of high redox value. This oxidizing zone would prevent the phosphorus releasing of the subjacent pore water because the organic matter of the newborn surficial sediment is comparatively low, and especially the aerobic microorganism is very limited.

Observing the ammonia releasing after dredging, there is an opposite result in Xuanwu Lake and Wuli Lake. The ammonia release from the sediment to overlying water evidently increased in X1 after dredging. NH_4^+-N releasing rate of simulated dredging cores after 3 d was two times that of the undredged ones (Fig. 1). But the ammonia released in Wuli Lake was similar to the phosphorus release, indicating a great decrease of releasing rate in a short period (Fig. 2). This result was related to different concentration gradients of NH_4^+-N between the pore water and overlying water. The mean thickness of sediment in Xuanwu Lake is about 70 cm; total nitrogen content was as high as 0.33%—0.69%[7], which is almost twice as high as that in Wuli Lake (0.16%—0.28%). But the nitrogen contents in the lake water were lower than the common polluted lakes. As an example, the average of nitrogen content in the water was only 1.10 mg/L in 1997. So the sediment can keep a higher releasing rate after dredging. However, the average content of NH_4^+-N in the water of Wuli Lake was as high as 3.34 mg/L, and the highest content was up to 7.9 mg/L. Although the average NH_4^+-N content in the pore water in the depth of 7—40 of the lake was 9 mg/L or so[13], the NH_4^+-N would partially change to nitride with high valence state (such as NO_3^-) when the oxygen in the water went into the newborn surface after dredging and hence would make the content of NH_4^+-N in lake waters possibly exceed the pore water. In this case, the NH_4^+-N flux would be from the water to the sediment. In fact, the NH_4^+-N releasing rate before dredging (0 cm) had been closed to zero or the sediment was in adsorb state (the releasing rate was a minus value) (Fig. 2), indicating that there is a great gradient of NH_4^+-N from water to sediment and thus would offer the possibility to adsorb nitrogen by sediment after dredging. Therefore, the direction and dimension of internal flux is mainly controlled by the nutrient content gradient between the overlying water and the pore water during the beginning of dredging, while the change of NH_4^+-N in the pore water was affected by the oxygen content in the interface.

After further analysis of the NH_4^+-N releasing curves in Fig. 2, it is found that there is only small difference in NH_4^+-N content of lake waters between simulated dredging with the depth of 10 and 40 cm. This represents that there is little difference in physical properties (such as porosity, redox potential) and biological characters (such as anaerobic microbial action) at the sediment surface of different dredging depth right after dredging. Thus, the sediment release rate in different dredging depth is almost similar. Besides, Fig. 1 also shows that the DCOD releas

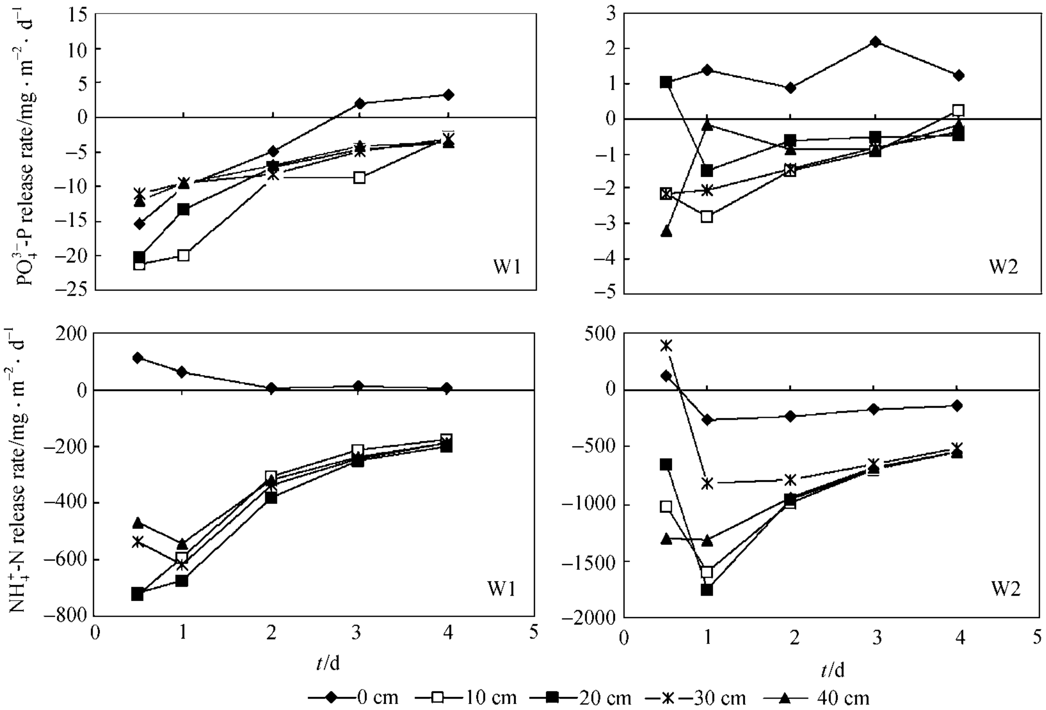

Fig. 2. The short term effect of sediment releasing with different dredging depths in Wuli Lake (W1) at temperature of 15℃.

ing is controlled in somewhat degree by dredging depth in Xuanwu Lake, but it is not very obvious. This would be related to the high organic content in the vertical profile of sediment[8].

(ii) The long term effect of dredging on internal loading control. On the basis of long time tracking for sediment release after dredging in Wuli Lake and Xuanwu Lake, whether the internal loading was controlled or whether the internal loading were renewed after dredging, the research results would be completely different with respect to different lakes. It is shown in Fig. 3 that the internal phosphorus release is obviously inhibited by dredging in Wuli Lake. With a lapse of time, phosphorus release rate decelerated with from 2.3 mg/(m^2 • d) before dredging to −0.6 mg/(m^2 • d) 11 months after dredging. But the NH_4^+-N release rate increased from −202.0 mg/(m^2 • d) just after dredging to 49.6 mg/(m^2 • d) 11 months after dredging. As for Xuanwu Lake, there is almost complete opposite result (Fig. 3). NH_4^+-N release rate is decreased from 168.5 mg/(m^2 •d) just after dredging to 49.0 mg/(m^2 • d) 7 months after dredging, only 13% of that in pre-dredging. Phosphorus release rate, 375.2 mg/(m^2 • d), however, is rapidly increased from 1.5 mg/(m^2 • d) just accomplishing dredging to 21.0 mg/(m^2 • d) after 7 months which is 2.3 times of that in pre-dredging, 9.1 mg/(m^2 • d). To some extent these results indicated that dredging can control phosphorus release in Wuli Lake and ammonia release in Xuanwu Lake in a long term, diminishing the internal loading of relevant pollutants and their content in lakes; but the dredging can hardly control the ammonia release in Wuli Lake and phosphorus release in Xuanwu Lake, even the release rate in post-dredging areas may exceed that in pre-dredging. Such reversion process would aggravate the internal loadings and increase the pollutant content in lake water.

(iii) Reason analysis for the discrepancy of dredging effect

(1) Effect of the dredging methods. Cutterhead suction method was carried in dredging of Wuli Lake, in process of which the surficial sediments was firstly loosened by Cutter Head then immediately sucked away by a special cutterhead suction dredge ship. Only a little silt was remained in the dredged sediment surface. Therefore, the sediment surface of cores taken from the dredging area just after dredge was quite smooth and dense, with a lower porosity, organic matter content and rarer microbe, all of which are inhibitors for internal nutrients' release. In the initial period after dredging, the release rate can be controlled in a low level, even a negative value. It is clear that this kind of dredging method is taken the ecological consideration into account[8]. The dredging method in Xuanwu Lake is drying and hydraulic purged flushing dredge[14], in which the lake water was discharged firstly, then the sediments were flushed with a water blast gun and concentrated in lower place, finally sucked away by a pump. In this project, the mean depth of dredging was about 30 cm. At present, this dredge method is adopted mostly in the internal loading control of lakes in China. Evidently, this method usually cannot ensure the precision of actual dredge depth and the low amount of residual silt. In fact, there were still much fine silts covering on the sediment surface after dredging. The dredge quality was much worse than the above mentioned cutterhead suction method in Wuli Lake. According to the research results, the total nitrogen in Xuanwu Lake was as high as 0.33%—0.69%[7], which is more than that in Wuli Lake of 0.16%—0.28% by two times. These N-rich residue silts is favorable to develop anoxic or anaerobic condition under which the nitrogen in the surficial sediment and pore water might be transformed to ammonia resulting in ammonia release[15]. Thus, the ammonia release can be seen in a degree in Xuanwu Lake. Because of the residual silt coverage by poor dredging quality in Xuanwu Lake, the oxidation zone at dredged sediment surface, like Wuli Lake, can be hardly formed after dredging. Additionally, the sediment surface was disturbed intensively; the original surficial sediment with reactive silt character mixed with the sediments in lower layer, and thus offered an inoculative condition for preservation of complete microbe species. With elapse of time, the residual sediment will gradually be restored to the original status.

(2) Effect of interface processes on newborn sediment surface. Usually, the newborn surficial sediments after dredging are composed of several sources, among which, the main part of the newborn surface is the sediment buried in definite depth below the bottom for hundreds, for even thousands of years. Secondly, the residual mud or diffluent returning silt is produced by the restriction of dredging methods or dredging quality. Thirdly, the precipitum is from the sinking of suspended particulate matter in the overlying water, whose amount increases with the time after dredging. Therefore, it is inevitable that the tendency of internal loading change depends on the interface process between renewal surface and overlying water, including physical, chemical and biological properties of complex material from sources, and exchange and circulation of nutrients at new interface. After dredging, the newborn surface will directly touch the overlying water and receive the settling particles from the overlying water. Usually, the organic contents in these particles are high and a great amount of microbes is absorbed by them. These microbes coupling with the particulate matter would sink to the newborn surface and reinforce the bioactivity of the sediment surface and the nutrients were regenerated by organic matter decomposition and bacteria propagation[2,16]. In shallow lakes, wind waves transfer the energy down to the bottom and cause resuspension[17,18] which makes the newborn surface frequently contact the medium rich in oxygen. It is possible to form a dense ox-

ide skin on the new surface[19]. Although the vertical distribution of redox potential (E_h) after dredging was a little similar to that before dredging, there was a proximate difference (Fig. 4). The redox potential of the newborn surface just after dredging was as high as 270 mV by analysis of the pore water collected by peepers. Because the redox potential was a middle oxide medium (200 mV < E_h < 400 mV), it was easy to form a solid oxidation skin on the sediment surface[19], which may exert an adverse effect for phosphorus release from the pore water to the overlying water. Wuli Lake is a semi-enclosed bay with the water depth of 3.5 m after dredging, namely the water depth increment of 0.6 m. So it is possible to form a barrier zone in the sediment surface and thereby to result in decrease of the releasing rate after dredging. On the basis of monthly monitoring data of Wuli Lake, it is reflected that the dissolved total phosphorus (DTP) in water declined nearly by 40% in half a year after dredging (Fig. 5).

Along with the augmentative effect from sedimentation, dynamic disturbation and biotransformation, the sinking material will attain a certain thickness covering the newborn surface. The organic particle will accumulate similarly on the surface to a certain extent. The water content, porosity and some other physical characters of the surficial sediment will greatly change[17]. The decomposition of organic matter in the cover layer by microbes will result in decrease of oxygen content and descent of redox potential, thus destroying the constructive condition of such the oxidation skin[19]. The phosphorus in higher content in the lower layer will release across the newborn interface which is governed by the Fick's First Law again. Thus, the dredging depression effect for phosphorus release will occur to change along with the continuous augment of the sediment precipitation from the overlying water (Fig. 3). In other words, the control status for internal loadings will become into the internal releasing or restoring state.

The higher content of nutrients and organics in the

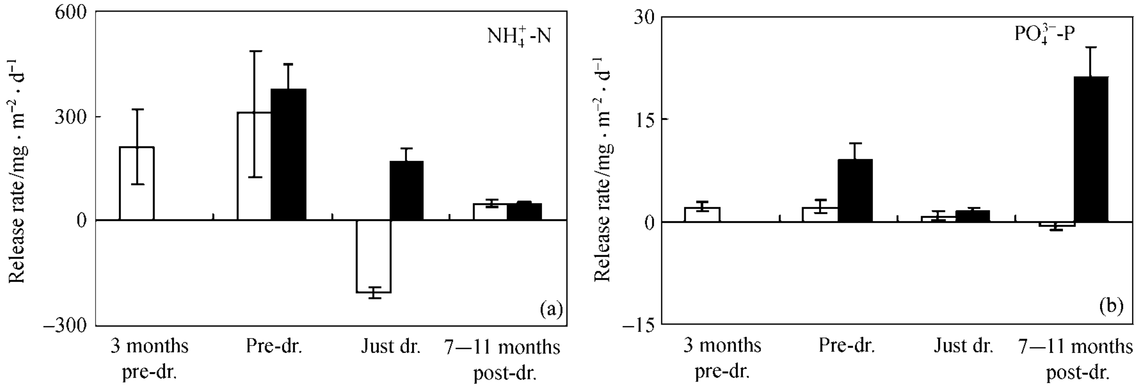

Fig. 3. The change of phosphorus and ammonia release rate after dredging in Wuli Lake (W1) and Xuanwu Lake (X1). □, Wuli Lake; ■, Xuanwu Lake.

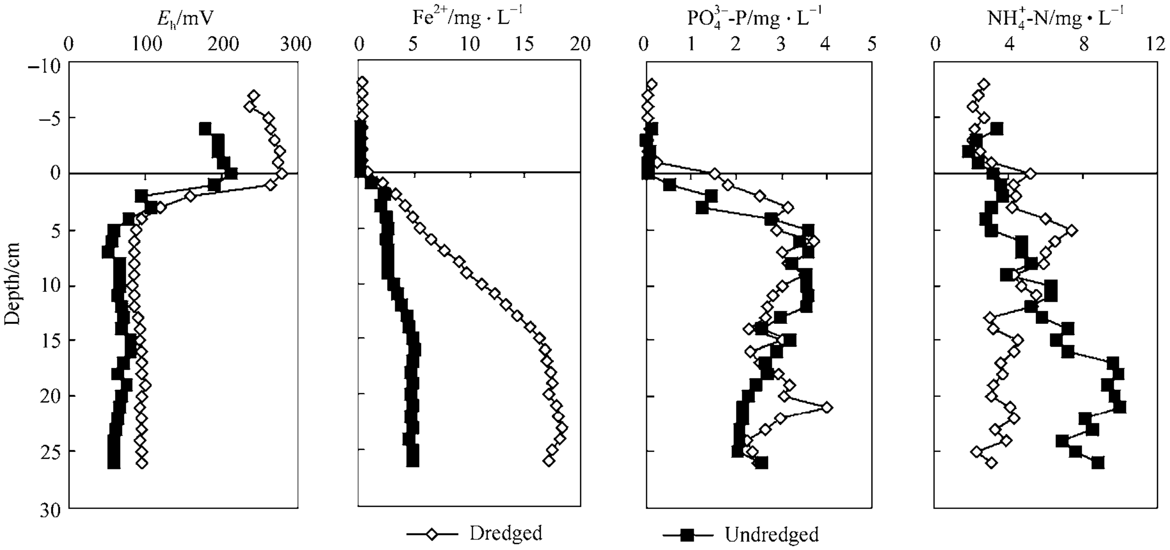

Fig. 4. The change of main physio-chemical characters of the pore water in dredged and undredged areas of Wuli Lake.

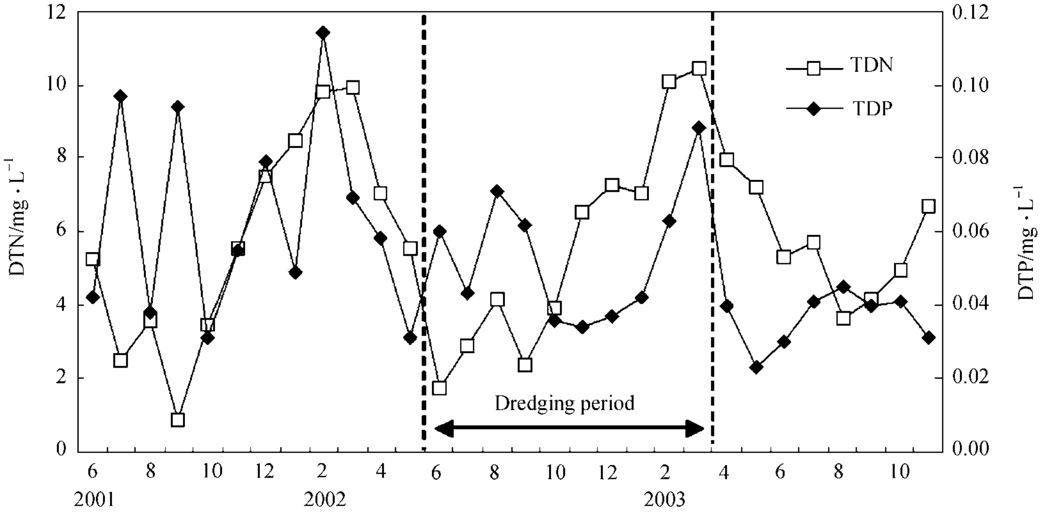

Fig. 5. The variations of nitrogen and phosphorus contents in Wuli Lake in pre- and post-dredging.

sediment will accelerate the sediment interface processes and boost the transformation to the status in pre- dredging. The organic content in Xuanwu Lake is as high as 11.9% with the loss of ignition (LOI) and TP is between 0.12% and 0.43%[9], in which 76% is inorganic phosphorus and 40% of inorganic phosphorus is iron-bounded phosphorus. With the time passing on, microbes will be propagated. The aerobe, facultative anaerobe and anaerobe in the sediment will transform the sedimentary phosphorus (mainly organic phosphorus) in layers. And the iron-bounded phosphorus in anaerobic condition will be dissolved into the pore water because of the transformation of Fe^{3+} to Fe^{2+}. It will result in a greater gradient phosphorus content between the pore water and the overlying water and hence accelerate the PO_4^{3-} to diffuse[20], which will make the dynamic balance be dominated by internal releasing. Moreover, the sediments with higher nutrient content are easily to be activated by polluted environment. For example, in Wuli Lake, in Aug. 2002 (11 months after dredging) the phosphorus concentration in the lake water was basically controlled at lower level, but the water pollution in Xuanwu Lake was much more serious than Wuli Lake. Only within 7 months after dredging, in Mar. 1998, the phosphorus concentration in the lake water began to increase gradually, by which the whole dredging effect was severely affected.

3 Conclusion

The surficial sediment dredging of polluted lakes will generally have an obvious effect in controlling the internal loading in the beginning period and the objective pollutant content in the lake water will greatly decrease at once. But with the time passing on, no matter whether using traditional dredging or precise dredging technology or not, the pollutant content in the lakes will be reversed after jump lapse of the internal loadings. The reversible components are different, depending on the surficial sediment property of lakes.

The difference of dredging methods and quality will greatly affect the internal loading control, concretely expressing the amount of the residual sediments on the newborn surface and the precise dredging depth. The newborn surficial sediments will be bio-activated by the residual sediment through “inoculation” effect in a short time. Moreover, the precipitation, dynamic disturbation and biotransformation effects in the surficial biogeochemistry process will make great impact on the internal loadings after dredging.

Nowadays, most of suburb lakes in the eastern China and the plateaus of Yunnan and Guizhou Provinces face the water and/or sediment pollution. Some dredging plans are just brewed or will be put into practice in the big lakes such as Taihu Lake and Chaohu Lake. It is necessary to consider the adopted dredging methods, study on the physical-chemical characters of the lake sediments, and predict the environmental effect of dredging.

Although by the core method adopted in this paper, the internal releasing can be simulated under control, the experiment system is limited by scale, usually not enough to reflect the actual condition by wall-effect. In addition, the static state method can not entirely display the dynamic situation and biologic action on sediment-water interface in disturbing shallow lakes. So the experiment precision will be affected and these problems need to be ulteriorly studied.

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References

1. Ogawa, H., Water-purification measures within Lakes, in Proceedings of 6th International Conference on the Conservation & Management of Lakes-Kasumigaura' 95 (eds. Hashimoto, M., Yamazaki, K.), Tsukuba: ILEC, 1995, 859—863.
2. Desprez, M., Physical and biological impact of marine aggregate extraction along the French coast of the Eastern English Channel: short and long-term post-dredging restoration, ICES Journal of Marine Science, 2000, 57: 1428—1438.[DOI]
3. Sebetich, M. J., Ferriero, N., Lake restoration by sediment dredging, Verh. -Int. Ver. Theor. Angew. Limnol., 1997, 26(2): 776—781.
4. Ogiwara, K., Morgi, K., The purification of Lake Suwa (dredging), in Proceedings of 6th International Conference on the Conservation & Management of Lakes-Kasumigaura'95 (eds. Hashimoto, M., Yamazaki, K.), Tsukuba: ILEC, 1995, 438—441.
5. Ruley, J. E., Rusch, K. A., An assessment of long-term post-restoration water quality trends in a shallow, subtropical, urban hypereutrophic lake, Ecological Engineering, 2002, 19: 265—280.[DOI]
6. Pu Peimin, Wang Guoxiang, Hu Chunhua et al., Can we control lake eutrophication by dredging? Journal of Lake Sciences (in Chinese with English abstract), 2000, 12(3): 269—279.
7. Jin Xiangcan, Lakes in China (2nd ed.) (in Chinese), Beijing: Ocean Press, 1995, 620—621.
8. Luo Qingji, Shi junze, Silt and ecological dredging of the Wulihu Lake, Management and Technology of Environment Monitoring (in Chinese with English abstract), 2003, 15(1): 27—29.
9. Wang Tingjian, Su Rui, Jin Xiangcan et al., The effects to water quality of phosphorus loading and release in the sediments of urban eutrophic lakes, Research of Environmental Sciences (in Chinese with English abstract), 1994, 7(1): 12—19.
10. Fan Chengxin, Qin Boqiang, Sun Yue, Substance exchange across water-sediemnt interface in Meiliang Bay and Wuli Lake, Journal of Lake Sciences (in Chinese with English abstract), 1998, 10(1): 53—58.
11. Webster, I. T., Teasdale, P. R., Grigg, N. J., Theoretical and experimental analysis of peeper equilibration dynamics, Environ. Sci. Technol., 1998, 32: 1727—1733.
12. Huang Xiangfei, Observation and Analysis of Lake Ecology (in Chinese), Beijing: China Criterion Press, 1999, 47—61.
13. Fan Chengxin, Yang Longyun, Zhang Lu, The vertical distributions of nitrogen and phosphorus in the sediment and interstitial water in Taihu Lake and their interrelations, Journal of Lake Sciences (in Chinese with English abstract), 2000, 12(4): 359• 366.
14. Li Yuan, Historical dredging projects of Xuanwu Lake, Nanjing Historical Record (in Chinese), 1998, 2: 27—29.
15. Fan, C., Aizaki, M., Kohata, K., Simulation of sludge dredging effects in controlling nutrient release of Lake Kasumigaura with large size core samples, J. Environ. Sci., 1996, 8(4): 385—399.
16. Lourey, M. J., Alongi, D. M., Ryan, D. A. J. et al., Variability of nutrient regeneration rates and nutrient concentrations in surface sediments of the northern Great Barrier Reef shelf, Continental Shelf Research, 2001, 21: 145—155.[DOI]
17. Jennings, A. A., Modeling sedimentation and scour in small urban lakes, Environmental Modelling & Software, 2003, 18: 281—291.[DOI]
18. Qin Boqiang, Hu Weiping, Gao Guang et al., Dynamics of sediment resuspension and the conceptual schema of nutrient release in the large shallow Lake Taihu, China, Chinese Science Bulletin, 2004, 49(1): 54—64.
19. Li Wenchao, Chen Kaining, Wu Qinglong et al., A preliminary study on phosphorus saturation of the top sediment in East Taihu Lake, Journal of Lake Sciences (in Chinese with English abstract), 1998, 10(3): 49—54.
20. Petticrew, E. L., Arocena, J. M., Evaluation of iron-phosphate as a source of internal lake phosphorus loadings, The Science of the Total Environment, 2001, 266: 87—93.[DOI]

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