Science of the Total Environment xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Evaluation of simulated dredging to control internal phosphorus release from sediments: Focused on phosphorus transfer and resupply across the sediment-water interface

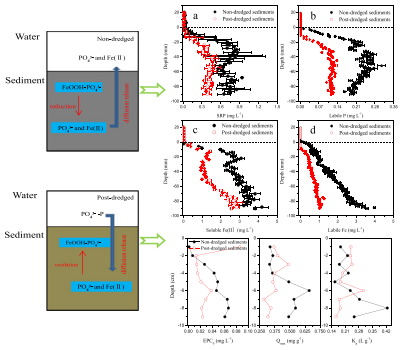
Juhua Yu [a,b], Shiming Ding [a], Jicheng Zhong [a,*], Chengxin Fan [a], Qiuwen Chen [b], Hongbin Yin [a], Lei Zhang [a], Yinlong Zhang [c]

[a] State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Number 73 Beijing East Road, Nanjing 210008, People's Republic of China
[b] CEER, Nanjing Hydraulic Research Institute, Nanjing 210029, People's Republic of China
[c] Laboratory of Forestry Ecological Engineering of Jiangsu Province, Nanjing Forestry University, Nanjing 210037, People's Republic of China

HIGHLIGHTS

- Evaluation of dredging was performed based on a one-year field simulation study.
- Dredging decreased the concentrations of P in pore waters and its release to water.
- Dredging reduced the resupply ability of internal P in the upper 20mm sediment.
- The upper 20mm sediments had higher ability to adsorb and retain P after dredging.
- Iron redox cycling of the upper 20mm sediment controlled internal P regeneration.

GRAPHICAL ABSTRACT



The probable mechanism of dredging on effectively controlling sediment internal P release to overlying waters is primarily to the removal of surface sediments rich in TP and/or OM combined with inactivation of P to iron (Fe) (hydr)oxides in the upper 20mm active layer sediments. Variations of SRP and soluble Fe (II) (a, c) measured by HP-Peepers and labile P and Fe (b, d) measured by DGT with depths in non-dredged and post-dredged sediments at the end of experiment. The location of the sediment-water interface is represented by zero. Values are means ±SD of three replicates. Variations of adsorption isotherm parameters with sediment depths using the nonlinear form of the Langmuir equation in non-dredged and post-dredged sediment profiles at the end of experiment.

ARTICLE INFO

Article history:
Received 3 January 2017
Received in revised form 27 February 2017
Accepted 27 February 2017
Available online xxxx

ABSTRACT

Sediment dredging is an effective restoration method to control the internal phosphorus (P) loading of eutrophic lakes. However, the core question is that the real mechanism of dredging responsible for sediment internal P release still remains unclear. In this study, we investigated the P exchange across the sediment-water interface (SWI) and the internal P resupply ability from the sediments after dredging. The study is based on a one-year field simulation study in Lake Taihu, China, using a Rhizon soil moisture sampler, high-resolution dialysis (HR-

Abbreviations: P, phosphorus; TP, total phosphorus; SRP, soluble reactive phosphorus; loose-P, loosely bound P; Fe-P, Fe-adsorbed P; Al-P, Al-adsorbed P; Org-P, organic P; Ca-P, Ca-bound P; Fe, iron; Al, aluminum; Ca, calcium; Mn, manganese; OM, organic matter; LOI, loss on ignition; APA, alkaline phosphatase activities; AVS, acid volatile sulfide; FDA, fluorescein diacetate; EPC_0, zero equilibrium P concentration; K_p, partitioning coefficient; Q_{max}, adsorption capacity; SWI, sediment-water interface; Rhizon SMS, Rhizon soil moisture sampler; HR-Peeper, high-resolution dialysis; ZrO-Chelex DGT, ZrO-Chelex diffusive gradients in thin film; DET, diffusive equilibrium in thin films; C_{DGT}, DGT-measured concentration; C_{HP}, HR-Peeper measured concentration.

* Corresponding author.
E-mail addresses: smding@niglas.ac.cn (S. Ding), jczhong@niglas.ac.cn (J. Zhong), cxfan@niglas.ac.cn (C. Fan), qwchen@nhri.cn (Q. Chen), hbyin@niglas.ac.cn (H. Yin), leizhang@niglas.ac.cn (L. Zhang), ecoenvylz@163.com (Y. Zhang).

http://dx.doi.org/10.1016/j.scitotenv.2017.02.219

Editor: F.M. Tack

Keywords:
Sediment dredging
Phosphorus
Release flux
Sediment-water interface
ZrO-Chelex DGT
Lake Taihu

Peeper), ZrO-Chelex diffusive gradients in thin film (ZrO-Chelex DGT), and P fractionation and adsorption isotherm techniques. The results showed low concentration of labile P in the pore water with a low diffusion potential and a low resupply ability from the sediments after dredging. The calculated flux of P from the post-dredged sediments decreased by 58% compared with that of non-dredged sediments. Furthermore, the resupply in the upper 20mm of the post-dredged sediments was reduced significantly after dredging ($P<0.001$). Phosphorus fractionation analysis showed a reduction of 25% in the mobile P fractions in the post-dredged sediments. Further analysis demonstrated that the zero equilibrium P concentration (EPC_0), partitioning coefficient (K_p), and adsorption capacity (Q_{max}) on the surface sediments increased after dredging. Therefore, dredging could effectively reduce the internal P resupply ability of the sediments. The reasons for this reduction are probably the lower contributions of mobile P fractions, higher retention ability, and the adsorption capacity of P for post-dredged sediments. Overall, this investigation indicated that dredging was capable of effectively controlling sediment internal P release, which could be ascribed to the removal of the surface sediments enriched with total phosphorus (TP) and/or organic matter (OM), coupled with the inactivation of P to iron (Fe) (hydr)oxides in the upper 20mm active layer.

1. Introduction

Eutrophication has become a global environmental problem that poses a series of threats to the aquatic ecosystem, including frequent harmful algal blooms, hypoxia and fish kills, taste and odor problems, and restriction of the drinking water supplies (Conley et al., 2009; Carpenter, 2005; Jin, 2003; Smith et al., 1999). Phosphorus has been identified as the crucial element responsible for freshwater eutrophication and the occurrence of algal blooms (Schindler, 1977; Krom et al., 1991). Sediment has been identified as a major source of phosphorus to the overlying water by releasing P from a large mobile P-pool and resupplying P from the sediment (Correll, 1998; Smolders et al., 2006; Ding et al., 2010). In addition, internal loading causes water bodies to remain in an eutrophic state for several decades, even when the external P input had been controlled effectively (Jiang and Shen, 2006; Søndergaard et al., 1992). Various restoration approaches have been applied over the last decades to reduce the internal P pollution and improve the water quality of lakes. These approaches include *in situ* capping (Pan et al., 2012), artificial circulation (Funes et al., 2016), hypolimnetic aeration (Dittrich et al., 2011), co-precipitation of P with Fe and Al salts (Wang et al., 2015; Yin et al., 2013; Hansen et al., 2003), and sediment dredging (Gustavson et al., 2008). Sediment dredging is an important eco-engineering remediation measure, employed to remove permanently the contaminated uppermost sediments from the lakes. However, the value of sediment dredging is still being debated, as the effectiveness of this technique has not yet been proven conclusively (Pu et al., 2000). An ongoing debate discusses the efficacy of dredging, as well as the degree to which the technique can reduce risks to biological health and the aquatic environment.

Literature on the effects of dredging on the control of nutrients is quite limited (Gustavson et al., 2008). More attention has been focused on the possible harm that dredging could cause by changing the sediment resuspension and transport processes (Yu et al., 2012), as well as by releasing persistent organic pollutants (POPs) and heavy metals, following the removal of the contaminated sediment (Bremle and Larsson, 1998; Bowman et al., 2003; Van den berg et al., 2001). Concerns have been raised about the long-term effectiveness of dredging on internal contaminant control (Kleeberg and Kohl, 1999; Reddy et al., 2007). At present, the effectiveness of dredging on the release of P is still unclear. Most of the relevant research has been conducted by means of field studies (Fan et al., 2004; Wang and Feng, 2007), laboratory simulation (Spencer et al., 2006; Zhong et al., 2008), and modeling experiments (Yenilmez and Aksoy, 2013). These approaches were used to determine the P concentrations in pore water and overlying water, based only on flux calculations or instantaneous measurements (Wang and Feng, 2007). The results of the various studies have pointed out contradictions, especially on the most effective way to decrease the internal P loading (Yenilmez and Aksoy, 2013; Reddy et al., 2007). Some studies have reported a rise in the P loading (Pu et al., 2000), whereas some showed decrease, the others have shown no obvious changes (Lohrer and Wetz, 2003). These discrepancies could be attributed to the widely varied nature of the chemicals in the sediments, the measurement methods employed, and the different experimental designs used in these studies, which have made cross-system comparison difficult.

Uncertainties relevant to dredging projects have raised a question on how long the beneficial effects of dredging could be sustained (Fan et al., 2004; Pu et al., 2000; Yoshida, 1982). Actually, the essence of these uncertainties is mainly the lack of direct evidence to indicate the real mechanisms responsible for the P release from the sediments that is induced by dredging. Theoretically, the dynamic P release from sediments to the overlying water are subjected to two basic processes: 1) the diffusion process of pore water P, which depends on the concentration gradients between the sediment-water interface (SWI); and 2) the resupply process of solid P to the pore water by the release of P from the binding sites of the sediment solids (Ding et al., 2015). Obviously, a few published studies have addressed the effectiveness of dredging on the P diffusion potential, based on the pore water P profiles (Zhong et al., 2008; Fan et al., 2004). However, to the best of our knowledge, the published studies have not addressed the effects of dredging on the ability of P to regenerate internally from the sediment solids. To date, only fragmentary studies have focused on sediment P fractions, affording some rudimentary insight into the P mobility of sediment and the P resupply potential from the sediments (Kleeberg and Kohl, 1999; Reddy et al., 2007; Jing et al., 2015). In fact, the internal P release from sediments is a complicated process. Published studies on the effects of dredging on the release of P from the sediment have not revealed either the mechanism responsible for the sediment P diffusion potential or the regeneration ability induced by the dredging. Likewise, the effects of dredging on P cycling near the SWI have not been thoroughly investigated. Generally, the mechanisms responsible for P release from the sediments involve various physical, chemical, and biological processes, such as temperature, dissolved oxygen, redox potential, pH, nitrate, sulfate (Smolders et al., 2006), wind turbulence, bacterial activity, and enzymatic hydrolysis reactions (Amirbahman et al., 2003; Baldwin, 1996). In addition, the sediment contents are significant, including Fe, aluminum (Al), and calcium (Ca) (Amirbahman et al., 2003; Murphy et al., 2001; Penn et al., 2000). Most studies have emphasized the importance of the adsorption of P to iron oxyhydroxides (Einsele, 1936; Ohle, 1937; Mortimer, 1941), and sulfur (S) cycling through several plausible mechanisms (Caraco et al., 1989; Ding et al., 2012; Murphy et al., 2001).

In terms of methodology, most studies have adopted centrifugation, squeezing, sippers, and dialysis to reveal the P release processes in sediments after dredging (Yu et al., 2016; Fan et al., 2004). However, traditional chemical extraction methods cannot evaluate accurately the P