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Phosphorus fractions and fluxes in the soils of a free surface flow constructed wetland in Hong Kong

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ABSTRACT

This study investigated the distribution of phosphorus (P) fractions in soils, and the magnitude and seasonal variations of P flux across the soil–water interface at the Hong Kong Wetland Park (HKWP), the largest free surface flow constructed wetland in the territory. Iron-bound P was the dominant P form comprising 29–59% of the total soil P, and its concentration was considerably lower than that in a nearby eutrophic marsh. The HKWP soils demonstrated a mean P release of 0.05 ± 0.01 mg m^{-2} d^{-1}, which was very low compared with the range reported for other constructed wetlands. Significantly higher soil P fluxes were obtained under anaerobic conditions that could possibly be attributed to the release of redox-sensitive iron-bound P to the overlying water column. Moreover, soil P flux was significantly higher in the dry season than the wet season, which was likely a result of differences in water column P concentration and hence diffusive flux. These findings suggest that the HKWP soils comprising fishpond bund materials, river sand and decomposed granite would not contribute to significant degradation in water quality.

1. Introduction

Phosphorus (P) is a common limiting nutrient in freshwater systems (Wetzel, 2001). Excessive levels of P can lead to eutrophication in various types of aquatic ecosystems (Correll, 1998). Wetlands can perform numerous biogeochemical functions, one of which is P retention and transformation that helps improve the quality of surface and subsurface waters (Hogan et al., 2004). In the last two decades, constructed wetlands have been increasingly used as an ecological means to treat nutrient-laden wastewater (Vymazal, 2011). Yet previous studies have reported large variations in P removal efficiency of wetlands across space and time (e.g. Greenway and Woolley, 1999; Luederitz et al., 2001 White et al., 2004). To account for such differences and maximize the water quality function of wetlands, there is a need to understand thoroughly the various components and mechanisms involved in P cycling.

Soil plays an important role in the overall retention of P in wetlands. It is the major compartment of P storage in wetlands, accounting for over 50% of the total standing stock, compared to other components including water, periphyton, and macrophytes (Noe et al., 2002; Richardson, 1999). Some researchers have examined the nutrient status and contamination level of wetland systems by determining the total P content in soils (e.g. Lau and Chu 2000; Tam and Wong, 1998). However, the total amount of soil P does not reveal any accurate information about the exchangeability and bioavailability of P, which are crucial in affecting water quality (Coelho et al., 2004). The characterization of soil P chemical forms with different mobility can shed light on the potential of P release from wetland soils, which has significant implications to future predictions of water column P levels (Sondergaard et al., 2001). An operational extraction is commonly employed in soil P fractionation that unfortunately provides no insights on the specific mechanisms involved in P retention (e.g. Goedkoop and Pettersson, 2000). In contrast, functional extraction is able to identify chemically well-defined and ecologically meaningful P fractions (De Groot, 1990), but is less frequently used because it involves repeated extractions with long time duration and complicated preparation of extractants (Ruban et al., 1999).

Cycling of P takes place actively at the soil–water interface of wetland ecosystems owing to the presence of a steep gradient in physical, chemical, and biological properties. Wetland soils may either act as a sink or source for P depending on the prevailing environmental conditions. The flux of P from soils to the overlying water column can perpetuate the eutrophic state of water bodies and bring about cascading and often adverse ecological impacts (Malecki et al., 2004). Hence, there is a pressing need for a better understanding of soil–water P exchange in wetlands, which can be

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regulated by various factors, including, for example, P concentration gradient across the interface and physico–chemical properties of soils (Reddy et al., 1995). While a number of studies have reported a significantly higher P flux from anoxic, reducing soils (e.g. Holdren and Armstrong, 1980; Moore and Reddy, 1994), de Montigny and Prairie (1993) found no significant difference between aerobic and anaerobic P release rates from organic lake sediments. It is still unclear how redox potential will affect P flux from different types of soils in wetlands. Moreover, given that soil P release mechanisms are coupled closely to temperature and biological activities (Sondergaard et al., 2001), P flux from estuarine soils has exhibited a distinct seasonal pattern (Malecki et al., 2004). The knowledge regarding the seasonal variations in soil P flux is essential for the development of mass balance models and proactive water quality management plans (Penn et al., 2000), but is largely lacking for constructed wetlands especially in the subtropical region.

The Hong Kong Wetland Park (HKWP) is the largest constructed wetland in Hong Kong that aims to mitigate the loss of wetland habitats owing to new town development as well as purify the stormwater collected in nearby urban areas. The soils in the HKWP originate from a mixture of fishpond bund materials, river sand, and decomposed granite. Previous research has examined the P sorption characteristics of the HKWP soils (Lai and Lam 2009), but little is known regarding the P fractions and fluxes in this kind of wetland substrate. As such, the objectives of this study were to: (1) determine the relative importance of different P forms in the HKWP soils, (2) investigate the spatial and temporal variations of P flux between the soils and overlying water column, and (3) examine the influence of redox potential on soil–water P exchange in the HKWP.

2. Materials and methods

2.1. Site description

During the hot and wet summer months between May and September, Hong Kong experiences a mean temperature of 27.7 °C

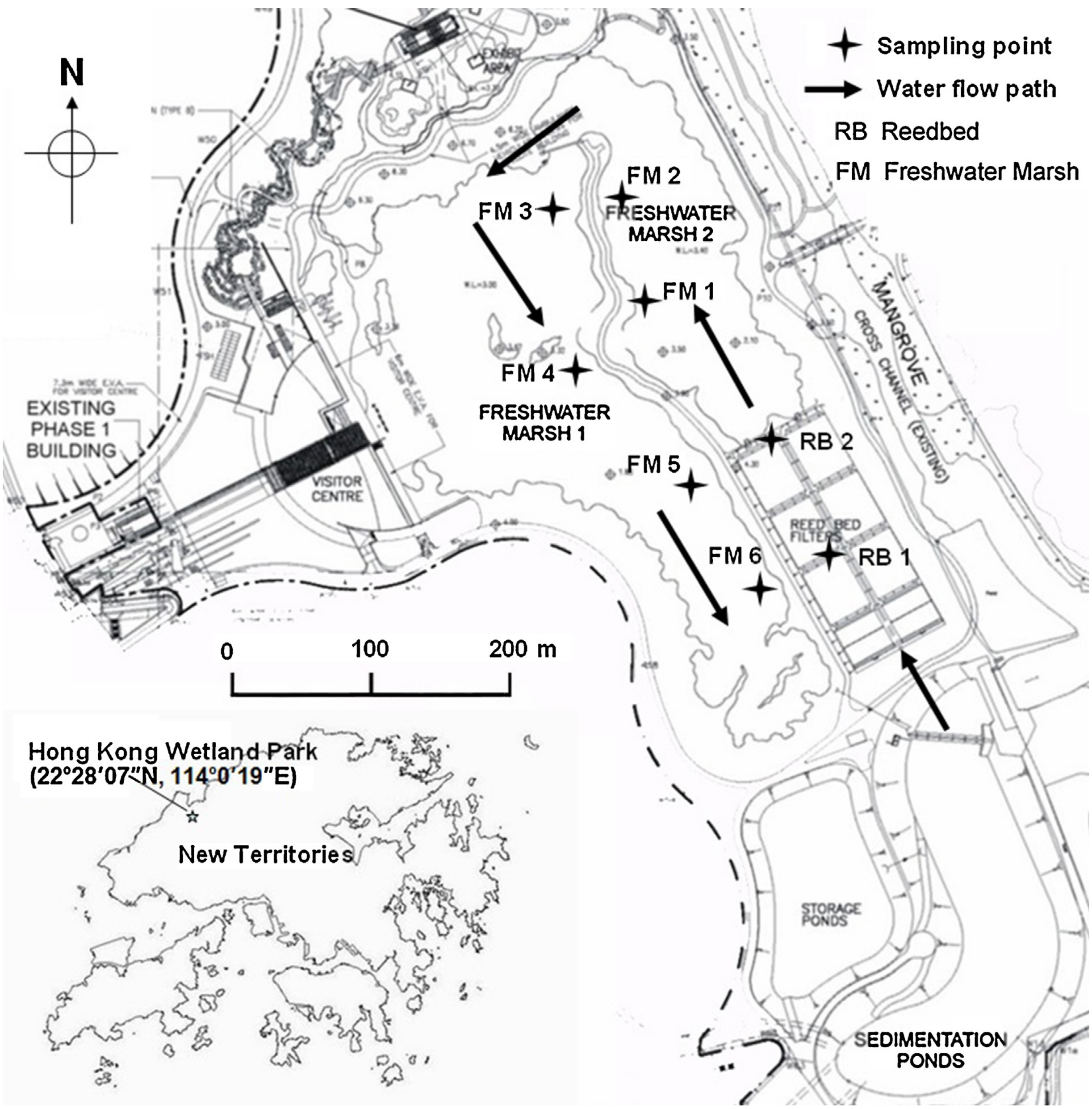

Fig. 1. A map indicating the water flow path and the locations of sampling sites in the Hong Kong Wetland Park.