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Vertical distribution of soil Fe in typical riparian subzones of the Sanjiang Plain

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ABSTRACT

Sanjiang Plain, in which marshes occupy the largest area of fresh wetlands in China, has historically been considered a key Fe source of the Amur River and the Sea of Okhotsk. Since the 1950s, extensive human activity and wetland reclamation in the Sanjiang Plain has resulted in aggravating fragmentation of marshlands into different hydrological units. In the present study, soil samples were taken from typical riparian subzones of three representative marsh rivers of the Sanjiang Plain (Yalu River, Bielahong River and Naoli River), including the wetland near river (wetland-R), the wetland near cultivated land (wetland-C) and cultivated land. Soil samples from each riparian subzone were collected vertically every 20 cm from surface to a depth of 1 m and analyzed for total Fe, free Fe oxides, amorphous Fe oxides, acid-soluble Fe(II), water-soluble Fe(II), dissolved carbon (DOC), soil total organic carbon (TOC) and pH. The results showed that the soil total Fe in the 0–60 cm layers increased in the sequence of wetland-R < wetland-C < cultivated land. On the contrary, the soil active ratio of Fe, water- and acid-soluble Fe(II) in the profile decreased in the sequence of wetland-R > wetland-C > cultivated land. These implied that the ability of Fe mobilization and export in the three river basins tended to decrease away from the river. DOC was positively correlated with acid-soluble Fe(II) while negatively correlated with total Fe, indicating that DOC might promote the production of acid-soluble Fe(II) and play a key role in export of Fe from riparian zones to adjacent waters. These findings will be useful to better understand the impacts of natural wetland reclamation in the Sanjiang Plain on the regional environment.

1. Introduction

Although Fe is abundant in nature, its availability is low due to its insolubility in aerobic circumneutral environments (Sorichetti et al., 2014a,b; Morel and Price, 2003). It has been documented that Fe can act as a limiting micronutrient to the primary productivity in high nitrogen low chlorophyll parts of oceans (Morel and Price, 2003; Han et al., 2011; Planquette et al., 2007; Takeda and Tsuda, 2005; Mills et al., 2004; Schulz et al., 2004), while the land-ocean linkage by Fe transport through rivers might help alleviate the Fe deficiency in ocean ecosystem (Narita et al., 2004; Shiraiwa, 2005; Yoh, 2004). The riverine wetland, which provides a large pool of organic carbon and nutrients, is believed to play a crucial role in export of Fe to rivers (Pan et al., 2010a). This Fe supply may exert control on the dynamics of plankton blooms in neighboring ocean, which in turn affect the biogeochemical cycles of carbon, nitrogen, silicon, and sulfur, and ultimately influence the earth's climate system (Han et al., 2011; Coale et al., 1996, 2004; Watson et al., 2000; Bishop et al., 2002; Boyd et al., 2007; Cassar et al., 2007; Buesseler et al., 2008).

Sanjiang Plain, occurs in the Amur River Basin, in which marshes occupy the largest area of fresh wetlands in China (Yang et al., 2013). It has historically been considered a key Fe source of the Amur River and even the Sea of Okhotsk in the northwest of North Pacific (Chi et al., 2010; Pan et al., 2010b). The Fe supplied from the Amur River has also been reported to contribute significantly as a Fe source for the Okhotsk Sea ecosystem (Yoshimura et al., 2010). Previous studies showed that the Amur River is one of the 10 longest rivers in the world (4350 km), and its basin covers 2.1 million km^2. Averaged water discharge from the Amur River is reported to be 11,000 $m^3\ s^{-1}$ (Ogi et al., 2001), which is the major source of fresh water to the Okhotsk Sea. The water contains 11 $mmol\ L^{-1}$ of dissolved Fe (Nagao et al., 2007). This concentration is four or five orders of magnitude greater than in coastal sea waters, typically assumed to be several $nmol\ L^{-1}$ (Lohan and Bruland, 2006). However, Sanjiang Plain has been experiencing extensive human activity and wetland reclamation by construction of numerous artificial drainage ditches since the 1950s (Liu et al., 2005; Wang et al.,

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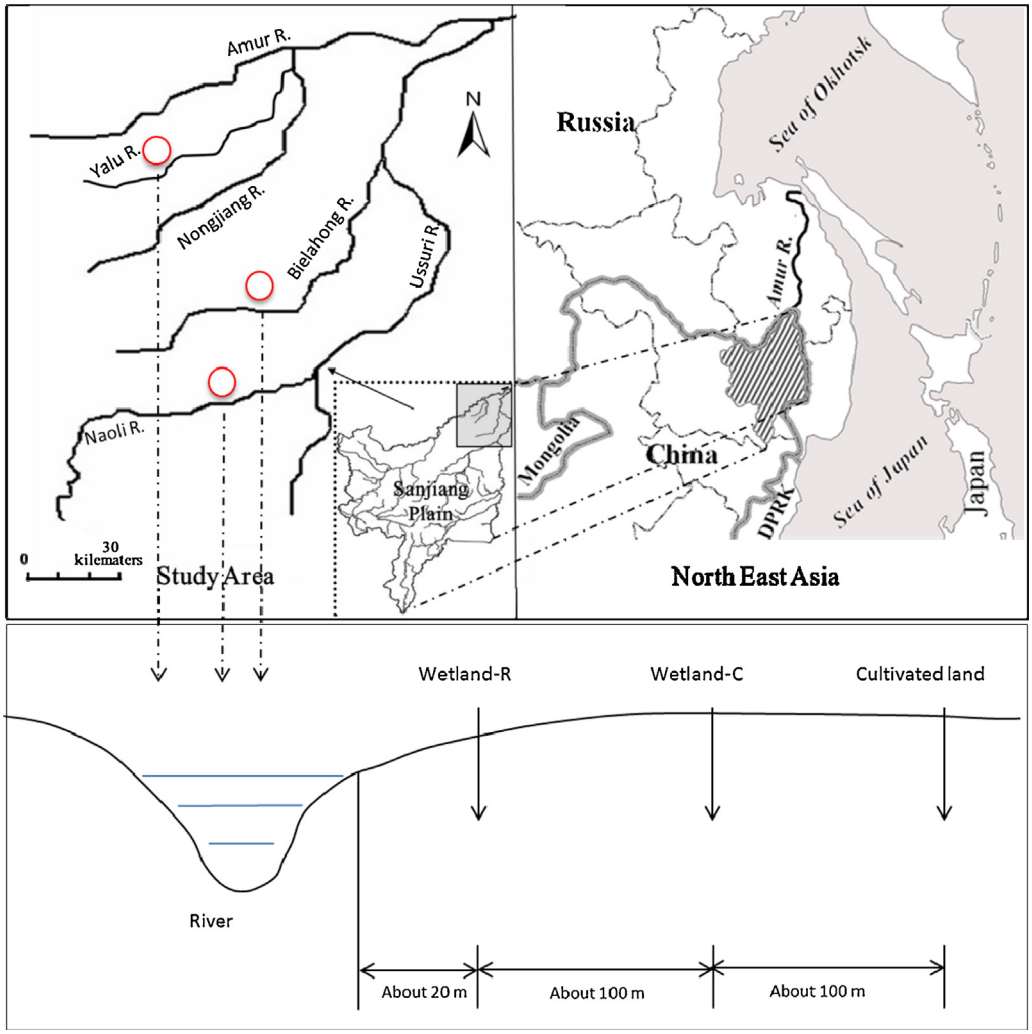

Fig. 1. Sampling sites in the study area. The distances from the wetland near river (wetland-R), the wetland near cultivated land (wetland-C) and cultivated land to the river were about 20 m, 120 m and 220 m, respectively.

2012, 2015a; Zhang et al., 2014; Ouyang et al., 2013). It has resulted in a reduction of natural wetlands from about 3.53×10^6 ha in 1954 to 0.96×10^6 ha in 2005 (Xu et al., 2012). About 80% of remaining wetlands were located on the northeast corner of the Sanjiang Plain. This area, especially the riparian zone, was historically a contiguous wetland, but is presently fragmented into different hydrological units by anthropogenic activities (Yang et al., 2012). Such changed land use and hydrological conditions will influence the biogeochemical cycling of Fe of riparian soil in Sanjiang Plain (Zou et al., 2009; Chi et al., 2010), affecting the export of Fe into rivers and the primary production in the neighboring marine environment.

Agricultural activities, especially wetland reclamation, have been considered major threats to the wetland ecosystems in Sanjiang Plain (Wang et al., 2006). To better explore the ecological impacts of wetland reclamation in the Sanjiang Plain on adjacent waters, the effects of reclamation on Fe mobility and export ability in its riparian zone should be well evaluated. Understanding the forms and spatial distribution of soil Fe in its riparian zone is a very necessary step for such evaluation. In the present study, soil samples were collected from three typical riparian subzones of three representative rivers of the Sanjiang Plain. The typical riparian subzones, with different distances to the river, included the wetland near river (wetland-R), the wetland near cultivated land (wetland-C) and cultivated land. The aims of this research were: (1) to identify the vertical distribution patterns of soil Fe in typical riparian subzones with different distances to the main watercourse, (2) to explore the activation and mobility of soil Fe in typical riparian subzones, and (3) to evaluate the ability of Fe export to adjacent waters from typical riparian subzones. The anticipated results would help to evaluate the ecological impacts of natural wetland reclamation in riparian zone in the Sanjiang Plain on the neighboring marine environment.

2. Methods and materials

2.1. Research area description

The Sanjiang Plain (43°49′55″–48°27′40″N, 129°11′20″–135°05′26″E) is located in the northeastern region of Heilongjiang Province, China. The total plain area is 10.89×10^6 ha (Liu et al., 2013). It has a typical continental monsoon climate; summer is short, warm and rainy while winter is long and cold. Average temperatures range from −18 °C in January to 21–22 °C in July, with a frost-free period of 120–140 days. Annual precipitation ranges from 500 to 650 mm, with 60% taking place from June to September. It is an alluvial plain with an altitude of <200 m in major parts and most of the rivers at the area have riparian wetlands supporting meadow and marsh vegetation (Guo et al., 2008). *Carex lasiocarpa* and *Calamagrostis angustifolia* are dominant and their coverage is up to 80–90%. Other plant communities