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Concentration and characteristics of dissolved carbon in the Sanjiang Plain influenced by long-term land reclamation from marsh

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HIGHLIGHTS

- Concentration of DOC and TC released from the Sanjiang Plain was greatly reduced after long-term land reclamation from marsh.
- The inorganic dissolved carbon exhibits obvious increased trends in the drainage ditches compared with the natural marshes.
- DOC in the degraded marsh and ditches has a simpler humification structure and contains less natural biological material.
- Presence of tyrosine and tryptophan-like substances in ditches indicates extensive agricultural organic pollution.

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ABSTRACT

Since the 1960s, the marshes in the Sanjiang Plain, Northeast China, which are an important reservoir for dissolved carbon, have undergone long-term reclamation to farmland, resulting in elevated marsh loss and degradation on a large scale. This study compared the concentrations of dissolved carbon, as well as the chemical characteristics of dissolved organic carbon (DOC), in natural marshes, a degraded marsh, and drainage ditches sampled during the growing seasons between 2008 and 2010 to clarify the temporal–spatial variability of the dissolved carbon in the fluvial system influenced by the long-term reclamation. The results show that the average concentrations of total dissolved carbon (TDC) and DOC are considerably greater in the natural marshes than in the degraded marsh and drainage ditches. The average DOC concentration for the natural marshes, approximately 35.53 ± 5.15 mg L^{-1}, is approximately 2.39 times that in the degraded marsh (14.84 ± 4.21 mg L^{-1}) and 2.77 times the average value in the ditches (12.84 ± 4.49 mg L^{-1}). The dissolved inorganic carbon (DIC) exhibits increased trends in the drainage ditches compared with the natural marshes, whereas the hydrophobic fraction of DOC is present at lower concentrations in the degraded marsh and ditches. Fluorescence indices also indicate that the DOC in the degraded marsh and ditches has a simpler humification structure. In total, the long-term reclamation has led to great variability in the DOC concentration and chemical characteristics in the fluvial system. Changes in the DOC production potential and hydrological regimes due to sustained reclamation are deemed the predominant causes of this effect. The continuously decreased DOC concentration and high variability of DOC in the surface fluvial systems are inevitable if reclamation continues in the Sanjiang Plain. More importantly, the presence of tyrosine and tryptophan-like substances in the ditches indicates that there has been extensive agricultural organic pollution in the fluvial systems. This pollution could lead to more unexpected impacts on the downriver aquatic system. To avoid a destructive ecological crisis in the future, adjustment of the reclamation policy and agricultural management measures in the Sanjiang Plain is urgently needed.

1. Introduction

The global transport of organic carbon by rivers to the oceans is estimated to be 0.36–0.9 Gt C yr^{-1} (Aitkenhead and McDowell, 2000; Cole et al., 2007), which represents only a small portion of the components in the global carbon cycle but plays an important role in many ecological processes in fluvial and coastal systems. This transport of carbon helps control the mobility of pollutants, such as trace metals and hydrophobic organic compounds (Bhatt and Gardner, 2009), and, most importantly, marine primary production processes (Raymond et al., 2000) and the rate of terrestrial carbon burial (Goñi et al., 1998). It is conservatively estimated that twice as much carbon enters inland river systems from land as is exported from the land to the sea, and over a prolonged period of time, net carbon fluxes in river systems tend to be greater per unit

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area than in much of the surrounding land (Cole et al., 2007). Thus, the river system is an important landscape form controlling the regional carbon balance.

During the past decade, changes in the concentration of dissolved organic carbon (DOC) in rivers have been widely reported in subboreal settings with wetlands (Driscoll et al., 2003; Hejzlar et al., 2003; Worrall and Burt, 2008). Several reasons have been proposed, including increasing temperature (Freeman et al., 2001), the occurrence of severe drought (Worrall and Burt, 2008), and changes in the amount of stream flow (Tranvik and Jansson, 2002). However, land use change, which represents the most powerful alteration of the terrestrial ecosystem in the past 300 years (Vitousek et al., 1997), has not been demonstrated as a main driving factor, especially in boreal wetland areas.

Wetlands in boreal areas are usually important potential land resources for agriculture because of their high soil organic content and plentiful water resources. Therefore, reclamation from wetlands to agricultural lands is pervasive all over the world. Agricultural land use has variable effects on the concentration and export of DOC (Cronan et al., 1999; Vidon et al., 2008; Wilson and Xenopoulos, 2008). In the short-term, following the reclamation, an initial increase in DOC concentration was usually observed due to mobilisation of the soil organic carbon (SOC) into the form of DOC. However, total DOC export from agricultural watersheds decreased over the long-term because the conversion from wetland to managed agricultural land depleted the soil organics gradually, owing to accelerated soil respiration and significantly reduced organic input to the soil. Several studies have reported decreased DOC concentrations in agricultural watersheds reclaimed from natural ecosystems (Meyer, 1994; Post and Kwan, 2000). There was high temporal–spatial variability in the DOC concentrations exported from the agricultural watersheds with different reclamation histories and management activities. Concentrations of between 2 and 50 mg/L in agricultural surface runoff were reported by Moore and Dalva (2001), and Zsolnay (1996) found more variable DOC concentrations, 0 to 70 mg/L, in agricultural runoff after land conversion. The high variability of DOC concentrations likely resulted from the fact that concentrations of riverine DOC are influenced by numerous factors, such as soil type, hydrologic flowpaths, wetland coverage, precipitation intensity and duration, and crop type, in addition to overall watershed land use (Hernes et al., 2008; Petrone et al., 2009). The alteration of the hydrological regime, usually introduced by the building of drainage ditches, contributes more to the temporal–spatial variability of riverine DOC than just the amount of land converted (Wilson and Xenopoulos, 2009). Therefore, factors related to hydrological and agricultural management should be accounted for. It is difficult to explain and predict the long-term tendency of DOC concentrations in agricultural runoff after reclamation from natural ecosystems based only on current knowledge (Chantigny, 2003). Hence, more detailed comparative surveys of the DOC dynamics in different agricultural and natural landscapes are needed to help understand the temporal–spatial variability as well as the main cause after long-term reclamation.

Reclamation from wetlands can also lead to great changes in the DOC chemical character in the surface runoff. Some studies have suggested that agricultural systems export compounds of lower molecular weights than natural ecosystems (Cronan et al., 1999), but more significant changes in the chemical character of the DOC with land use have not been thoroughly demonstrated. As to the overall carbon inputs to fluvial systems, DOC represents the largest bioavailable pool, acts as an important energy source to microbial metabolism, and strongly affects carbon cycling (Meyer, 1994; Battin et al., 2008). However, the validity of the action is closely linked to the chemical characteristics of the DOC, such as molecular weight, hydrophilicity and degree of humification (Amon and Benner, 1994; Vallino et al., 1996). DOC from wetlands differs from the DOC from converted agricultural systems with respect to the chemical characteristics because of the altered nutrient conditions, temperature and microbial community and activity. However, the major discrepancies in the chemical characteristics after long-term reclamation and whether the differences are stable during the seasonal changes have not been determined.

The conclusions above, however, are mainly based on surveys in European countries and North America; limited studies have been reported in North China, where there are large areas of marshes, especially in the Sanjiang Plain. The area of freshwater marsh in the Sanjiang Plain amounted to 3.53×10^4 km^2 in the 1960s, covering 32.7% of the total area of the plain. After the 1960s, however, the large-scale reclamation of marsh to paddy fields resulted in a significant decrease to 0.96×10^4 km^2 by 2005. This reclamation was promoted as a way to secure the food needs of China because the Sanjiang Plain is the largest commodity grain base in China. Land reclamation from marsh refers to the mechanical conversion of natural marsh into farmland by drainage and surface soil ploughing, resulting in complete alteration in the characteristics of the soil and vegetation. Furthermore, the natural hydrological conditions of the surface fluvial systems were completely altered by drainage digging for flood discharge, with the average lengths of the drainage ditches reaching 2.55 km km^{-2} in 2010. Therefore, a considerable number of marsh tracts were also left degraded because of water shortages or disturbances in the hydrological regime. The dramatic loss of natural marshes significantly changed the export potential of the dissolved carbon produced from the organic soil that accumulated there for thousands of years (Song et al., 2011). Consequently, significant alteration in the dynamics of the dissolved carbon from the Sanjiang Plain could directly alter the carbon flux to the Amur River and even the Sea of Okhotsk in the northwest of the North Pacific.

It is important to elucidate the characteristics of the dissolved carbon from the Sanjiang Plain to estimate the possible consequences of the lower aquatic ecosystems. To date, however, the spatial–temporal features of the concentrations and chemical components of the dissolved carbon from the plain have not been surveyed in detail, and the extent to which the dissolved carbon characteristics were altered through the long-term reclamation has also not been well-demonstrated. Thus, the objectives of this study are to investigate the temporal–spatial features of the concentrations and chemical characteristics of DOC in the surface fluvial systems and to elucidate the effect of the long-term land reclamation on the features of the dissolved carbon in the Sanjiang Plain.

2. Materials and methods

2.1. Site description

The Sanjiang Plain is located in the winter-cold zone in Northeast China and is formed by three major rivers: the Amur, Ussuri, and Songhua. The boreal climate conditions and the low slope grade provide the plain with the greatest marsh concentration in China (Fig. 1). The plain experiences a mean annual temperature of 1.9 °C and a mean annual precipitation of 565.3 mm. The rainfall primarily occurs in the summer and early fall when the warmest months emerge, with a mean temperature of 21.6 °C (1981–2008). The surface water and soil are completely frozen by late October. The snow accumulated throughout the winter is approximately 20–40 cm in thickness, and it begins to melt in late April, followed by thawing of the surface of the frozen soil in early May. The plants in the natural marsh, primarily *Calamagrostis angustifolia*, *Carex lasiocarpa*, and *Betula fruticosa*, burgeon at the end of April and wilt in mid-October. The gleying swampy soil in the marsh is extensively distributed, and its organic contents usually exceed 15% in the upper 50 cm layer, with albic soil underneath. The Bielahong, Nongjiang and Naoli are the three main rivers connected to the marshes in the plain, and detectable runoff occurs at the beginning of May and disappears usually in mid-October.

2.2. Field sampling and data collection

The basin of the Bielahong River was chosen as our target to clarify the characteristics of the dissolved carbon in different fluvial systems