Study on the changes of nitrogen and phosphorus release with time from sediment in Taihu Lake after ecological dredging

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Abstract: The changes of nitrogen and phosphorus release with time from sediment in Taihu Lake after ecological dredging were tested in laboratory. Experiment results showed that in a simulated environment of Taihu Lake, dredging was effective to reduce the endogenous pollution release, and the effect weakened gradually along with time. When the velocity of flow increased, nitrogen and phosphorus release intensity increased, so did the largest nitrogen and phosphorus emission. Considered the resedimentation, the release of nitrogen and phosphorus were similar in the area of five years after dredging and just dredging. Re-dredging should be considered.

1. Introduction
Taihu is the third largest fresh water lake in China. But eutrophication of the lake is getting worse with the developing of the economy. The release of nitrogen and phosphorus was considered as one of the reasons of eutrophication [1,2]. The government takes a lot of actions to cut down the pollutants. Ecological dredging was carried out since 2008, to reduce the risk of endogenes is release.

Plenty of researches were carried on about endogenesis release and ecological dredging. But generally, the researches include: 1) the relationship between flow velocity and release amount of sediment[3,4], 2) the changes of internal load in Taihu lake before and after dredging[5,6]. These studies are significant to the research on the secondary sediment release rule and the impact of dredging to sediment nutrients release, but not able to reveal the sediment nitrogen and phosphorus release law along with time after dredging.

Based on the endogenesis release of sediment from area of different time after dredging test and three different water flow conditions, sediment nitrogen and phosphorus release process is discussed in the paper, which make great significance for the evaluation on the effect of the Taihu Lake ecological dredging along with time as well as the guidance to carry out follow-up ecological dredging.

2 Materials and methods

2.1 Sample collection and analysing
Water and sediment samples were collected at Zhushan bay and Meiliang bay in october 2014. Five spots were set according to the completion time of dredging, as showed in fig. 1: 1# point (Zhushan bay, 31°24′45″N, 120°2′57″E, just dredging), 2# point (Meiliang bay, 31°28′35″N, 120°9′31″E, dredging completed for 1 year), 3# point (Meiliang bay, 31°29′39″N, 120°11′54″E, dredging completed for 3 years), 4# point (Meiliang bay, 31°29′2″N, 120°10′59″E, dredging completed for 5 years), 5# point (Meiliang bay, 31°31′57″N, 120°10′54″E, no dredging).
With a clamshell-like mud logger acquisition, sediment of lakebed was collected and put into sample bags, then stored at 4.0 °C freezer until ready to use; water samples were collected from Taihu Lake at the sample point, and were put into clean polyethylene plastic buckets, stored in the laboratory at 5.0 °C freezer. TN and TP of sediment and water were determinated and listed in Tab. 1.

| Dredging completed time | water pollutant content (mg/L) | surface sediment pollutant content (mg/kg) |
|-------------------------|-------------------------------|------------------------------------------|
|                         | TN                            | TP                                       |
| Just dredging           | 1.717                         | 0.144                                    |
| 1 year ago              | 2.47                          | 0.168                                    |
| 3 years ago             | 2.31                          | 0.168                                    |
| 5 years ago             | 2.594                         | 0.168                                    |
| No dredging             | 2.373                         | 0.154                                    |

2.2 Sediment releasing test set

2.2.1 Experimental installation. PMMA flume was used to carry out the test, and its schematic diagram and photo were shown in Fig 2. Each flume is 72cm high and 12cm width, the internal baffle consists of 80cm rectangular glass sheets and semicircular glass sheets in 20cm diameter. When the experiment starts, an air pump is used to push the overlying water flow by changing power of the pump, and the flow velocity of the overlying water is adjusted by the change of power to reach the experiment set.
2.2.2 Experiment settings. Some studies\textsuperscript{[7,8]} have shown that the average water temperature of Taihu Lake is 18 °C, therefore, the experiment can be carried out at room temperature (about 20 °C). According to the ratio of mud to water in the experiment of nitrogen and phosphorus release\textsuperscript{[9,10]}, the average flow rate (about 2cm/s) and maximum flow rate (about 6-7cm/s) in the Taihu Lake survey\textsuperscript{[8]}. 1kg dried sediment samples from the areas of no-dredging, just dredging, dredging 1 year ago, dredging 3 years ago and dredging 5 years ago, were placed into the annular flume, and 100L simulation lake water was added into the flume. Water flow rate was set to 0, 2.8cm/s and 5.8cm/s respectively, then sediment nitrogen and phosphorus release were measured under various conditions.

Each experiment carried out for 16 days. The TN, TP concentration of the overlying water was measured once every two days. 100mL of water was collected every time, and then 100mL of simulation lake water was added into the flume. In order to ensure the reliability and rationality of experimental data, two sets of parallel experiments were carried out, and the average values of the tests were used.

2.3 Calculation method of $N, P$ release intensity
The release intensity of $N, P$ from sediment was calculated in following formula\textsuperscript{[7,11]}.

$$
\gamma = V(C_N - C_0) + \sum_{j=1}^{n} V_n (C_{j-1} - C_0) , \quad R = \gamma / t_A , \quad \gamma' = \gamma / A
$$

$V$ is the volume of water above the mud sample (L); $C_N$ is the nutrient concentration in the $N$-th sampling water (mg / L); $C_0$ is the initial nutrient concentration in water (mg / L); $V_n$ is the volume of each water sample ($V_n = 100mL$); $C_j$ is the nutrient concentration in the $j$-th sampling water (mg / L); $C_0$ is the nutrient concentration in water after 100mL simulation water added; $t$ is the release time (d); $A$ is the area of sediment where contacts with water ($m^2$); $\gamma$ is the release amount of each water sample (mg); $\gamma'$ is the release intensity (mg / $m^2$); $R$ is the average release rate (mg / ($m^2 \cdot d$)).

3 Result and analysis

3.1 $N$ and $P$ release under the different flow rate

3.1.1 $N$ and $P$ release under the static condition. In the condition of 20 °C temperature and overlying water static, nitrogen and phosphorus release situation of sediment is shown in Figure 3, Figure 4.

![Fig.3氮累积释放强度曲线图](image1)

![Fig.4磷累积释放强度曲线图](image2)

As shown in Fig. 3 and 4, under the static conditions, the differences of the nitrogen cumulative release intensity in different areas were inconspicuous during the initial period of the experiment. After 10 days of experiment, the nitrogen cumulative release intensities of sediment from areas of just dredging, dredging 1 year ago, dredging 3 years ago remained stability or decreased those of never dredging and dredging 5 years ago still increased. In the experiments of phosphorus release, the cumulative release intensities of sediment from the areas of never dredging and dredging 5 years ago always greater than others during the entire period of the experiment.
Compared with those without dredging area, nitrogen release intensities in the areas of just dredging, dredging 1 year ago, 3 years ago and dredging 5 years ago, reduced 25.5 %, 23.5%, 29.4% and 0%, respectively; phosphorus release intensities decreased 33.9%, 26.4%, 23.4% and 11.4% respectively.

3.1.2 N and P release under a flow rate of 2.8cm/s condition. In the condition of 20 ℃ and flow rate of 2.8cm/s, nitrogen and phosphorus cumulative release intensity of sediment is shown in Fig. 5, Fig.6.

![Fig. 5 Nitrogen cumulative release intensity under a flow rate of 2.8cm/s](image)

As can be seen from Fig.5, it is relatively similar that the nitrogen release law in area of just dredging and dredging 1 year ago, as well as dredging five years ago and without dredging area. In comparison with the other three regions, the nitrogen release intensities in areas of just dredging and dredging 1 year ago are higher at the beginning of the experiment, but reach to balance in a short period of time, and at end of the experiment, the total cumulative release intensities are lower. Compared with those without dredging area, nitrogen release intensities in areas of just dredging, dredging 1 year ago, 3 years ago and dredging 5 years ago reduced 28.0%, 17.3%, 18.3% and 6.2%.

Fig.6 showed that the phosphorus release law is similar in the areas of just dredging; dredging 1 year ago and dredging 3 years ago, and the release law of other two areas is similar. The phosphorus release intensities in the areas of no dredging and dredging five years ago are greater than other three areas, but the time of reaching release balance is approaching. Compared with those without dredging area, phosphorus release intensities in areas of just dredging, dredging 1 year ago, 3 years ago and dredging 5 years ago reduced 29.1%, 23.7%, 18.2% and 3.2%.

3.1.3 N and P release in a flow rate of 5.8cm/s condition. In the condition of 20 ℃ temperature and 5.8cm/s flow rate overlying water , nitrogen and phosphorus release situation of sediment is shown in Figure 7, Figure8.

![Fig. 7 Nitrogen cumulative release intensity under a flow rate of 5.8cm/s](image)

As can be seen from Figures 7 and 8, when flow rate increased to 5.8cm/s, compared with those without dredging area, the final cumulative release intensities of nitrogen in areas of just dredging,
dredging 1 year ago, 3 years ago and dredging 5 years ago, reduced 33.8%, 11.3%, 27.2% and 6.0%. Similarly, the final cumulative release intensities of Phosphorus reduced 11.8%, 14.9%, -1.8% (namely increased 1.8%) and 5.9%.

The effect of controlling endogenesis release was weakened by the increasing of flow rate, especially the phosphorus release. The difference of cumulative release intensities of phosphorus between area of dredging and the area of no-dredging was inconspicuous.

3.2 The max. Cumulative N and P release intensity
During the experiment, the maximum cumulative nitrogen and phosphorus release intensity was recorded, as shown in Table 2.

| Tab.2 Max. cumulative N and P release intensity (mg/m²) |
|---------------------------------|-----------------|---------------|---------------|---------------|---------------|
| Content                        | flow velocity   | just          | 1 year after  | 3 years after | 5 years after |
|                                |                 | dredging      | dredging      | dredging      | dredging      |
| Nitrogen max. cumulative       | static          | 8.9           | 8.9           | 7.9           | 10.3          | 11.2          |
| release intensity              | 2.8cm/s         | 16.9          | 21.7          | 17.9          | 23.0          | 24.3          |
| Phosphorus max. cumulative     | static          | 10.8          | 11.4          | 12.2          | 13.3          | 13.6          |
| release intensity              | 2.8cm/s         | 14.1          | 14.9          | 16.6          | 19.4          | 18.4          |
|                                | 5.8cm/s         | 20.1          | 23.6          | 23.6          | 25.3          | 24.9          |

When the flow rate increased from 0cm/s to 2.8cm/s, in the areas of just dredging, dredging 1 year ago, dredging 3 years ago, dredging 5 years ago and no-dredging, the maximum nitrogen cumulative release intensities respectively increased 35.65%, 58.93%, 66.06%, 43.92% and 43.13%, and the maximum phosphorus cumulative release intensities increased 31.57%, 31.07%, 36.19%, 54.50% and 54.30% respectively. When the flow rate increased from 2.8cm/s to 5.8cm/s, the maximum nitrogen cumulative release intensities respectively increased 39.86%, 53.16%, 36.19%, 54.50% and 54.30%, and the maximum phosphorus cumulative release intensities increased 42.31%, 58.80%, 42.21%, 30.95% and 35.74% respectively.

It might be the following reason why sediment nitrogen and phosphorus maximum cumulative release intensity increases with the growth of flow rate. First, the shearing force the sediment received increases with the growth of the flow rate. The soil surface dislocation occurs with the water, the aerobic layer of mud suspends, the nutrients absorbed in sediment particles release to the water. In the same time, the lower sediment layer is exposed because of the upper mud suspension, so that the nitrogen dissolved in the lower sediment pore water also can be released\textsuperscript{[12]}

The second, the DO concentration increases with the growth of the flow rate, so that the process of nitrification or denitrification is improved, the nitrogen transformation is fasted\textsuperscript{[13,14]}. The re-suspension of particles enhances the phosphorus exchange between the mud surface and the water, and the diffusion of the interstitial water in sediment which can increase the phosphorus release\textsuperscript{[15,16]}.

4 Conclusions
With the sediment from the area of just dredging, dredging 1 year ago, dredging 3 years ago, dredging 5 years ago and no-dredging, the nitrogen and phosphorus release under different flow rate was studied. Following conclusions can be made. (1) Dredging is an effective way to the control of endogenous pollution release in Taihu Lake, but the control effect tend to weaken gradually along with the time after dredging. (2) The nutrient release intensity increases with the growth of the flow rate. (3) At circumstances of three flow rate, the nutrient cumulative release intensities in the areas of just dredging and dredging 1 year ago were far smaller than that in no-dredging area. But in the areas of dredging 3 years ago and 5 years ago, especially the latter, the release intensity was close to that of sediment from no-dredging area. So the frequency of dredging should be set to the maximum of 5 years.
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References
[1] Fan C. X., Zhang L., Qin B. Q., Hu W. P., Gao G., Wang J. J., 2004. Migration Mechanism of Biogenic Elements and Their Quantification on the Sediment-water Interface of Lake Taihu: I. Spatial Variation of the Ammonium Release Rates and Its Source and Sink Fluxes[J]. Journal of Lake Science, 16(1),10-20 (in Chinese).
[2] Fan C. X., Zhang L., Bao X. M., You B. S., Zhong J. C., Wang J. J., Ding S. M., 2006. Migration mechanism of biogenic elements and their quantification on the sediment-water interface of lake Taihu: II. Chemical thermodynamic mechanism of phosphorus release and its source-sink transition. Journal of Lake Science, 18(3), 207-217 (in Chinese).
[3] Wang F., Pang Y., Han T., Li Y. P., 2009. Release and transportation of internal nutrients in Tai Lake. Environmental Pollution & Control, 31(1), 21-25 (in Chinese).
[4] Hu K. M., Pang Y., Yu H., Wang H., 2011. Study on the law of sediment release in lake Taihu. Environmental Science & Technology, 34(12H), 7-12 (in Chinese).
[5] Mao Z. G., Gu X. H., Lu X. M., Zeng Q. F., Gu X. K., Li X. G., 2014. Ecological effects of dredging on aquatic ecosystem in the different regions of eastern Lake Taihu. Journal of Lake Science, 26(3), 385-392 (in Chinese).
[6] Zhong J. C., Liu G. F., Fan C. X., Zhang L., Ding S. M., Ren X. L., 2009. Environmental effect of sediment dredging in lake(I): the role of sediment dredging in reducing internal phosphorus release. Journal of Lake Science, 21(1), 84-93 (in Chinese).
[7] Yuan J. X., Huang Y. P., 1993. Preliminary study of pollutant load in the rivers around Taihu Lake[J]. Oceanologia ET Limnologia Sinica, 24(5), 485-493 (in Chinese).
[8] Luo L. C., Qin B. Q., Zhu G. W., Zhang Y. L., Ji J., 2004. Current circulation pattern in winter Meiliang Bay, Lake Taihu[J]. Journal of Lake Science, 16(1), 73-76 (in Chinese).
[9] Lei J. S., Hong M., Liu H. L., Zheng H. T., Wang X. N.,2014. Research of influence factors of TN, TP and COD release from Songhua Lake sediment. Water Saving Irrigation, 8, 45-52 (in Chinese).
[10] Zhu J., Li H. D., Wang P., 2009. The impact of environmental factors on COD, TN, TP release from sediment. Technology of Water Treatment, 35(8), 44-49 (in Chinese).
[11] Jin X. C., Tu Q. Y., 1990. Survey Standards of Lake Eutrophication (2nd Edition), China Environmental Press (in Chinese).
[12] Zhu Y. Q., 2014. Study on the releasing of nutrient from sediment of Dianshan Lake and its influencing factors. Environmental Pollution & Control. 36(5), 70-77 (in Chinese).
[13] Mo Z. L., Shao W. Y., Liu X. W., 2014. Effects of natural and water diversion factors on self-purification of the receiving waters. Bulletin of Sci. & Tech. 20(9), 202-207 (in Chinese).
[14] Bryan M. S., Laurence C., Rupert P., David M. P., 2008. Effects of light on sediment nutrient flux and water column nutrient stoichiometry in a shallow lake. Water Research. 42(4), 977-986.
[15] Fan J. Y., Wang D. Z., Zhang K., 2010. Experimental study on a dynamic contaminant release into overlying water-body across sediment-water interface. Journal of Hydrodynamics. Ser. B, 22(5), 354-357.
[16] Yin Q. F., Sun J., Jin D., Bian H. X., Xu P., Lu J., Wu C. L., 2009. Morphology distribution of phosphorus in Hongze Lake sediment and its effect on water body. Journal of Anhui Agri. Sci. 37(12), 5631-5633 (in Chinese).