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Phosphorus fluxes at the sediment–water interface in subtropical wetlands subjected to experimental warming: A microcosm study

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HIGHLIGHTS

- ▶ The warming enhanced the P fluxes from sediment to water in wetland ecosystem.
- ▶ A build-up of P in porewater increased potential of P transport into overlying water.
- ▶ Warming increased the dominance of fungi, leading to secreting of phosphatase.
- ▶ Microbial activities in P-low sediments were highly susceptible to warming.

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ABSTRACT

Global warming is increasingly challenging for wetland ecological function. A temperature controlled microcosm system was developed to simulate climate change scenarios of an ambient temperature (control) and an elevated temperature (+5 °C). The effects and associated mechanisms of warming on phosphorus (P) fluxes at the sediment–water interface of six subtropical wetlands were investigated. The results indicated that P fluxes were generally enhanced under the experimental warming as measured by higher P concentrations in the porewater and overlying water as well as higher benthic P fluxes. The release of P from sediment to porewater occurred more strongly and quickly in response to experimental warming compared to the subsequent upward transfer into overlying water. The average accumulative benthic P output from the tested wetlands under the experimental warming was greater by 12.9 $\mu g\ cm^{-2}\ y^{-1}$ (28%) for total P and 8.26 $\mu g\ cm^{-2}\ y^{-1}$ (25%) for dissolved reactive P, compared to the ambient scenarios. Under warming the redistribution of P fractions in sediments occurred with greater NH_4Cl–P and lower BD–P (extracted by a bicarbonate buffered dithionite solution) accompanied by greater NaOH–P. The higher temperature enhanced total phospholipid fatty acids. A shift in the microbial community was also observed with a relative dominance of fungi (a 4.7% increase) and a relative decline (by 18%) in bacterial abundance, leading to the higher secretion of phosphatase. Comparing between wetlands, the potential P fluxes in the nutrient-enriched wetlands were less impacted by warming than the other wetland types investigated. Thus wetlands characterized by low or medium concentrations of P in sediments were more susceptible to warming compared to P-rich wetlands.

1. Introduction

Global air temperatures are predicted to increase by 1.8–4.0 °C over this century (IPCC, 2007). Many ecosystems are particularly vulnerable to elevated temperatures induced by global climate change (Scheffran and Battaglini, 2011). Understanding of nutrient dynamics and matter fluxes within wetland ecosystems are considered as major knowledge gaps in predicting climate change impacts (Paul et al., 2006).

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As one of the most productive and biologically diverse ecosystems, wetlands are well known for their carbon storage functions and the capacity to remove nutrients from regional waterbodies, both of which are critical for phosphorus (P) retention at the sediment–water interface (Zedler and Kercher, 2005; Verhoeven et al., 2006). Protection and restoration of wetlands is now a priority in many subtropical areas including large parts of China. However, there is little published work on warming impacts on subtropical wetland biogeochemical cycles. After the reduction of external nutrient loading, P transfer from the sediment into water column becomes a major P source, preventing improvements of water quality for a considerable period. Global warming may change both the direction and strength of P transfer processes at the sediment–water interface, thus further enhancing primary production and accelerating eutrophication in aquatic ecosystems (Elser et al., 2007).

Phosphorus transfer at the sediment–water interface can be enhanced due to changes in environmental conditions such as light, pH, dissolved oxygen, microbial activities and temperature (Sanchez and Boll, 2005; Jiang et al., 2008). For example, light stimulates the growth of autotrophic algae but there is a strong interaction with sediment-derived P fluxes (Cymbola et al., 2008). High pH values result in a competitive exchange of phosphate anions with OH^-, increasing the potential to release P (Christophoridis and Fytianos, 2006). Depletion of dissolved oxygen in overlying water leads to a decrease in the thickness of the oxidized surface sediment layer, suggesting a redox-sensitive P release (Grunth et al., 2008). Microbial activity may play a vital role in degradation of organic matter, liberating soluble P from soil-microorganism complexes (Pages et al., 2011). Among these various physicochemical factors, elevated temperature is considered one of the main contributors to nutrient fluxes from sediments (Liikanen et al., 2002), through enhancing organic mineralization (Asmus et al., 2000), solute chemical diffusion (Bally et al., 2004), and microbial metabolic processes (Maassen and Balla, 2010). Accordingly, P processes and flux rates within wetland systems will be impacted in response to global warming.

Elevated temperature may account for a large part of the P budget in some water bodies due to P release at the sediment–water interface (Banaszuk and Wysocka-Czubaszek, 2005). Previous climate change studies of P fluxes in wetlands have mainly focused on the impact on the hydrological regime (Aldous et al., 2005; Maassen and Balla, 2010) and seasonal P variations (Davis et al., 2003; Duff et al., 2009). However, few studies have not examined responses to warming when the warming is conducted in comparison to natural variability in temperature over daily cycles. In addition to understanding P biogeochemical characteristics, quantifying P fluxes and their direction of change at the sediment–water interface is a key prerequisite for scientists and policy-markers so they can develop practical P eco-technologies for wetland management under global warming. Previous studies, which have been mainly based on lab-scale temperature manipulation incubation experiments at fixed temperatures (i.e., 16 °C and 25 °C) (Liikanen et al., 2002; Jiang et al., 2008), have demonstrated that elevated temperature has pronounced effects on sediment P dynamics. Studies of microbial shifts in response to experimental warming (using buried heating cables), such as microbial community composition and soil enzyme activities, have been limited to terrestrial ecosystems (Allison and Treseder, 2008; Frey et al., 2008).

Use of realistic real-time temperature control systems to reflect hourly, daily and seasonal temperature behavior are extremely limited in the literature. Such temperature control would enable experiments that more readily reflect temperature patterns in the natural environment and reduce the chances of experimental artifacts biasing results. In our paper, by means of a novel outdoor microcosm device enabling high resolution temperature control, the objective of our study was to compare P fluxes (benthic P fluxes and potential P fluxes) from six subtropical wetlands located in the delta of the Yangtze River in southeast China, in response to simulated global warming. The corresponding abiotic (P fractions and carbon fractions) and biotic (soil enzyme activities, microbial communities and ratios) factors in sediments were also examined to show their associations with P fluxes. We hypothesize that the global warming scenario of +5 °C will induce greater P fluxes from sediment to water. Such changes in the magnitude and direction of P fluxes are likely to be related to the transformation of sedimentary P forms as well as biological activities, especially for microbes in sediments.

2. Materials and methods

2.1. Microcosm configuration

A custom-built novel microcosm (Figs. S1 and S2) simulating climate warming at a minute-scale for both daily and seasonal temperature variations was developed using independently monitored water-bath jackets for this study. The microcosm consisted of four major components: a storage section, a heating section, water circulation, and a real-time temperature control section. The storage section was composed of two square stainless steel incubation boxes (100 cm in length and width, and 40 cm in height): one for the ambient temperature treatment (control), and the other for the +5 °C-increased temperature treatment (warmed). The real-time temperature controlling section was composed of a computer (HP a6315cn), a custom-built controller, and two digital temperature probes (NB 407-25a, China). The temperature signals were transmitted through the temperature probes into the controller which regulated the heater and the pump. With lab-designed software written in C++ language, the temperatures in both incubation boxes were continuously recorded and the temperature differences were compared by signals of temperature probes at 2-min intervals for this study. The temperature difference between the two incubation boxes was set at 5 ± 1 °C. Except for the computer and the controller, the rest of the microcosm components were set up outdoors in May 2008. Data in this paper were collected from May 2008 to Nov 2009. While daily temperature variability over a 24-h period is projected to increase under future climate (Fischer and Schar, 2009), our novel microcosm provided a significant advance of the experiments used in previous studies. By having the Warmed treatment track the ambient control continuously provided a much more natural setting for the experiments, with more realistic simulations (Fig. S2), compared to studies which just set at fixed and constant temperatures (e.g., 15 °C, 20 °C, and 25 °C).

2.2. Study sites and sampling regime

The study sites were located in the southern region of the Taihu Lake Basin and the NingShao plain within the delta of the Yangtze River. The climate in this area is subtropical monsoon with an annual average rainfall of 1350 mm and an annual average temperature of 26 °C in summer and 4 °C in winter (2004–2008 inclusive). Six wetland sites, with a large spatial and temporal variability in sediment–water nutrient exchanges, were chosen for wetland soil sampling (Table S1, Fig. S3). Those tested wetlands belong to typical subtropical wetlands with different uses and nutrient status. YaTang riverine (YT) wetland suffered pollution from duck farms and other rural activities, while XiaZhuhu (XZ) wetland was threatened by aquaculture, typical of contaminated wetlands. The wetlands of JinHu (JH), BaoYang (BY), XiXi (XX), and ShiJiu (SJ) were generally preserved for tourism and used as water reservoirs, typ-