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Research article

# Influence of macrophytes on phosphorus fractionation in surface sediments in a constructed wetland: Insight from sediment compositions

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ABSTRACT

The effect of two widely distributed macrophytes, reed and cattail, on phosphorus fractionations (PFs) of surface sediments distributions from a near-nature constructed wetland were studied in both autumn and spring. The results showed that the average values of PFs in the sediments were ranked in the order of Ca-P > Org-P > Al-P ≈ Fe-P > Ex-P > O-P. The mobile PFs, such as Al-P, Fe-P, Ex-P and Org-P influenced the TP concentrations in macrophytes free area. Only Ca-P was related with TP in macrophytes covered area, indicating the P stability of reed community sediment (RCS) and cattail community sediment (CCS). The other compositions of sediments, i.e. organic matter (OM), alkaline phosphatase activity (APA), and active-Fe were greatly decreased in the presence of macrophytes, while active-Al were slightly increased. OM and active-Al were found to be more significant related with PFs in OWS and RCS, while APA and active-Fe were related with PFs in the macrophytes covered sediments. Therefore, macrophytes induced the variation of sediment compositions and further influenced the distributions and stabilization of PFs. Moreover, cattail community performed better in declining the sediment compositions, P accumulation and its release.



## 1. Introduction

Phosphorus (P) has been regarded as the common limiting factor responsible for eutrophication in aquatic ecosystems (Jin et al., 2006a,b,c; Zan et al., 2011; Wu et al., 2014; Chen et al., 2015; Wang and Liang, 2015). It is well understood that once introduced to aquatic ecosystems, P is accumulated in sediments, which are considered net sinks as well as sources of many organic and inorganic compounds (Rydin, 2000; Beutel, 2006; Dittrich et al., 2011; Lin et al., 2011; Wu et al., 2014). Sediment can contribute phosphate to the overlying waters at levels comparable to the external source (Jin et al., 2006a,b,c). However, not all the forms of P are labile and are likely to be released from the sediment and thereby increase eutrophication (Zhang et al., 2015). The bioavailability of P mainly depends on their forms and compositions in the sediment (Ahlgren et al., 2005). Research concerning the mobility of PFs is crucial for evaluating of the amount of phosphorus that can be released from the bottom sediments (Tuszynska et al., 2013; Maitra et al., 2015).

The factors influencing P release from sediments have been extensively studied (Jin et al., 2006a,b,c; Tuszynska et al., 2013; Chen et al., 2015). Relevant environmental factors are mainly classified as follow: firstly, physiochemical factors including temperature, pH, redox potential, DO, and hydrological conditions etc. (Tuszynska et al., 2013); secondly, phosphorus speciation in overlying water, such as dissolved P and particulate P (Chuai et al., 2011; Jin et al., 2013); thirdly, sediment compositions, for instance, organic matters (OM), alkaline phosphatase activity (APA) and active metal elements (Detenbeck and Brezonik, 1991; Liu et al., 2009; Jin et al., 2013; Tang et al., 2014); last but not least, organisms in the sediment ecosystems, such as benthic organisms, phosphate solubilizing bacteria and plants (Jin et al., 2006a,b,c; Maitra et al., 2015). More importantly, all the above-mentioned factors would be influenced by the presence of vegetation in aquatic ecosystems, such as reed and cattail (Duke et al., 2015; Schneider and Melzer, 2004; Wang et al., 2012). However, most of the previous literatures were focused on the effect of physiochemical factors and the influence without vegetation on PFs (Gomez et al., 1999; Liu et al., 2009; Vergeles et al., 2014; Wu et al., 2014; Wang and Liang, 2015; Zhang et al., 2015).

For almost three decades constructed wetlands have been extensively applied worldwide as an effective low-cost ecologi-

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cal technology for secondary, tertiary and, in some case the only treatment of wastewaters (Vergeles et al., 2014). Among those constructed wetlands, reed and cattail are two of the most frequent use of widely distributed macrophytes (Salem et al., 2014; Vergeles et al., 2014). Reed, due to an extensive root and rhizome system, had a high plasticity with respect to variable nutrient conditions and had higher production rates at lower P stocks (i.e., lower P concentrations) (Zak et al., 2014). Previous studies manifested that reed or cattail performed very well in removing pollutants from wastewaters (Duke et al., 2015; Klink et al., 2016; Łojko et al., 2015; Salem et al., 2014). However, lack of information was about the influences of reed or cattail on the processes of sediment formation, the modifying effect on the roots environment, sediment composition or further impact on P release (Vergeles et al., 2014). Fundamental information regarding systemic synchronous studies on PFs and P profile distributions in sediments of reed and cattail dominated area is limited which is going to be studied in the present study.

The objectives of this study were to (1) investigate the distributions and relationships of PFs in surface sediments of open water, reed and cattail community areas in different seasons in a near-nature constructed wetland, (2) analyze the influences of OM, APA, active Al and active Fe on the contents of PFs basing on statistical analysis. This research is trying to find the mechanism of macrophytes' effect on the distribution and release of PFs and to provide references for species selection and constructed wetlands management.

## 2. Materials and methods

### 2.1. Study area

The present study were conducted in a newly constructed wetland in two seasons, i.e. autumn (end of October of 2012) and spring (end of May of 2013). The wetland located in the south of the warm temperate zone semi humid region. It was established from a sunk coal mine in 2009 (named Qixinghu wetland, used to be called Quanshang wetland) locating in Tengzhou, Shandong province, China (Fig. 1). The total study area was around 0.2 $km^2$, with the east-west width of 1200 m and south-north length of 680 m. The inflow of Qixinghu wetland came from Cheng River. The direction of the flow was from north-east to south-west. The total phosphorus concentrations in the inflow was higher in spring than in autumn. The flux was controlled by the rubber dam with daily average flux of 0.188 $m^3/s$ during the study period. The flow velocity of the wetland can be found according to our previous research (Xu et al., 2012). The characteristics of the climate, inflow and removal efficiency can be found in Table 1.

As shown in Fig. 1, there were many kinds of plants in the wetland, including emerging plants (reed, cattail, lotus etc.), floating-leaved plants (duckweed, *Salvinia natans*, water chestnut, Gorgon fruit etc.) and submerged plants (watermifoil, hornwort, *Hydrilla varticillata*, eel grass, water caltrop etc.). Among these, the primary plants were reed and cattail. The distributions of reed and cattail were not mixed with other macrophytes. Meanwhile, due to the high density of reed and cattail, no clear floating plants or submerged plants were found in the sampling sites. At the end of October, the plants in the wetland were in the senescence stage, and the submerged leaves started to decompose. The above water leaves of the plants started to wither However, the roots of the reed and cattail were still alive and would start to grow once the next spring came. The over ground biomass and plant densities of reed and cattail were shown in Table 1. The developmental phases can be found Fig. S1.

### 2.2. Sample sites arrangement

For each season, seven transects were set following the flow direction for sampling the sediments (Fig. 1). For each transect, three kinds of sediments (0–5 cm) were collected, i.e. sediments in open water area (OWS, S1, S2. . . S7), reed community area (RCS, R1, R2. . . R7) and cattail community area (CCS, C1, C2. . . C7), and analyzed for investigating the distribution of PFs, OM, APA, active Al and active Fe. The detail description for each sampling sites can be found in Table S1. In general, S1 was located around the inflow with narrow terrain and high flow velocity of 0.8 m/s. S2 and S3 located in the forepart of the wetland with wide open water surface, higher water depth and reduced flow velocity (0.4 and 0.1 m/s for S2 and S3, respectively). S4 and S5 were in the middle of the wetland. The water surface became narrow again and the flow velocity increased as well (0.4 m/s). The flow at site S6 slowed down again (0.1 m/s), while the water depth was similar with site S4 and S5. S7 located in the effluent of the wetland which was surrounded by many plants with the flow velocity of 0.3 m/s. The flow velocity was decreased by the vegetation, with average flow velocity of 0.01–0.12 m/s (Table S1).

### 2.3. Analytical methods

All the sediment samples were kept in dark cryogenic box (2–8 °C) and brought back to the lab to be measured as soon as possible. The total phosphorous in water ($TP_w$), solubility reactive phosphorus (SRP), total dissolved phosphorous (TDP) and total organic carbon (TOC) were determined according to the standard methods (Wei et al., 2002). The content of OM was obtained by multiply 1.724 to the content of TOC. The active Fe content was measured by an atomic absorption spectrometry (AAS) after digesting the sample with DTPA solution (0.005 M DTPA-0.01 M $CaCl_2$-0.1 M TEA) (Bao, 2000). The active Al content was measured basing on the chromogenic reaction with aluminon (Wang, 1986). APA was measured using disodium phenyl phosphate colorimetric method (Kwon et al., 2011).

The air-dried sediments for measuring the PFs were grounded into powder and passed a 100 mesh sieve. The classified extraction of PFs in this study was based on Pierzynski's method (Pierzynski, 2000) and combined with Bao' method (Bao, 2000). The PFs included exchangeable phosphorus (Ex-P), Aluminum-bound phosphorus (Al-P), Iron-bound phosphorus (Fe-P), Occluded phosphorus (O-P), Calcium- phosphorus (Ca-P) and Organic phosphorus (Org-P). TP in the sediment was the sum of all PFs.

### 2.4. Statistic analysis

All the data shown in the tables and figures were the mean value of two repeats. One-way analysis of variance (ANOVA) and Pearson correlation analysis were performed in Statistical Package for the Social Science (SPSS, 17.0, Chicago, IL, USA) software. Mean values were separated by the least significant difference (LSD) test at 5% and 1% levels of significance, as indicated by * ($p < 0.05$) and ** ($p < 0.01$), respectively.

## 3. Results and discussion

### 3.1. Impact of macrophytes on PFs distributions and interact relationships

#### 3.1.1. Seasonal and spatial distributions of PFs

Fig. 2 showed the distributions of TP and PFs in the sediments in both autumn and spring. It was clear that TP concentrations in spring (538.44–3940.83 mg/kg) were higher than that in autumn (290.60–1078.22 mg/kg). There were three possible reasons for this