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Controls of carbon flux in a semi-arid grassland ecosystem experiencing wetland loss: Vegetation patterns and environmental variables

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ABSTRACT

Inner Mongolia, China, contains the world's largest grassland ecosystem. This has many areas of wetland, which provide important ecological services, especially carbon sequestration in the semi-arid terrestrial ecosystems. However, the area of wetland has decreased sharply in the past two decades. This study examined ways to recognize and extract wetland from grassland to determine the difference among net ecosystem exchange (NEE), gross primary production (GPP) and ecosystem respiration (R_{eco}) between wetland and grassland and to evaluate the influence of wetland loss on carbon sequestration in the grassland. The eddy covariance (EC) flux technique was coupled with the Vegetation Photosynthesis and Respiration Model (VPRM) to upscale the spatial patterns of carbon flux. The results showed that the region was a carbon source in 2016, probably caused by overharvesting and degradation of forests. The value of the NEE (average: $6.63 \pm 3.50\,g\,C\,m^{-2}\,d^{-1}$) in grassland was apparently higher than that in wetland (average: $0.86 \pm 1.69\,g\,C\,m^{-2}\,d^{-1}$), which suggested that the capability of carbon sequestration in wetland was still stronger than that in grassland even in carbon loss condition. The results showed a positive relationship between aboveground biomass (AGB) and ground-based daily GPP or R_{eco} for both wetland and grassland and a negative relationship between AGB and NEE. The ground-based daily NEE was also significantly related to soil water content (SWC) but showed no relationship with daily precipitation (PRE), which suggested that SWC was a more important impact factor than precipitation on CO_2 flux exchange in the study area. The change between wetland and grassland did not influence the positive relationship between AGB or SWC and CO_2 flux. Our study provides a new way to determine the spatial CO_2 flux exchange and its controlling factors (environmental variables and vegetation patterns) and to successfully analyze its differences in wetland and grassland.

1. Introduction

Inner Mongolia, where grassland covers approximately 78 million ha and occupies 21.7% of the total grassland in China, is regarded as one of the world's five largest prairies (Ellis, 1992). The grassland has been recognized as a significant ecological barrier, supplying numerous ecosystem service functions for northern China, such as carbon sequestration, soil and water conservation, and a genetic library (Xu et al., 2009; Wu et al., 2015). The carbon sequestration function of grassland is considered as its most important ecosystem function; however, the climate in Inner Mongolia is classified as semi-arid and therefore grass in this area is often subjected to limited water and even to droughts. Most climate model estimations indicate that the atmosphere will become drier as carbon dioxide (CO_2) increases in the area, caused by rising temperature and potential evapotranspiration (IPCC Climate Change, 2007). Hence, the issue of net ecosystem CO_2 exchange (NEE) in the semi-arid grassland ecosystem becomes increasingly important because of its interactive mechanisms with environmental variables.

The region's many areas of wetland are especially found in Hulun Buir (Zhang et al., 2008). Wetland plays an important role in the carbon cycle and is estimated to store 15% of total carbon in global terrestrial ecosystems (Laffoley and Grimsditch, 2009; Crooks et al., 2011; Liu and Zhou, 2012). Carbon sequestration in wetland, whose actual carbon sink capacity depends on the net balance of its carbon fluxes, has attracted growing attention in recent years. Wetland has a higher accumulation of organic matter compared with other ecosystems, because of its higher net primary productivity (NPP) and the lower rate of decomposition of organic matter in terrestrial ecosystems (Crooks et al., 2011; Hu et al., 2012, 2017; Sjögersten et al., 2014; Han et al., 2014). In recent decades, wetland has got shrunk rapidly and started to disappear to date (Zhang et al., 2008). Previous studies indicated that wetland

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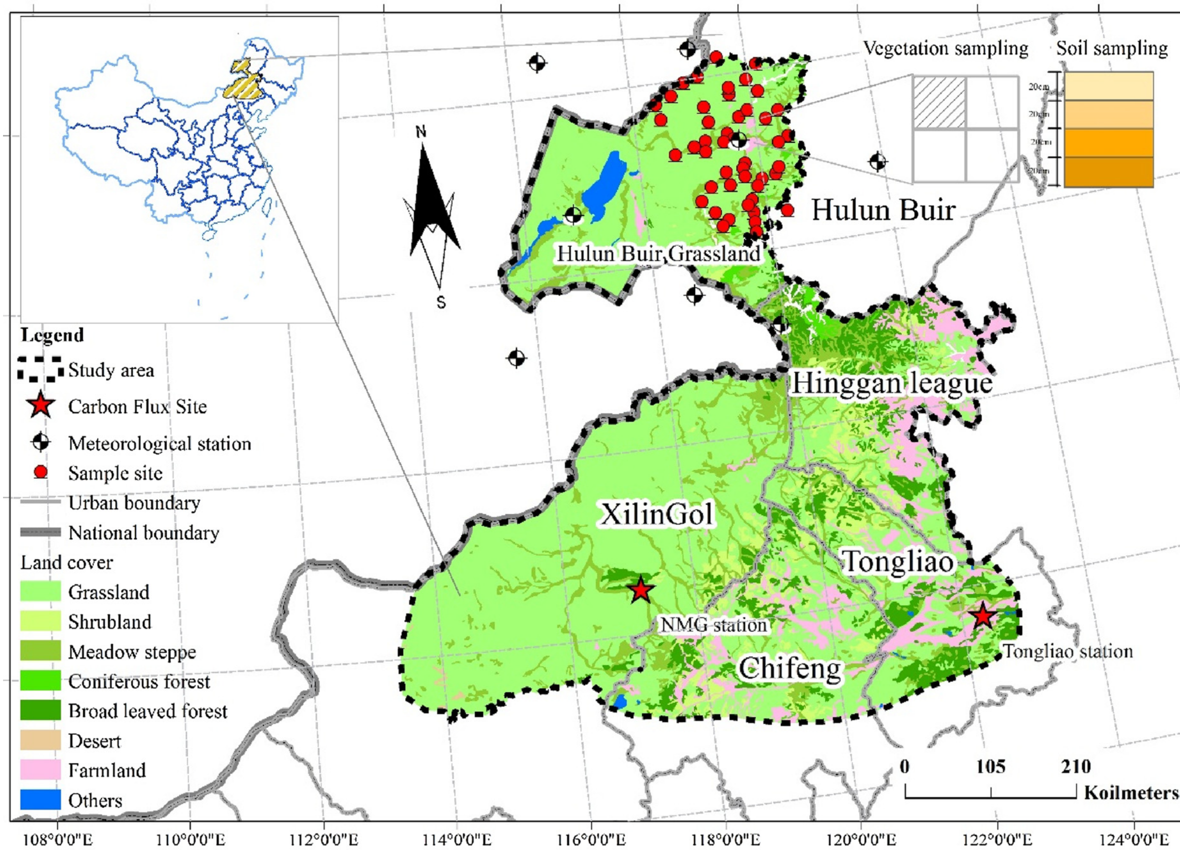

Fig. 1. Schematic map of the study area.

loss might halt ongoing carbon sequestration and release soil carbon stores (Wang et al., 2010; Crooks et al., 2011). Wetland loss might also change soil properties, such as soil organic matter, by changing above- and belowground productivity and the communities of dominant plant species (Keller et al., 2004). Therefore, the change in carbon flux, especially NEE, as a result of wetland loss in the semi-arid grassland ecosystem has become the first priority in the region. Additionally, the acknowledged CO_2 flux is subject to photosynthesis and CO_2 emissions via plant and soil respiration caused by the environmental variables and vegetation patterns (Gu et al., 2003; Li et al., 2005; Fu et al., 2006a; Nakano et al., 2008). CO_2 flux response sensitively to environmental variables (e.g. meteorological factors and hydrological factors) and vegetation patterns (e.g. leaf area index (LAI) and AGB), particularly in water-limited ecosystems (Ni, 2003; Miyazaki et al., 2004; Nakano et al., 2008). Additionally, previous study found the AGB were better in representing the vegetation characteristic and pattern in grassland ecosystem and the importance of its impact on CO_2 flux (Nakano et al., 2008). However, to date few studies have quantified the influence of wetland loss on CO_2 flux on the grassland ecosystem and clarify the mechanisms: the impact of environmental variables and vegetation patterns on CO_2 flux in both wetland and grassland.

The eddy covariance (EC) technique, coupled with biogeochemical and satellite-based remote sensing models, is recognized as the most direct and common method to estimate NEE (Baldocchi, 2003). In this study, the Vegetation Photosynthesis Respiration Model (VPRM) was selected and validated to estimate carbon flux on a regional scale. VPRM shares many characteristics of earlier models for surface CO_2 fluxes, for example NASA-CASA (Potter et al., 1999), SiB2 (Sellers et al., 1996), and the Vegetation Photosynthesis Model (VPM) (Xiao et al., 2002, 2004) and has the advantage of providing much finer representation of surface fluxes; therefore, it has been widely used to estimate carbon flux in recent years (Mahadevan et al., 2008; Yuan et al., 2014). VPRM estimates NEE by calculating gross primary production (GPP) and ecosystem respiration (R_{eco}) separately. GPP is also important in representing the vegetation productivity of the ecosystem and R_{eco} indicates the vegetation respiration and soil microbial activity (Huxman et al., 2004). Although the uncertainty in the model may originate from the indirect measurement of remote sensing data and parameter validation, it can provide a continuous, long-term temporal series carbon flux for a local ecosystem (Mahadevan et al., 2008; Ran et al., 2016). Thus, we used separate EC flux data sets to parametrize and validate VPRM and then upscaled this to the regional scale to explore the spatial patterns of carbon flux for the grassland ecosystem experiencing wetland loss.

Two important issues have to be resolved before estimating the region's NEE: (1) recognition and extraction of the wetland; and (2) quantification of the NEE in wetland and grassland. Because EC systems are established in relatively homogeneous ecosystems, spatial variation in the structural characteristics of the vegetation is minimal to reduce uncertainly (Ran et al., 2016). We thus assumed that EC data were applied reasonably and validly to the entire grassland ecosystem in the study. Moreover, since it is difficult to estimate accurately the location of a wetland in a large, rural area (He et al., 2009) and field investigation is time-consuming, we proposed a new, rapid and simple method to estimate the location of a wetland. Although several literatures have found a relationship between NEE and environmental parameters in grasslands (Suyker and Verma, 2001; Li et al., 2005; Nakano et al., 2008; Hussain et al., 2015), few of them focus on a grassland ecosystem experiencing wetland loss.

The main objectives of this study were: (1) to extract the location of wetland in the grassland ecosystem; (2) to evaluate the CO_2 flux that is modified by GPP and ecosystem respiration (R_{eco}), and to estimate the contribution of wetland loss to CO_2 flux in the semi-arid grassland ecosystem; and (3) to quantify the influence of atmospheric constraints and vegetation patterns on CO_2 flux in both wetland and grassland.