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Identifying organic matter sources using isotopic ratios in a watershed impacted by intensive agricultural activities in Northeast China

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ABSTRACT

Knowledge about the origin and variation of OM (organic matter) pools in a receiving river might provide a basis for addressing non-point sources of pollution resulting from intensive agricultural activity. In this study, an isotopic approach ($\delta^{13}C$, $\delta^{15}N$ and C/N ratios) was used to identify potential OM sources and C and N cycle processes occurring in the Abujiao River watershed located in the Sanjiang Plain. A Bayesian model (stable isotope analysis in R, SIAR) was utilized to apportion the contributions of potential sources. In this watershed, isotopic ratios of $\delta^{13}C$ ranged from −30.62‰ to −23.71‰ and from −28.22‰ to −23.98‰ in particulate organic matter (POM) and sedimentary organic matter (SOM), respectively. Slightly lower $\delta^{15}N$ values (3.12 ± 4.12‰ in POM; 3.7 ± 2.42% in SOM) and C/N ratios (6.62 ± 5.28 in POM; 10.73 ± 6.58 in SOM) were found in SOM pools. Considerable spatio-temporal variability of the organic carbon and nitrogen isotopic ratios was present in the POM pool, which was controlled by storms and land use. The unusually low $\delta^{15}N$-POM values accompanied by high chlorophyll-a concentrations suggested that an isotopic fractionation effect caused by phytoplankton existed in the POM pool. However, isotopic characteristics indicated that the isotopic fractionation was absent in the SOM pool. SIAR modeling result showed that source contributions differed significantly among different sampling periods. During storms, "soil OM" was the major source (accounting for 45.50%) in the POM pools. During other periods, effluent detritus and phytoplankton sources were predominant in the downstream region. Compared with POM, almost half of SOM came from terrestrial sources, and the effluent detritus and "soil OM" sources predominated in the SOM pool. This study suggested that assessment of behaviors and sources of OM could lead to the implementation of effective non-point source pollution reduction strategies and management practices for protecting water quality.

1. Introduction

The Sanjiang Plain is one of the largest freshwater marsh regions in China. However, since the 1950s, the Sanjiang Plain has experienced four major agricultural development activities and numerous wetlands and native forests have been exploited as crop lands (Song et al., 2008). Intensive agricultural activities caused eco-hydrological changes, soil organic matter loss (black soil resources decreased from 60–100 cm to 16–72 cm), and serious non-point nitrogen pollution in aquatic systems (Hao et al., 2012). For example, severe surface water pollution was observed in the second Songhuajiang River, Yinma River and Yitonghe River (Sun et al., 2014). Meanwhile, relatively high NO_3^- concentrations (up to 153.29 mg/L) had been also observed in the groundwater, especially in agricultural areas (Cao et al., 2012). Because most of nutrient and pollutant input served to fill organic matter (OM) pools (including the suspended particulate organic matter pool (POM) and the sedimentary organic matter pool (SOM)), a knowledge in the origin and variation in POM and SOM in the receiving river Could provide a basis for addressing environmental problems caused by intensive agricultural activity (Ko and Baker, 2004; Liu et al., 2007; di Lascio et al., 2013; Lu et al., 2013).

Numerous studies in the Sanjiang Plain were conducted to investigate the characteristics and factors affecting soil degradation in agro-ecosystems (Zhou et al., 2009; Wang et al., 2012), the effect of nutrient losses on soil ecosystems (Wang et al., 2006; Zhao et al., 2012; Ouyang et al., 2013a,b), and characteristics and sources of nitrate in receiving rivers (Cao et al., 2012; Lu et al., 2015). However, studies on the migration and transformation processes of organic matter are sparse. In particular, little information relating to the sources of organic matter in receiving river ecosystems in

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the Sanjiang Plain is available. Although some researches on characteristics and sources of OM were conducted in other regions of China (Liu and Xing, 2012; Fu et al., 2014), the distinctive black soil properties and the seasonal freezing–thawing processes in this unusual high latitude agricultural area inevitably resulted in a significant difference in OM sources. Additionally, because of intensive agricultural activities, ecological structures of original landscape was changed, and single natural ecosystems was replaced by a hybrid ecosystem in which the identification of OM sources was more complicated (Lu et al., 2014). These constraints have limited the control and management of environmental problems caused by intensive agricultural activity in the Sanjiang Plain.

Geochemical indicators are widely used to identify the origin of OM in aquatic ecosystems, and stable isotope ratios have been reported to be one of the most diagnostic (Finlay and Kendall, 2007). In freshwater ecosystems, the $\delta^{13}C$ value was the most effective indicator of organic C sources and energy flow (Nagel et al., 2009). Conversely, the $\delta^{15}N$ value was a powerful indicator of the nitrogen cycle and food web interactions (Middelburg and Nieuwenhuize, 2001). Moreover, other tracers, particularly elemental ratios (i.e., the C/N ratio), might also be used to complement isotopic approaches for determining organic matter sources (Kendall et al., 2001). For example, $\delta^{13}C$ values coupled with C/N ratio can effectively separate land-derived organic matter (from C_3 and C_4 plants) from aquatic plants (Meyers, 1994). Additionally, researchers have successfully quantified different OM source contributions using a mass-balance mixing model (Xiao and Liu, 2010; Lu et al., 2013; Ford et al., 2015). However, a mass-balance mixing model is often performed to find unique solutions with the assumption that there is no variability within sources (Xue et al., 2009). To fully incorporate those sources of uncertainty, Parnell et al. (2008) have developed and implemented a stable isotope mixing model called SIAR. SIAR model used a Bayesian framework to establish a logical prior distribution based on Dirichlet distribution (Evans et al., 2000) for estimating possible proportional source contribution, and then to determine the probability distribution for the proportional contribution of each source to the mixture. This model has been successfully applied in food-web and multiple nitrate source contributions in complex situations (Xue et al., 2012; Lu et al., 2015). Thus, a combination of C and N isotopes, C/N ratios and the SIAR model might provide more detailed information regarding the OM sources and potential C and N cycling processes from intensive agricultural activity in impacted watersheds.

In this study, we investigated the OM sources and C and N cycles in aquatic systems from a watershed undergoing intensive agricultural activity with mixed land use types in the Sanjiang Plain. By analyzing the stable isotope ratios ($\delta^{13}C$, $\delta^{15}N$) and the C/N ratio of OM, we systematically examined the potential OM sources and C and N cycling processes during different sampling periods. The SIAR model was used to quantitatively apportion contributions of potential sources. The objectives of this study were to (1) determine the factors that explained variability and isotopic composition of OM in aquatic ecosystems, (2) identify the main C and N cycling processes in different OM pools, and (3) apply

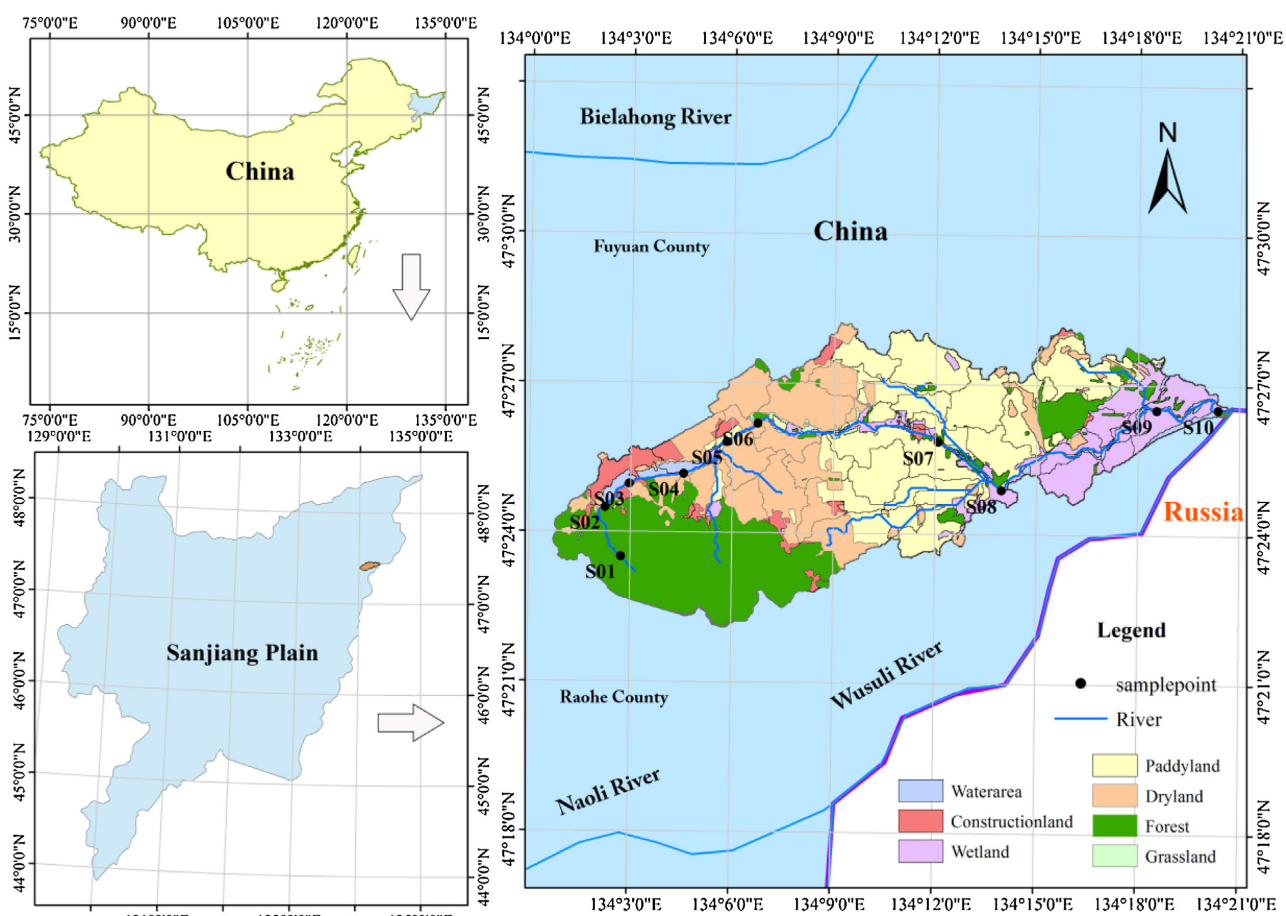

Fig. 1. Study area and sampling sites.