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Phosphorus release of metazoan zooplankton in two bays with different trophic status in Lake Taihu (China)

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ABSTRACT

Key-words: *Lake Taihu, subtropical lake, metazoan zooplankton, phosphorus release*

The contribution of metazoan zooplankton to internal phosphorus (P) cycling was investigated in Meiliang and Wuli Bays of Lake Taihu, a eutrophic, shallow lake in China by determining biomass and biomass specific P release rates. The zooplankton community of eutrophic Meiliang Bay was dominated by cladocerans, particularly *Daphnia* spp. and copepods, while dominant groups in hypereutrophic Wuli Bay included rotifers, copepods, and cladocerans. Release rates of PO_4^{3-}-P ranged from 0.20 to 0.57 mg·g (dry weight)$^{-1}$·h^{-1} in Meiliang Bay and 0.20 to 0.76 mg·g^{-1}·h^{-1} in Wuli Bay. In most cases, P release rates were higher in Wuli Bay than Meiliang Bay. Phosphorus fluxes from zooplankton excretion varied from 5.34 to 57.41 mg·m^{-2}·d^{-1} in Meiliang Bay and 8.20 to 70.02 mg·m^{-2}·d^{-1} in Wuli Bay. Since P released by zooplankton in this study was in a form available to phytoplankton, zooplankton may represent a significant source of P contributing to high phytoplankton biomass in Lake Taihu.

RÉSUMÉ

Rejet de phosphore par le zooplancton métazoaire dans deux baies d'état trophique différent du lac Taihu (Chine)

Mots-clés : *lac Taihu, lac subtropical, zooplancton métazoaire, rejet de phosphore*

La contribution du zooplancton métazoaire à la circulation du phosphore interne (P) a été étudiée dans les baies Meiliang et Wuli du lac Taihu, un lac eutrophe, peu profond en Chine, par la détermination de la biomasse et les taux de libération de P par biomasse spécifique. La communauté du zooplancton de la baie eutrophe Meiliang a été dominée par les cladocères *Daphnia* spp, en particulier, et des copépodes, tandis que les groupes dominants dans la baie hypereutrophe Wuli comprenaient des rotifères, des copépodes, et des cladocères. Les taux de libération de PO_4^{3-}-P variaient de 0,20 à 0,57 mg·g (poids sec)$^{-1}$·h^{-1} dans la baie Meiliang et de 0,20 à 0,76 mg·g^{-1}·h^{-1} dans la baie Wuli. Dans la plupart des cas, les taux de rejet en P étaient plus élevés dans la baie de Wuli que dans la baie Meiliang. Les flux de phosphore provenant de l'excrétion du zooplancton varient de 5,34 à 57,41 mg·m^{-2}·d^{-1} dans la baie Meiliang et de 8,20 à 70,02 mg·m^{-2}·d^{-1} dans la baie Wuli. Comme le P libéré par le zooplancton dans cette étude était dans une forme disponible pour le phytoplancton, le zooplancton peut représenter une source importante de P contribuant à la biomasse phytoplanctonique élevée dans le lac Taihu.

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INTRODUCTION

Phosphorus (P) is often a key factor controlling eutrophication in lacustrine systems. Major P sources typically include urban and agricultural runoffs and internal fluxes. In shallow, eutrophic lakes, P flux from the sediment is an important internal process maintaining a high water column P pool (Søndergaard *et al*., 2012). Excretion by zooplankton also is considered an internal source of P (Lehman, 1980b; Urabe *et al*., 1995; Kowalczewska-Madura and Gołdyn, 2010). Grazing by large zooplankton, particularly cladocerans, can regulate phytoplankton biomass and species composition (Carpenter *et al*., 1987; Reynolds, 1994; Sommer and Sommer, 2006). However, nutrient excretion by zooplankton may also affect the supply and stoichiometry of nutrients and thereby influence phytoplankton and lake trophic status (Lehman, 1980a; Elser *et al*., 1988; Sterner and Hessen, 1994; Kowalczewska-Madura *et al*., 2007).

The role of zooplankton has been well studied in temperate lakes, but and less so in tropical and subtopical systems where zooplankton are smaller and likely to be less efficient in grazing phytoplankton (Jeppesen *et al.*, 2010; Havens and Beaver, 2011). However, small zooplankton exhibit high P release rates and may thus play a significant role in nutrient cycling in tropical and subtropical lakes (Pinto-Coelho and Greco, 1999). Lake Taihu is a subtropical freshwater lake in China's Yangtze delta, with a surface area of 2338 km^2 and mean depth of 1.89 m. Situated in one of the most rapidly industrializing and populous regions of the world, Lake Taihu has suffered greatly from anthropogenic eutrophication since the 1980s (Qin *et al*., 2007). Although the lake is well-mixed and usually turbid due to sediment resuspension and high phytoplankton biomass, a clear water phase may be observed in spring and early summer due to low phytoplankton abundance. Water transparency decreases later in summer due to *Microcystis* blooms, while large zooplankton, particularly *Daphnia* spp., decrease in density, most likely due to increased fish predation and reduced food quality (Yang *et al*., 2008; Song *et al.*, 2010; De Kluijver *et al.*, 2012). In this study, the role of zooplankton in nutrient cycling in Lake Taihu was evaluated through estimates of P release and flux by metazoan zooplankton were estimated compared with data on P release from sediments and external P loading gleaned from the literature. The work contributes to a better understanding of the role of zooplankton in subtropical lakes.

STUDY SITE

Two areas with contrasting trophic states (Song *et al.*, 2010) located in the north part of Lake Taihu (Figure 1) were selected for this study. Meiliang Bay (area 124 km^2, average depth 2.1 m) exhibits total nitrogen levels ranging from 2.3 to 5.2 mg·L^{-1} and total phosphorus ranging from 0.12 to 0.31 mg·L^{-1}, and experiences severe summer algal blooms dominated by cyanobacteria. Wuli Bay (area 9 km^2, average depth 1.8 m), considered the most polluted area of main Lake Taihu, is isolated artificially from Meiliang Bay by a dam. Total nitrogen here ranges from 3.13 to 8.85 mg·L^{-1} and total phosphorus from 0.15 to 0.24 mg·L^{-1} (Table I).

MATERIALS AND METHODS

Vertical integrated water samples from the surface to a depth of about 1.5 m were taken with a tube sampler biweekly in March–May 2004 in Meiliang Bay and Wuli Bay (Figure 1). For identification and enumeration of zooplankton, samples were filtered with a 63-μm sieve into plastic vials and preserved with 5% formalin solution. Zooplankton were identified according to Wang (1961), Zhuge (1997), Shen (1979) and Chiang & Du (1979). Animals were counted, and the lengths of 20–30 individuals were measured using a microscope. Zooplankton biomass (Bz), expressed as mg (dry weight)·L^{-1} or g·m^{-3}, was estimated according to length-weight relationships given in the literature (Dumont *et al*., 1975; Huang and Hu, 1986).

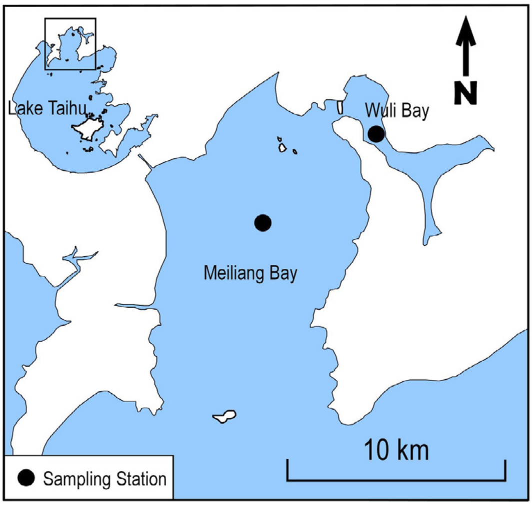

Figure 1
Sampling stations in Meiliang Bay and Wuli Bay, Lake Taihu.

Table I
Mean and range of environmental variables in Meiliang Bay and Wuli Bay.

Parameters	Meiliang Bay		Wuli Lake	
	Mean	Range	Mean	Range
Water Depth (m)	2.1		1.8	
Secchi Depth (cm)	25	15–32	38	27–49
Total nitrogen (mg·L^{-1})	3.34	2.32–5.20	5.25	3.13–8.85
Total phosphorus (mg·L^{-1})	0.19	0.12–0.31	0.20	0.15–0.24
Chlorophyll a (mg·m^{-3})	32.91	9.20–65.88	54.30	38.25 –73.85

Table II
Incubation temperatures for zooplankton P release experiments.

Date	9 Mar	18 Mar	26 Mar	6 Apr	15 Apr	22 Apr	16 May	25 May
Temperature (°C)	12.0	11.0	11.8	17.0	15.8	25.0	20.5	24.0

On each experiment day, zooplankton were collected from each bay with horizontal hauls using a 63-µm mesh net. Although a plankton net of such mesh size could result in loss of smaller sized rotifers, a smaller sized net was not practical since it is difficult to separate animals from algae. After collection from the lake, zooplankton were transferred immediately into a 20-L tank containing filtered lake water, which was transported to the laboratory where zooplankton were concentrated with a 63-µm sieve. After rinsing three times with distilled water, animals were transferred into three experimental flasks containing 500 ml filtered (0.45-µm) lake water. Temperature was maintained at or near *in situ* lake temperature (Table II). Three reference flasks without animals were run during each experimental series as controls. After incubation (1 h), a 200-ml water sample was taken by a pipette with the tip opening covered with a fine-mesh net to prevent the introduction of particles, such as feces. Water samples were analyzed for PO_4^{3-}-P according to Murphy and Riley (1962). All experiments were carried out between 10 h and 15 h.

At the end of the experiments, animals in each flask were filtered onto GF/C filters and dried at 60 °C for 24 h. Dry biomass was determined using a microbalance. Phosphorus (PO_4^{3-}-P) release rates were calculated as the difference between experimental and control flasks. Biomass specific P release rate (Rp) was expressed per gram dry biomass per hour (mg·g^{-1}·h^{-1}). Daily zooplankton community P flux (Pfz) was estimated by following formula:

$$\mathrm{Pfz} = \mathrm{Rp} \times \mathrm{ZB} \times 24$$

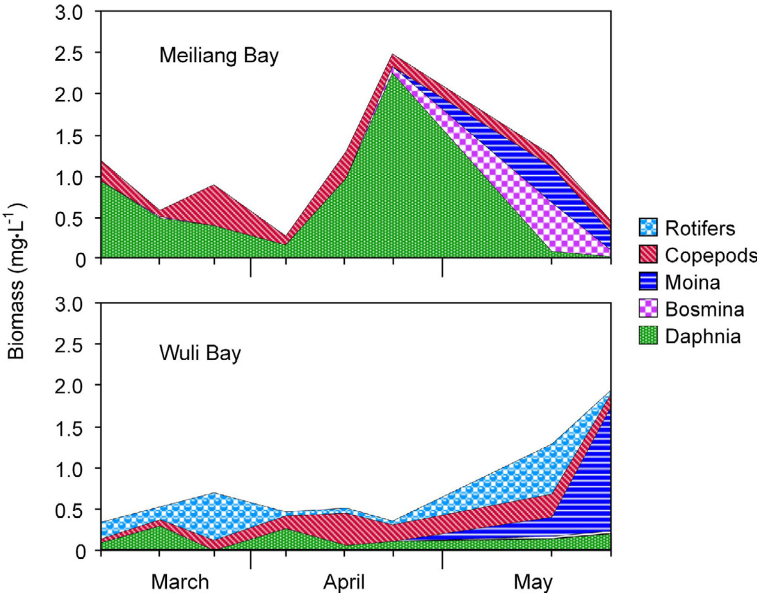

Figure 2
Biomass (dry weight) composition of metazoan zooplankton of Meiliang Bay and Wuli Bay, Lake Taihu during the study period.

Where Pfz is daily zooplankton community P flux, $mg{\cdot}m^{-2}{\cdot}d^{-1}$; Rp is biomass specific P release rate, $mg{\cdot}g^{-1}{\cdot}h^{-1}$; ZB is zooplankton biomass expressed as $g{\cdot}m^{-2}$. ZB = Zb × D, where Zb is zooplankton biomass ($g{\cdot}m^{-3}$), and D is the mean depth of the study area (m).

P release rates and fluxes of zooplankton in the two study bays were compared with a t-test using software SPSS 18.

RESULTS

Metazoan zooplankton community composition during the study period was similar in the two bays, but there were differences in dominant species. In Meiliang Bay, the dominant species included cladocerans *Daphnia hyalina*, *D. longispina*, *D. pulex*, *Moina* spp., *Bosmina* spp. and copepods *Sinocalanus dorrii*, *Cyclops vicinus vicinus*, *C. strenuus*, and *Thermocyclops taihokuensis*. However, in Wuli Bay, the dominant zooplankton species were rotifers *Brachionus calyciflorus*, *B. angularis*, *Asplanchna priodonta*, *Keratella tropica*, *Polyarthra* spp., *Filinia longiseta*, copepods *Cyclops vicinus vicinus*, *Cyclops strenuus*, *Thermocyclops taihokuensis*, *Mesocyclops thermocyclopoides* and cladocerans *Moina* spp.

Biomass (dry weight) of metazoan zooplankton in Meiliang Bay was variable (Figure 2). Cladocerans, dominated by *Daphnia* spp. from March to April and *Bosmina* spp. and *Moina* spp. in late May, were the largest component of zooplankton biomass, followed by copepods, while the biomass of rotifers was negligible.

In Wuli Bay, however, rotifers contributed a significant proportion of metazoan zooplankton biomass. Although cladocerans also were an important contributor to zooplankton biomass, the proportion was lower than in Meiliang Bay, and copepod biomass was similar in the two bays.

Mean P release rates ranged from 0.20 to 0.57 $mg{\cdot}g^{-1}{\cdot}h^{-1}$ in Meiliang Bay and 0.20 to 0.76 $mg{\cdot}g^{-1}{\cdot}h^{-1}$ in Wuli Bay (Figure 3). In most cases, P release rates were higher in Wuli Bay than Meiliang Bay although only four experiments yielded statistically significant results.

Based on biomass and release rates, zooplankton contribution to internal P cycling was estimated (Figure 4). Phosphorus flux varied from 5.34 to 57.41 $mg{\cdot}m^{-2}{\cdot}d^{-1}$ in Meiliang Bay and 8.20 to 70.02 $mg{\cdot}m^{-2}{\cdot}d^{-1}$ in Wuli Bay. Maximal values for P flux occurred at highest zooplankton biomasses.

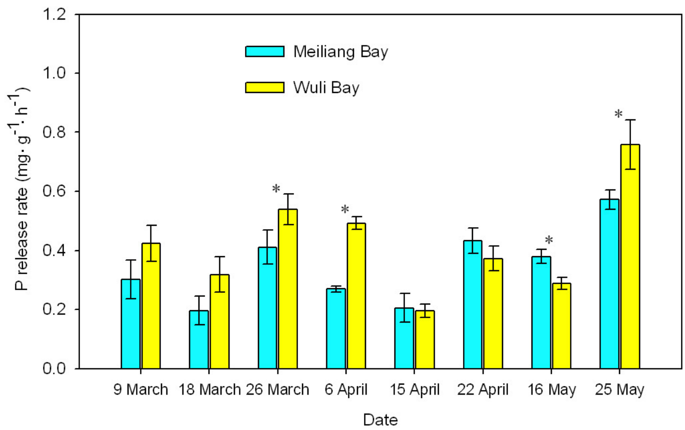

Figure 3
*Phosphorous release rates of zooplankton in Meiliang Bay and Wuli Bay, Lake Taihu during the study period. Vertical bar shows standard deviation. * Indicates that the difference is significant ($P < 0.05$).*

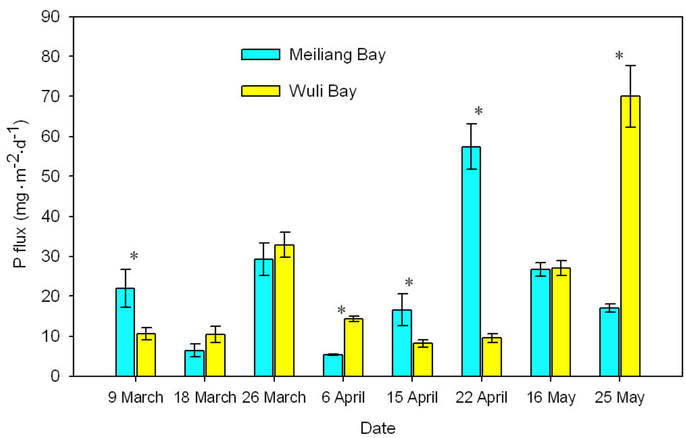

Figure 4
*Phosphorus flux by metazoan zooplankton in Meiliang Bay and Wuli Bay, Lake Taihu during the study period. Vertical bar shows standard deviation. * Indicates that the difference is significant ($P < 0.05$).*

DISCUSSION

Zooplankton are an important influence on phytoplankton succession during spring and summer via grazing activity (Sommer *et al*., 1986). However, nutrient regeneration by zooplankton also is an important factor determining phytoplankton composition (Kowalczewska-Madura *et al*., 2007). Earlier studies revealed that most soluble P is released by zooplankton as PO_4^{-3}-P and, therefore, is available for phytoplankton growth (Lehman, 1980a). During our study, large zooplankton were abundant in Lake Taihu. The highest biomass of *Daphnia* spp. was more than 2.0 mg·L^{-1}. Zooplankton P release rates were variable but fall within ranges reported in other studies (Table III). In an experimental study, Lehman (1980b) reported a range of 0.58–0.83 mg·g^{-1}·h^{-1} for zooplankton P release rates. Urabe *et al*. (1995) showed that zooplankton P release rates in Lake Biwa ranged from 0.01 to 0.11 mg·g^{-1}·h^{-1}. In a tropical reservoir, Pinto-Coelho and Greco (1999) reported zooplankton P excretion rates from 0.49 to 1.05 mg·g^{-1}·h^{-1}.

Our results showed differences in P release rates between the two bays with different eutrophication levels. In most cases, P release rates were higher in Wuli than Meiliang Bay, which may be attributed to differences in zooplankton community structure. Wuli Bay is close to the urban area of Wuxi and receives (treated and untreated) sewage. There were more rotifers in Wuli than in Meiliang Bay, while the number of large zooplankton, mainly *Daphnia*

Table III
Literature comparison of P release rates by zooplankton.

Zooplankton	P release rate ($mg \cdot g^{-1} \cdot h^{-1}$)	References
Zooplankton community	0.20–0.76	Our study
Zooplankton community	0.49–1.05	Pinto-Coelho and Greco, 1999
Daphnia pulex	0.58–0.83	Lehman, 1980b
Daphnia magna	0.31–2.12	Ruan, 1999
Zooplankton community	0.07–0.13	Gulati *et al.*, 1995
Zooplankton community	0.01–0.11	Urabe *et al.*, 1995

Table IV
Comparison of P fluxes from different sources of Lake Taihu.

Sources	P fluxes ($mg \cdot m^{-2} \cdot d^{-1}$)	References
Zooplankton P release (PO_4-P)	5.3–70.0	Our study
Sediment P release (PO_4-P)	3.0	Fan and Wang, 2007
External P loading (TP)	10.0	Qin *et al.*, 2007

spp., in Meiliang Bay was higher than in Wuli Bay. Nutrient release rates are related inversely to zooplankton size (Pérz-Martínez and Gulati, 1999; Ruan, 1999). Given equal biomass, small zooplankton, such as rotifers, should play a more important role in P cycling than large-sized zooplankton, such as daphnids (Ejsmont-Karabin, 1983; Ejsmont-Karabin *et al.*, 2004). Variation in zooplankton community composition likely is a main factor in the different P release rates between Meiliang and Wuli Bay.

The contribution of zooplankton to internal P cycling was estimated by multiplying biomass specific excretion rates by integrated biomass on each sampling date. The lowest estimate was 5.34 $mg \cdot m^{-2} \cdot d^{-1}$ in Meiliang Bay when zooplankton biomass was lowest, while the highest value of 70.02 $mg \cdot m^{-2} \cdot d^{-1}$ was observed when both zooplankton biomass and P release rate were high in Wuli Bay. A recent study showed that mean PO_4^{3-}-P release from Meiliang Bay sediments was below 3.0 $mg \cdot m^{-2} \cdot d^{-1}$ (Fan and Wang, 2007). The external loading of total P to Lake Taihu was ~10.0 $mg \cdot m^{-2} \cdot d^{-1}$ (Qin *et al.*, 2007), which is the same order of magnitude as PO_4^{3-}-P flux from zooplankton excretion (Table IV). Considering that P released by zooplankton in this study was in a form available to phytoplankton, zooplankton may supply a significant source of P contributing to high phytoplankton biomass in Lake Taihu.

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