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RESEARCH ARTICLE

A study of bioavailable phosphorus in the inflowing rivers of Lake Taihu, China

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Abstract

Phosphorus (P) is a vital nutrient for algal growth. Aside from soluble reactive P (SRP), organic P (OP) is used by algae via alkaline phosphatase (AP) hydrolysis, which can play an important role in supplying P. Enzymatically-hydrolysable OP (EHP) can potentially be used as an indicator of bioavailability of P other than SRP in natural waters. We investigated the ecological significance of alkaline phosphatase activity (APA), EHP concentration and P turnover time in the inflowing rivers of Lake Taihu (Taihu) during three hydrologic periods. Results indicated high SRP concentration and low SRP demand by algal suppressed APA in the inflowing rivers, the highest proportion of OP mineralization rate (v) to the maximum reaction velocity of AP (V_{max}) is only 14.7%. P turnover time of the inflowing rivers was generally from 3 to 7 days and in exceptional cases, it could exceed 10 days. The high EHP reserve and the sufficient AP for OP mineralization render the rivers a significant source of utilizable OP, further exacerbating eutrophication of Taihu.

Keywords Eutrophication · Human sewage · Alkaline phosphatase activity · Organic phosphorus mineralization rate · Phosphorus turnover time · Hydrologic periods

Introduction

Eutrophication is one of the most challenging environmental problems in nutrient-enriched waters (Qin 2009; Smith and Schindler 2009; Wang and Wang 2009; Zhu et al. 2015; Schindler et al. 2016). It is generally accepted that key nutrient inputs include nitrogen (N) and phosphorus (P) (Hecky and Kilham 1988; Lowery 1998; Gurkan et al. 2006; Bhagowati and Ahamad 2018). Phosphorus is an essential element for plant growth and its input has long been recognized as necessary to maintain primary production. P is also a vital nutrient stimulating problematic harmful cyanobacterial blooms and so its control is of prime importance in mitigating the global proliferation of such blooms in freshwater ecosystems (Daniel et al. 1998; Schindler and Vallentyne 2008).

P in water can be separated into numerous forms, such as total P (TP), total dissolved P (TDP), organic phosphorus (OP), molybdate reactive P or soluble reactive P (SRP), molybdate unreactive P (Xie et al. 2011). Among the various forms of P, SRP is the most biologically available and readily usable for phytoplankton and bacteria (Cembella et al. 1982; Kwon et al. 2011). However, OP often represents the largest phosphorus pool in water and can greatly exceed SRP concentrations (Shun et al. 1994; Oh et al. 2005; Lin et al. 2018). OP may also be an important P storage for phytoplankton when depletion of SRP occurs in the surface water (Oh et al. 2002; Kwon et al. 2011; Lin et al. 2018).

Microbial utilization of OP through enzymatic hydrolysis is one of the most important pathways in the P cycle (Cembella et al. 1982; Suzumura et al. 1998). Alkaline phosphatase (AP)

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hydrolyzes OP to SRP under SRP depleted conditions (Kuenzler and Perras 1965; Jin et al. 2006; Xie et al. 2011; Li et al. 2015; Lin et al. 2018). Enzyme assays with soluble substrate showed that extracellular AP is important in providing P for phytoplankton growth, particularly during blooms induced by nutrient over-enrichment (Harke et al. 2012; Okubo et al. 2014; Ivančić et al. 2016). Alkaline phosphatase-hydrolyzable OP or enzymatically-hydrolysable OP (EHP) have potential use as indicators of bioavailability of P other than SRP in natural waters (Shun et al. 1994), and the enzyme plays an important role in P supply (Zhang et al. 2007). The most common practice to evaluate OP utilization under P limited conditions is to determine alkaline phosphatase activity (APA) (Hoppe 2003; Ryzhakov and Stepanova 2016).

Lake Taihu (Taihu) is the third largest freshwater lake in China, located in the Changjiang (Yangtze) Delta. It has a surface area of about 2338 km^2 and mean depth of 1.9 m (Qin et al. 2007). Taihu serves as a drinking water source for approximately 20 million local inhabitants and plays an important role in the Jiangsu Province economy. However, in recent decades, cyanobacterial blooms occur regularly from late spring through fall throughout the lake (Chen et al. 2003; Xu et al. 2015). P is the primary limiting nutrient in winter and spring in Taihu, while in summer and autumn N and P co-limit algal growth (Xu et al. 2010). Controlling P supply is thus a critical step in reversing eutrophication and the restoration of the lake (Zhu et al. 2013).

Inflowing rivers are a key source of nutrient pollution in Taihu (Zhao et al. 2011). Previous studies have shown that about 80% of the nutrients discharged to Taihu came from these rivers and surface runoff (Xie et al. 2007; Wang et al. 2011). Therefore, monitoring and controlling nutrient discharge from inflowing rivers is a necessary component of effective lake management (Zhao et al. 2011; Wang and Bi 2016).

Past research and development of water quality standards have focused on TP, TDP and SRP. However, few studies have investigated the contributions of EHP and APA to P cycling in rivers discharging to Taihu. In view of their potential ecological significance, we measured EHP, APA, OP mineralization rate (v) and P turnover time (t) in inflowing rivers of Taihu during various hydrologic periods. The objective of the study was to evaluate the rate of P turnover, P bioavailability and mobility. These results could help show the impact of inflowing rivers on Taihu's algal bloom potential.

Materials and methods

Sampling times and sites

The rainy season in the Taihu Basin begins in April, with water levels usually reaching their peak in late July, while the lowest water levels occur between February and March every year, according to long-term hydrology data from the Lake Taihu Basin Authority of Ministry of Water Resources (http://www.tba.gov.cn/channels/43.html). Therefore, we chose February, May and August 2009 to represent low, moderate and high flow periods. Samples were collected from 21 to 25 February, from 24 to 26 May and from 26 to 28 August of 2009. Nine rivers discharging to Taihu (30°55′40″–31°32′58″N; 119°52′32″–120°36′10″E) were selected for this study. In1 (Zhihu port), In2 (Hengtang river) and In3 (Wangyu river) are polluted by industry and they are located on the north side of Taihu. Se4 (Xujiang river), Se5 (Zhi port) and Se6 (Cao port) are polluted by domestic sewage and they are located on the east side of Taihu. Ag7 (Zhongtang river), Ag8 (Changxing port) and Ag9 (Jiapu port) are heavily influenced by agricultural pollution and they are located on the southwest side of Taihu (Fig. 1). Three sampling sites were set up along the upper, middle and lower reaches of each river, amounting to a total of 27 sample sites examined in our study. The downstream sampling sites were at the intersection of each river and Taihu.

Sample collection and laboratory analysis

Water samples were collected at 0.5 m below the surface. The transparency of water was measured by Secchi depth (SD). Water temperature, pH, dissolved oxygen (DO), turbidity and chlorophyll-*a* (Chl-*a*) were measured in situ using a Yellow Springs Instruments (YSI) 6600 V2 multisensor sonde. TP, TDP, SRP, EHP and APA were measured in the laboratory. TP and TDP were determined by persulfate digestion and then determined by spectrophotometry at 700 nm after reaction with molybdate, ascorbic acid, and trivalent antimony (Jin and Tu 1990). A flow-injection system (Skalar Co., http://www.skalar.com) was used to determine SRP concentrations in Whatman GF/F membrane-filtered water samples.

EHP was measured as follows: 1 mL 1.0 mol/L Tris buffer (pH 8.2) and 5 mL pure chloroform was added to 100 mL of initial water sample, with subsequent incubation at 30 °C for 5 days (Peters 1981; Chrost et al. 1986). Subsamples were filtered on Whatman GF/F filters, followed by SRP concentration measurements using a flow-injection system (Skalar Co., http://www.skalar.com). EHP concentration was calculated as the difference between the SRP concentration in the incubated subsample and the initial water sample. All samples were run in triplicate.

APA was determined by analyzing the production of *p*-nitrophenol (pNP) from model substrate *p*-nitrophenyl phosphate (pNPP) hydrolyzed by AP in the initial water samples (Berman 1970; Sayler et al. 1979; Joner et al. 2000). In the assay, 1 mL 0.5 mol/L Tris butter (pH 8.4) and 2 mL millimolar pNPP were added to 2 mL of sample, followed by

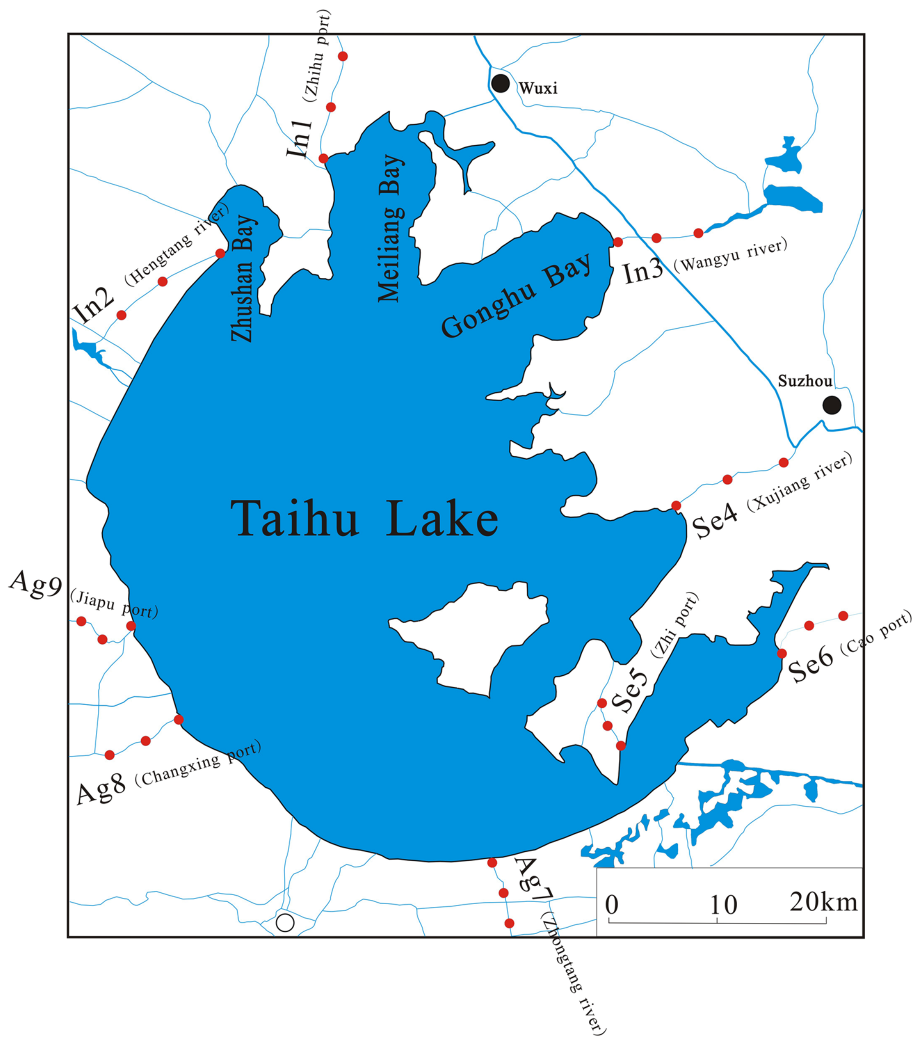

Fig. 1 Location of nine sampled rivers around Taihu and 27 sampling sites in the rivers

incubation at 30 °C for 6 h in the dark (Gao et al. 2006). The absorbance at 410 nm was measured and enzymatic activity was calculated from absorbance using a standard curve based on pNP. Eight gradient millimolar pNPP concentrations ranging from 0.02 to 2.0 mmol/L were chosen to determine the following kinetic constants and APA was determined at the final substrate concentration of 1.0 mmol/L. All samples were run in triplicate.

It was found that the reaction rate was determined by enzyme concentration and substrate concentration if other conditions remained constant. If enzyme concentration remains unchanged, the reaction rate presents a complex process of change when substrate concentration is changed. The Michaelis–Menten equation is a velocity equation of the relationship between the initial enzymatic reaction rate and substrate concentration of the enzymatic reaction. It includes the enzymatic reaction rate and other factors, such as inhibitors. The affinity between enzyme and substrate as well as potential reaction rate of extracellular AP hydrolysis can be inferred by using the Michaelis–Menten equation (Tabatabai and Bremner 1971; Manzoni and Porporato 2009; Allison et al. 2010; Wang and Post 2013; Hui et al. 2013):

$$v = V_{\max}[S] / \left(K_m + [S]\right)$$

where v (nmol/L/min) is OP mineralization rate; V_{max} (nmol/L/min) is the maximum reaction velocity of AP; K_m (μmol/L) is the Michaelis constant; $[S]$ (μmol/L) is substrate concentration. We used Lineweaver–Burk transformation ($\frac{1}{v} = \frac{K_m}{V_{\max}} \cdot \frac{1}{[S]} + \frac{1}{V_{\max}}$) of the Michaelis–Menten equation to calculate V_{max} and K_m (Zhou et al. 2004). K_m and V_{max} were computed by linear regression analysis on the values obtained in the assay (Han and Srinivasan 1969; Zhou et al. 2004; Xu et al. 2018). v was calculated by using K_m, V_{max} combined with the EHP as substrate concentration. P turnover time t (min) was calculated with EHP and v (Larionova et al. 2007; Tischer et al. 2015).

Mean value and standard deviation of the variation of the upper, middle and lower reaches of each river were all calculated using Microsoft Excel 2007 software. Pearson correlation coefficients were determined with a Statistical Program for Social Sciences (SPSS) 16.0 software. Significance levels were reported as significant ($0.01 \le p < 0.05$) or highly significant ($p < 0.01$).

Results

Dynamic parameters (K_m, V_{max}) of AP in the inflowing rivers of Taihu

Average K_m value of AP in the nine inflowing rivers ranged from 14 to 61 μmol/L during low flow period, from 19 to 52 μmol/L during moderate flow period and from 10 to 34 μmol/L during high flow period. The highest K_m values of AP appeared in rivers polluted by domestic sewage (Se4, Se5, Se6) and the lowest K_m values of AP appeared in rivers polluted by agriculture (Ag7, Ag8, Ag9) during the various hydrologic periods. A comparison of average SRP concentrations of the three types of rivers (Gao et al. 2016) shows that SRP concentrations in the rivers polluted by domestic sewage (Se4, Se5, Se6) contained the highest SRP and rivers polluted by agriculture (Ag7, Ag8, Ag9) were the lowest.

K_m values of AP showed no significant difference ($p = 0.691$) between the low flow period and the moderate flow period. K_m values of AP in the high flow period showed a significant difference with the low flow period ($p = 0.021$) and with the moderate flow period ($p = 0.024$). The linearly dependent coefficients between K_m and SRP are 0.65, 0.60 and 0.54 during low, moderate and high flow periods. Statistical results showed there were no significant differences in pH among the low, moderate and high flow periods ($p \ge 0.068$). K_m values of AP were negatively dependent on temperature (linearly dependent coefficient $r = -0.87$).

Average V_{max} of AP in the inflowing rivers ranged from 2.7 to 10.6 nmol/L/min during the low flow period, from 1.6 to 10.9 nmol/L/min during the moderate flow period and from 1.5 to 13.6 nmol/L/min during the high flow period. There was no significant difference in the V_{max} of AP among the low, moderate and high flow periods ($p \ge 0.644$).

Organic P mineralization rate (v) in the inflowing rivers of Taihu

OP mineralization rate v in the inflowing rivers increased gradually from the low flow period to the high flow period. There was no significant difference between the low and moderate flow periods ($p = 0.289$) as well as between the moderate and high flow periods ($p = 0.098$), but there was a significant difference between the low and high flow periods ($p = 0.032$). There was no significant difference among the three types of rivers ($p > 0.9$). It shows that OP mineralization rate v was much lower than V_{max} of AP in the inflowing rivers by comparing V_{max} of AP with v in the nine sampled rivers of Taihu. The highest proportion of v to V_{max} (v/V_{max}) is only 14.7%. The average v/V_{max} for rivers polluted by industry ranging from 2.6 to 12.5%, for rivers polluted by agriculture ranging from 0 to 11.3% and for rivers polluted by domestic sewage ranging from 1.3 to 14.7%. v/V_{max} increased gradually from the low flow period to the high flow period, which means that the AP enzymatic hydrolysis reaction in the inflowing rivers increased from the low flow period to the high flow period.

v and V_{max}/K_m had similar variation trend during the low, moderate and high flow periods (Fig. 3). The variation trends of EHP concentration and OP mineralization rate v in the inflowing rivers were also similar (Fig. 4), and OP mineralization rate increased with the increase of EHP concentration. The proportion of EHP to TP (EHP/TP) was nearly equal to the proportion of SRP to TP (SRP/TP) during the moderate flow period and EHP/TP was higher than SRP/TP during the high flow period in the three types of inflowing rivers (Fig. 5).

P turnover time (t) in the inflowing rivers of Taihu

We measured P turnover time in the inflowing rivers of Taihu and there were no significant differences among low, moderate and high flow periods ($p \ge 0.167$), nor were there significant differences among the three types of rivers ($p \ge 0.08$). EHP concentrations in the inflowing rivers ranged from 0.011 to 0.113 mg/L and it generally needed half a week to a week (range 3–7 days) to be mineralized (Fig. 6).

Discussion

Characteristics of AP in the inflowing rivers of Taihu

Michaelis constant K_m and V_{max} of AP are responsible for the major part of the phosphatase activity (Bogé et al. 2014). K_m is used to measure the affinity between enzyme and substrate (Tischer et al. 2015). A smaller K_m value represents a stronger affinity (Wang et al. 2006; Xiao et al. 2018). The temporal patterns showed that Affinity between AP and substrate in the inflowing rivers during high flow period was higher than that during low and moderate flow periods. V_{max} is used to characterize the intrinsic catalytic rate of the enzyme. When the substrate is combined completely with the enzyme, the maximum reaction velocity can be obtained.

In Fig. 2a–c it appears that K_m values of AP are also high when SRP concentrations are high. The variation characteristic of SRP concentrations and K_m values in the nine inflowing rivers during low, moderate and high flow periods (Fig. 2a–c) indicates that affinity between AP and substrate is inversely related to SRP concentrations in the inflowing rivers. Natural environmental conditions such as pH, substrate concentration and temperature could markedly affect the APA (Hui et al. 2013). However, there were no significant differences in pH among the low, moderate and high flow periods and K_m values of AP were negatively dependent on temperature indicated that the high water temperature (average 31 °C) during high flow period increased the affinity between AP and substrate in the inflowing rivers. These

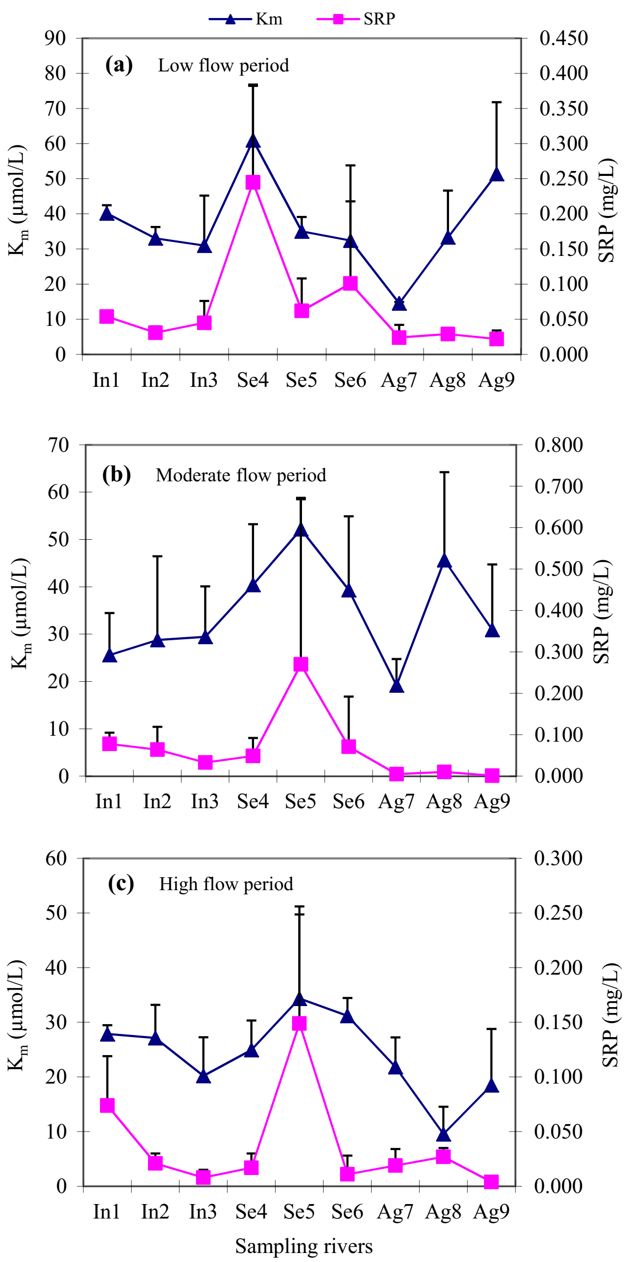

Fig. 2 Soluble reactive P (SRP) concentration and its variation with Michaelis constant (K_m) in the inflowing rivers of Taihu during **a** low, **b** moderate and **c** high flow periods

results were similar to Gershenson et al. (2009) and Tan et al. (2018).

Based on different habitats of Taihu, Lu et al. (2009) reported the K_m values of AP in the grass type zone, Gonghu Bay zone, Zhushan Bay zone, Meiliang Bay zone, the central zone and estuary zone of the western bank were 20.50, 20.11, 15.70, 13.34, 11.75 and 9.17 μmol/L respectively. K_m values of AP in Taihu were lower than those in the inflowing rivers and it indicated that affinity between AP and substrate in Taihu was higher than that in the inflowing rivers. V_{max} of AP in Taihu in 2008 ranged from 7.70 to 26.9 nmol/L/min and the average V_{max} was 13.70 nmol/L/min (Lu et al. 2009). The average V_{max} of AP in Taihu in 1999 was 191 nmol/L/min (Gao et al. 2004). The average V_{max} of AP in Taihu in 2011 was 16.0 nmol/L/min under no turbulent condition (Ding et al. 2016). The V_{max} of AP in Taihu in 2014 increased from 39 nmol/L/min under calm condition to 458 nmol/L/min under long-term moderate wind condition, averaging 184 nmol/L/min (Chao et al. 2017). V_{max} of AP in Taihu was far higher than that in the inflowing rivers. Taihu is a typical shallow hyper-eutrophic lake, with an average depth of 1.9 m and it is disturbed by wind-induced wave most of time (Qin et al. 2007). Wind-induced wave disturbances can cause rapid sediment resuspension (Tammeorg et al. 2013). APA and TP in sediment were resuspended in the water column with the sediment resuspension, adding P cycling rate and bio-available P (Chao et al. 2017). As a result, algae largely grew and reproduced, accompanying high V_{max} of AP.

AP is often repressed at high SRP concentrations and reactive at low SRP concentrations (Jansson et al. 1988). APA has therefore been used as a SRP deficiency indicator in algae and in natural plankton populations. Previous studies indicate that phytoplankton and bacterioplankton began to synthesize AP to hydrolyze phosphate esters when SRP was depleted (Berman 1970; Chrost et al. 1986). Previous work carried out on Taihu showed that APA was significantly increased when SRP concentrations were less than 0.020 mg/L and 0.020 mg/L is the SRP threshold to activate APA of phytoplankton (Gao et al. 2000). SRP concentrations were far higher than 0.020 mg/L in most of the inflowing rivers (Fig. 2a–c) and APA was repressed in the rivers. However, SRP was only about 8% of TP and the average SRP concentration was 0.0137 mg/L in Taihu (Gao et al. 2004). As a result, V_{max} of AP in Taihu was far higher than that in the inflowing rivers.

Phytoplankton are influenced by a wide range of factors including water temperature, water column stability, flushing rate, irradiance, and available nutrients (Havens et al. 2019; Islam et al. 2013). Many types of algae flourish in lakes with poor water flow and a flush of water suppress blooms (Islam et al. 2013; Havens et al. 2019). It has been documented that, on a global scale, cyanobacteria are favored by warmer water temperatures (Kosten et al. 2012). However, water temperature of the nine inflowing rivers had no significant difference with Taihu during low ($p = 0.274$), moderate ($p = 0.830$) and high flow periods ($p = 0.425$). Water transparency of the nine inflowing rivers had no significant difference with Taihu during low ($p = 0.812$), moderate ($p = 0.074$) and high flow periods ($p = 0.826$). So, water temperature and irradiance were not the main causes for slow algal growth in the inflowing rivers. Taihu is relative stable because of the water control gates (Wu and Kong 2009) and the water retention time of the lake is approximately 180 days (Xu et al. 2015). The water retention time of the inflowing rivers were short because of their high flow velocity. Though the algal cells are in a thick (low Reynolds number) environment and cannot sense the movement of water, algae cannot make full use of SRP in the inflowing rivers because of the short water retention time. Therefore, high flow velocity of the inflowing rivers indirectly affected the growth of algae. High flow velocity of rivers is not suitable for algae growth compared with the lake, so the demand for SRP by algae in the inflowing rivers is lower than that in Taihu. This helps explain why V_{max} of AP in Taihu was far higher than that in the inflowing rivers. High SRP concentration and low demand for SRP by algae lead to V_{max} of AP in the inflowing rivers being lower than that in Taihu.

Impact of OP mineralization rate in the inflowing rivers of Taihu

K_m and V_{max} represent the characteristics of AP itself, and OP mineralization rate v is the actual reaction rate between AP and substrate EHP. v is affected by the catalytic efficiency of AP, substrate concentration and SRP concentration according to the reversible enzyme-driven reaction principle. However, the two catalytic property parameters K_m and V_{max} have different characteristics, the decrease of K_m and the increase of V_{max} means enhanced OP mineralization by simultaneously increasing the reaction velocity v and improving the affinity for the substrate. In order to analyze the relationship between OP mineralization rate v and catalytic efficiency of AP in the inflowing rivers, V_{max}/K_m is used here as a proxy for the catalytic efficiency of AP (Wang et al. 2018). Figure 3 indicates that OP mineralization rate increases with the increase of AP catalytic efficiency. v accounts for only a small proportion of V_{max} and v can potentially increase. The results of Fig. 3 indicate that AP in the inflowing rivers is sufficient for OP mineralization and AP is not the reason for the low OP mineralization rate.

Another possible controlling factor of v is substrate concentration. The substrate refers to phosphatase-hydrolyzable OP in our study, namely EHP. OP mineralization rate increased with the increase of EHP concentration (Fig. 4) indicated that substrate concentration was enough for the

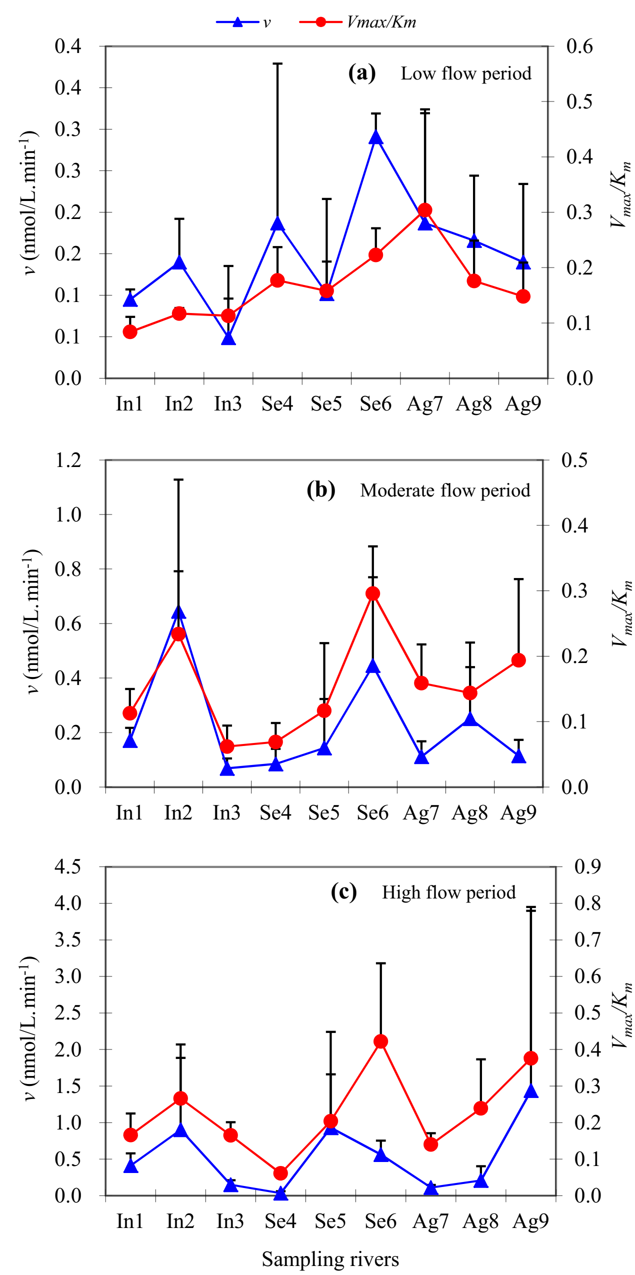

Fig. 3 The variation characteristic of organic P (OP) mineralization rate (v) and catalytic efficiency (V_{max}/K_m) of alkaline phosphatase (AP) in the inflowing rivers of Taihu during **a** low, **b** moderate and **c** high flow periods

enzyme-driven reaction and it was not the reason for the low OP mineralization rates.

The reason for the low OP mineralization rate v in the inflowing rivers was not due to the catalytic efficiency of AP or the substrate (EHP) concentration according to the above analysis, but rather the inhibition by the higher SRP concentration. Compared with Taihu, algae cannot make full use of SRP in the inflowing rivers because of the short water retention time. As a result, SRP in rivers was utilized

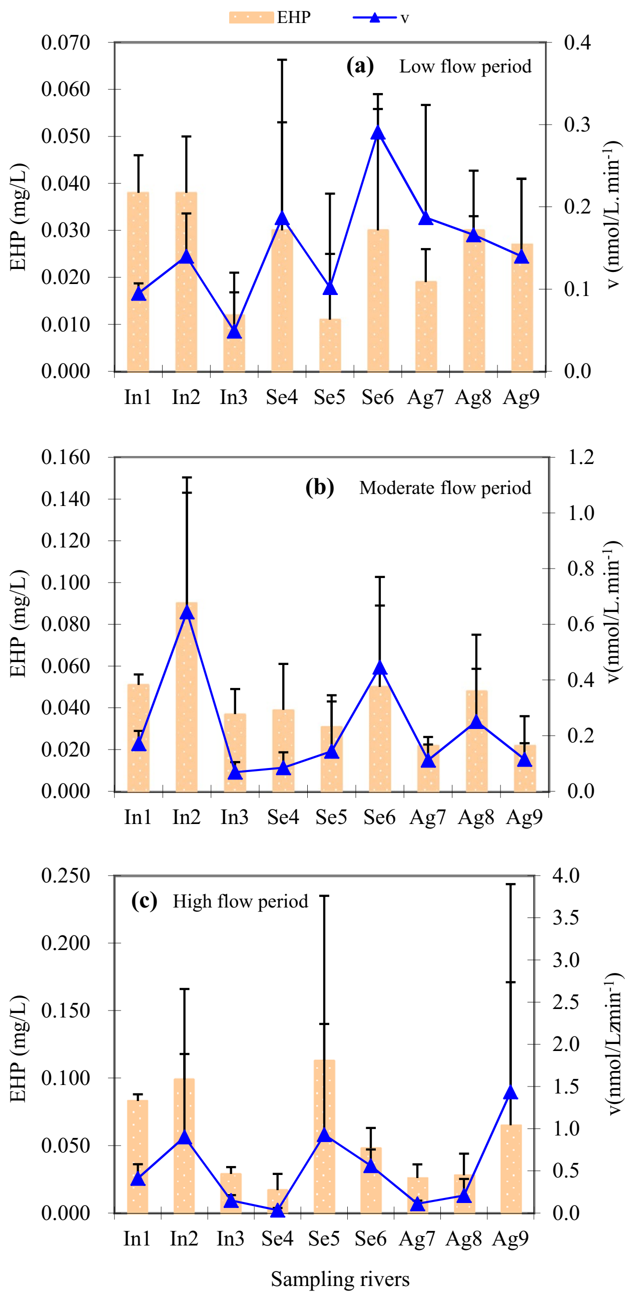

Fig. 4 The variation characteristic of enzymatically-hydrolysable organic P (EHP) concentration and organic P (OP) mineralization rate (*v*) in the inflowing rivers of Taihu during **a** low, **b** moderate and **c** high flow periods

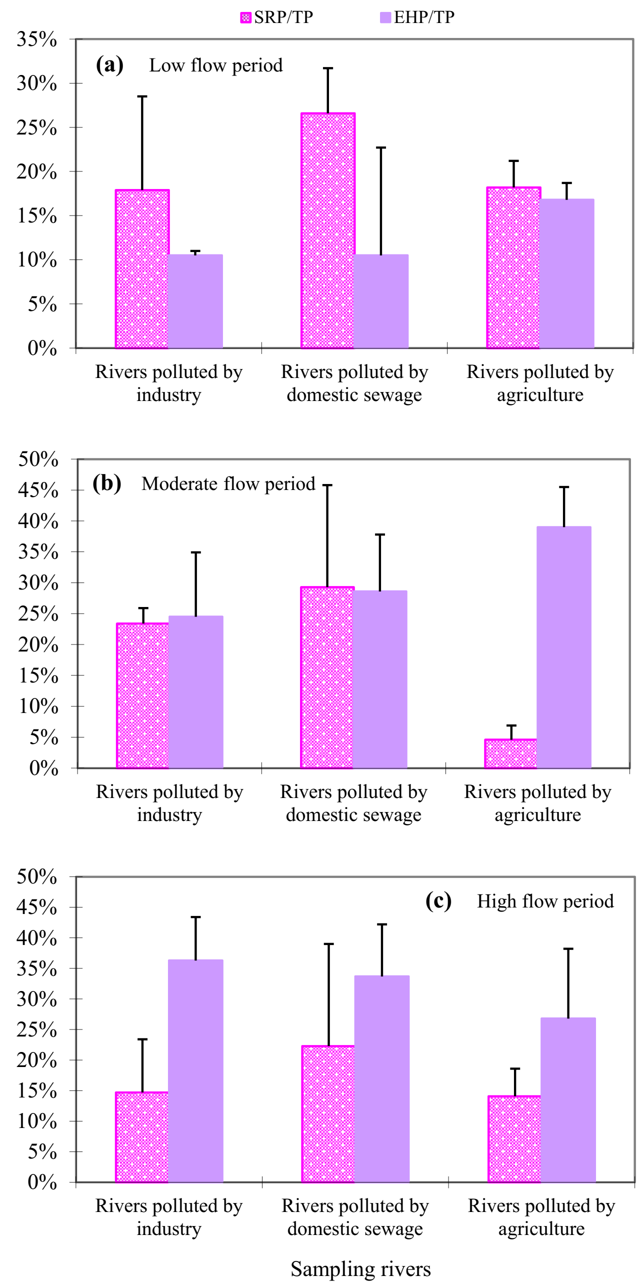

Fig. 5 The proportion of EHP to TP (EHP/TP) and the proportion of SRP to TP (SRP/TP) in the inflowing rivers of Taihu during **a** low, **b** moderate and **c** high flow periods

slowly by algae and the existent higher SRP concentration inhibited the reversible enzyme-driven reaction. Thus, OP mineralization rate *v* in the inflowing rivers was very low. The high EHP reserve (Fig. 5) and the sufficient AP for OP mineralization point to the inflowing rivers as a potential threat to water quality in Taihu.

The difference of P turnover time (*t*) between Taihu and its inflowing rivers

Halemejko and Chrost (1984)'s study on Lake Glebokie in Poland found that phosphatases participated in the mineralization of approximately 70% OP in the spring seston after a 60 day decomposition period. During the summer, seston decomposition was accompanied by 90% mineralization of P after 30 days (Halemejko and Chrost 1984). During autumn, after 60 days, 96% of the initial content of OP in the algae was mineralized (Halemejko and Chrost 1984). Hudson et al. (1999) measured phosphorus regeneration rates from 20 temperate freshwater lakes from three major physiographical regions of North America and found regeneration could release an amount of P equal to particulate P pool every 5 days (range 3.5–7 days). P turnover time was from 275.9 to 20.3 min in different ecotype sites of Taihu and the most rapid P turnover time was on the order of several minutes (Gao et al. 2006). P turnover time in the inflowing rivers of Taihu was far longer than the P turnover time of Taihu (Fig. 6). One reason was that Taihu had longer hydraulic residence times, more algal biomass and higher demand for SRP by algae than inflowing rivers. The difference in structure and form of OP compounds might be another reason for the difference in P turnover time. A variety of soluble organic P compounds is present in the upper layer of water (Halemejko and Chrost 1984). These compounds include phospholipids, phosphomononucleotides and their derivatives (Kleerekoper 1953; Lean and Nalewajko 1976). Sugar phosphates and aminophosphoric acids contain very stable C–P bonds (Demain et al. 1965). Phosphoric monoester or diesters contain easily hydrolysable P–O–C bonds (Halemejko and Chrost 1984). Further studies will focus on the relationship between the specific molecular structure of EHP and P turnover time in different types of inflowing rivers.

Conclusions

The affinity between AP and substrate is inversely related to SRP concentration in the inflowing rivers and the affinity in Taihu was higher than that in the inflowing rivers. High SRP concentration and low SRP demand by algae suppressed APA in the inflowing rivers. As a result, the highest proportion of v to V_{max} is only 14.7%. The EHP concentrations in the inflowing rivers ranged from 0.011 to 0.113 mg/L and half a week to a week (range 3–7 days) was needed to mineralize it. In exceptional cases, the P turnover time could exceed 10 days. The high EHP reserve and the sufficient AP for OP mineralization render the inflowing rivers a potential threat to water quality and cyanobacterial bloom formation in Taihu, especially during warm, maximum irradiance summer periods when maximum bloom potential exists.

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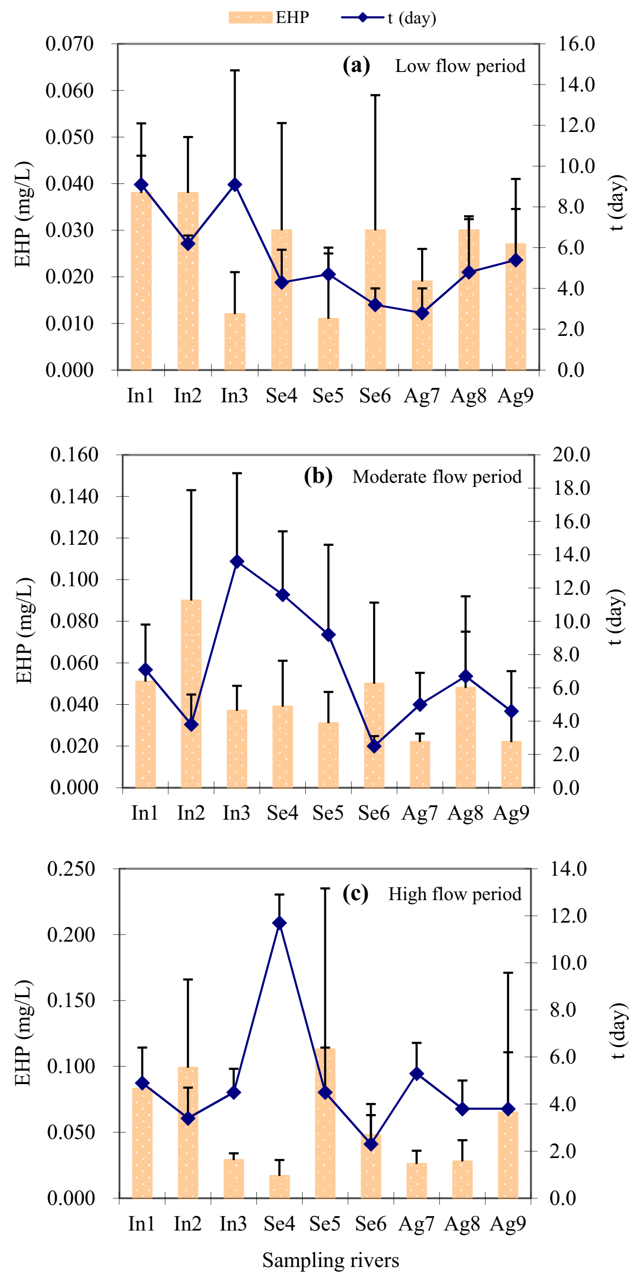

Fig. 6 Enzymatically-hydrolysable organic P (EHP) concentration and the corresponding P turnover time (t) in the inflowing rivers of Taihu during **a** low, **b** moderate and **c** high flow periods

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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