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Effects of seasonal hypoxia on the release of phosphorus from sediments in deep-water ecosystem: A case study in Hongfeng Reservoir, Southwest China☆

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ABSTRACT

Using the diffusive gradients in thin films (DGT) technique and microelectrode technique, hypoxia and its effects on the release of phosphorus (P) from sediments were carefully investigated in Hongfeng Reservoir, a typical deep-water ecosystem where eutrophication and hypoxia is still an environmental challenge in Southwest China. The results suggested that hypoxia significantly promotes the release of P from sediments and the release of P under hypoxic condition mostly comes from the release of BD–P. Together with the *in-situ* and high resolution evidences from DGT and microelectrode, the release of P from sediments under hypoxic condition was assumed to be coupled processes which are associated with the combined cycles of “P-Fe-S”. Evidences from the present work implied that the internal P-loadings induced by hypoxia, especially after a reduction of external P-loading, should be paid more attention in eutrophic deep-water reservoirs, Southwest China.

1. Introduction

Hypoxia, defined as dissolved oxygen (DO) levels less than 2 mg/L, has becoming a global environmental challenge (Diaz, 2001; Rabalais et al., 2007; Alvisi and Cozzi, 2016). The expansion of hypoxic areas is largely associated with eutrophication (Conley et al., 2009a), because excess nutrient input results in the rapid consumption of DO (Bianchi, 2007; Djakovac et al., 2014). Hypoxia not only destroys the benthic communities, but also promotes the release of phosphorus (P) from sediments (Conley et al., 2009b; Bianchi et al., 2010). Such sedimentary P loadings (internal P-loadings) may create positive feedback loop, further enhancing prolonged hypoxia (Reddy et al., 2011; Roy et al., 2012; Adhikari et al., 2015). Previous researches on hypoxia were mainly conducted in the estuarine and coastal ecosystem. However, little is known in the freshwater ecosystems (Breitburg, 2002; Howarth et al., 2011; Lin et al., 2016), especially in deep-water ecosystems, where hypoxia is an environmental challenge (Wang et al., 2015a, b). Southwest China is home to many deep-water (>10 m) reservoirs (Yang and Lu, 2014), where hypoxia often occurs during the summer (Zhang et al., 2015; Bunch et al., 2015).

Many works have proven that, at low level of DO, Fe(III)-host minerals are easily reduced to Fe(II), resulting in the release of Fe-bound P. This process was regarded as the major mechanism of the release of P from sediments (Steinberg, 2011). Meanwhile, under the hypoxic condition, elevated temperature and the mineralization of organic matter can also accelerate the release of P from the sediments (Pizarro et al., 1995; Wang et al., 2007, 2008; Jiang et al., 2008). Understanding on the release of P from sediments under hypoxic condition has been significantly improved in recent decade (Fan et al., 2004; Qin et al., 2006; Kuster-Heins et al., 2010; Lin et al., 2016). However, the release of P from sediments is a complicated process, which involves a number of micro-scale physical, chemical and biological processes at the sediment-water interface (SWI) (Søndergaard et al., 2003). Available knowledge is largely obtained by the traditional methods and there remains a

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great gap to fully understanding the mechanisms of P release from sediments, due to lacking of *in-situ* and high resolution evidences. Fortunately, the diffusive gradients in thin films (DGT) technique has been developed and proved to be an effective tool for *in-situ* detecting the labile solutes in sediments (Davison et al., 1997; Warnken et al., 2004; Stockdale et al., 2008; Robertson et al., 2008). Using Zr-oxide DGT, this technique was further improved to have the capacity of one or two dimensional measurement of labile P in sediment at millimeter or submillimeter level (Ding et al., 2010, 2013). On the other hand, more and more investigations showed that high resolution microelectrode with small needle-shaped probe (a tip diameter of 1–20 μm) had great advantage in microscale studies, especially for obtaining distributions of oxygen, pH, and hydrogen sulfide at the SWI (Revsbech, 1989; Pedersen et al., 2011).

Hongfeng Reservoir (HF) is a typical deep-water ecosystem in Southwest China (Wang et al., 2015b). Though biogeochemical forms of P and their distribution in sediments from HF have been carefully investigated, detailed information were extremely scanty associated to the biogeochemical cycles of P under seasonal hypoxia and the release of P from sediments at sub-millimeter resolution. In this study, Zr-oxide DGT, together with microelectrode, were employed to determine the physical and chemical characteristics at the SWI. The objectives of this study are: 1) to explore the effects of hypoxia on the release of P in deep-water ecosystem; and 2) to get a deep insight in the release of P from sediments.

2. Materials and methods

2.1. Study site

Hongfeng Reservoir (N 106.24°, E 26.30°), a seasonal hypoxic water body heavily polluted by P, is an ideal field for investigating the release of P under hypoxic condition (Wang et al., 2015b). It has a surface area of 57.2 km^2, a mean water depth of 10.5 m (max. 45 m), and holds 6.01 × 10^8 m^3 of water (Fig. 1). The average annual inflow and outflow of HF were 7.06 × 10^8 $m^3$and 6.20 × 10^8 m^3 during 1961–2010 (Data source: the Administration Bureau of Hongfeng, Baihua, and Aha Reservoirs). HF provides drinking water for over 3 million people, and any slight deterioration in water quality may cause serious problems. HF is a P-limited eutrophic reservoir with total P (TP) concentration of 0.03–0.10 mg/L and TN/TP ratio of ~30 (Zhu et al., 2013). The concentrations of TP in surface sediments (0–5 cm) ranged from 766 to 4306 mg/kg, with a mean value of 1815 mg/kg (Wang et al., 2015b).

2.2. Sample collection

Sediment cores were collected from the North Central (NC), South Central (SC), and Houwu (HW) on July 27 and December 10, 2014 (Fig. 1). Selecting of these sites was due to the relatively higher concentrations and the release potential of nutrients in sediments (Wang et al., 2015b). The water depth at NC, SC, and HW was 23 m, 16 m, and 9 m, respectively. Sediment cores were taken each time from each site using a gravity corer. Upon collecting, sediment cores were transported to the laboratory immediately, where DGT device was inserted into the cores as soon as possible and cultured for 24 h. The cultivation temperature was set close to the temperature of benthic region. All the cores were sealed by rubber plug and warped with aluminum foil.

2.3. Laboratory experiment of P release from sediments

Surface sediments were collected at NC in April 2016. Upon collecting, all samples were put in sealed bags and carried to the laboratory immediately. After mixed together, these samples were divided into three parts and put into three organic glass cores as quickly as possible. Each core was then filled with filtered benthic water via a siphon and sealed with an organic glass cover. Experiment was conducted in a Perspex box (20 × 20 × 50 cm, width × length × height). The incubation temperature was set at 20 ± 1 °C, close to the temperature of bottom water during summer.

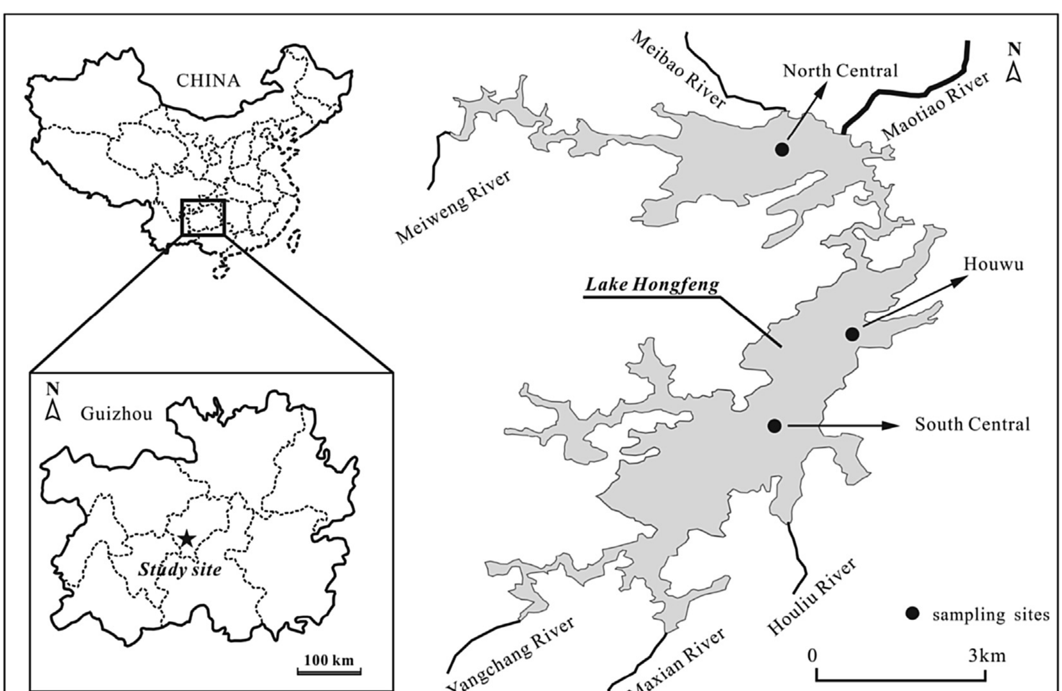

Fig. 1. Study area and the sampling sites.

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