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Determinants of soil erosion during the last 1600 years in the forest–steppe ecotone in Northern China reconstructed from lacustrine sediments

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ABSTRACT

Wind erosion of soil in northern China contributes to the environment of East Asia and even the Northern Hemisphere. It is commonly thought that human-induced grassland degradation determines soil erosion in the semi-arid steppe region. In this study, we revealed determinants of soil erosion during the last ~1600 years through analyzing lacustrine sediment from Huangqihai Lake in this region. Our results showed that soil erosion indicated by sediment particle size was enhanced during three periods: 1570–1330 cal. yr. BP with warm and dry climate, 1250–1000 cal. yr. BP with warm and wet climate, and 470–150 cal. yr. BP with cold and dry climate. The common feature of vegetation regimes for enhanced soil erosion was replacement of forest by steppe, suggesting that decline in vegetation cover from forest to steppe, which was attributed to climatic changes, might lead to enhancement in soil erosion. The trend of historical soil erosion did not match the steady increase in historical human population in China and the very short history of massive cultivation in southern Inner Mongolia. In summary, our results supported nature- rather than human-dominated soil erosion in the semi-arid steppe region in north China during the last 1600 years.

1. Introduction

Soil erosion in semi-arid regions could significantly contribute to the environment at regional and even continental scales (Creamean et al., 2014). Wind erosion of grassland soil has become serious during the last decade in the semi-arid region of China (Liu S et al., 2013), which is significant for the environment of East Asia and even the whole Northern Hemisphere (Millennium Assessment, 2005). Dust transported from this area increases aerosol concentrations, lowers temperatures in the downwind areas, alters nutrient cycles in the Pacific Ocean and harms human health in East Asia and even North America (Uno et al., 2001; Mori et al., 2003; Creamean et al., 2014).

The wind erosion of grassland soil depends on strong wind and low vegetation cover, both of which are related to climatic drying (Nandintsetseg and Shinoda, 2015). The current grassland cover decline along the precipitation gradient implies that grassland cover decline driven by climatic drying enhances the soil erosion (Liu et al., 2008). We therefore hypothesized that soil erosion is determined by low vegetation cover under a dry climate. However, we cannot exclude the role of human disturbance such as overgrazing and cultivation on soil erosion, as stressed by studies on contemporary soil erosion (e.g. Xu et al., 2007).

Environmental change during the past two millennia remains a hotspot of past global changes (PAGES) because of its close relationship with human activities (Newman et al., 2010). Paleoenvironmental reconstruction might help identify the roles of natural and anthropogenic factors in controlling environmental change. Previous studies suggested that low-frequency magnetic susceptibility of sediment well indicates soil erosion (Wang et al., 2012). In regions dominated by wind-erosion process, coarse magnetic grains were blown into lakes, leading to increase in both low-frequency magnetic susceptibility and mean soil grain size in sediment (Wang et al., 2010). In this study, we first reconstructed soil erosion, climatic aridity and vegetation cover with sediments collected from Huangqihai Lake in the semi-arid forest–steppe ecotone in Inner Mongolia, China. We further combined these reconstructions with reconstructed regional temperature and vegetation type from previous studies to reveal relationships between different environmental factors during the past 1600 years, which were rarely considered in previous studies in the semi-arid region of China (Zhao et al.,

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2009). In particular, we tried to identify what determined soil erosion under the changing climate of the past 1600 years.

2. Study area and methods

2.1. Study area

The study area, Huangqihai watershed, is located at the southeastern edge of the Inner Mongolian Plateau (40°47′–40°54′N, 113°05′–113°23′ E) in the marginal belt of the Pacific monsoon influence (Fig. 1). Mean annual temperature is 4.5 °C and mean annual precipitation is 372.7 mm, with about two-thirds of annual rainfall occurring during June–August (Hao et al., 2014).

The Huangqihai Lake is mainly supplied by surface runoff. There are four main rivers flowing into the lake: Bawang, Quanyulin, Mopanshan and Longshengzhuang Rivers. The lake water area has shrunk in recent decades, leaving a current area of about 80 km^2 (Hao et al., 2014).

2.2. Methods

2.2.1. Sampling

A 70-cm section was dug in September 2012. The location of the section was selected to avoid direct inflow influences, to ensure continuous deposition of the lake sediments. The section was sampled at 1-cm intervals in the field. The samples were packed and transferred to the laboratory of Peking University, where they were dried.

2.2.2. Chronological model

Nine samples were selected from different depths, and dated by accelerated mass spectrum (AMS) ^{14}C in the AMS Laboratory of Peking University (Table 1). All dates were calibrated to years before present (cal. yr. BP) based on IntCal13 (Reimer et al., 2013) (Table 1). A possible reservoir effect of 1440 years – the sum of 1378 years and the difference between 2012 and 1950 (before which BP is defined) – was removed from the sediment surface as also performed for a 820-cm core at Huangqihai Lake (Hao et al., 2014). Because of its high temporal variability in old carbon effect and gradual accumulation of ‘old carbon’ in inland lakes, we assumed a gradually increasing old carbon effect from bottom to top of the section, as we did in previous work at this lake (Hao et al., 2014) and Hulun Nuur, a lake 200 km northeast of Huangqihai Lake (Yin et al., 2015).

Table 1
AMS radiocarbon dates and calibrated years of samples from the Huangqihai sediment core.

Code	Depth(cm)	Sediment type	^{14}C age	Cal. age (cal. yr. BP)
BA12653	3–4	Bulk sediment	1540 ± 25	1464–1511
BA13266	11–12	Bulk sediment	1525 ± 30	1346–1447
BA13263	18–19	Bulk sediment	2060 ± 25	1967–2073
BA13261	27–28	Bulk sediment	1640 ± 20	1512–1574
BA13264	34–35	Bulk sediment	3285 ± 25	3450–3569
BA13262	44–45	Bulk sediment	3230 ± 25	3380–3484
BA13265	58–59	Bulk sediment	2740 ± 25	2771–2879
BA13260	63–64	Bulk sediment	2585 ± 25	2710–2757
BA12655	67–68	Bulk sediment	2740 ± 50	2775–2874

Using the original ^{14}C measurements, the possible carbon reservoir effect and their associated uncertainty as prior information, we obtained a probable distribution of chronology using Bayesian age–depth analysis (Fig. 2). Two samples from respective depths of 34–35 and 44–45 cm were located far from the curve because of possible reversal of ^{14}C ages and, therefore, uncertainties of calibrated ages were larger in the middle than in the upper and lower sections.

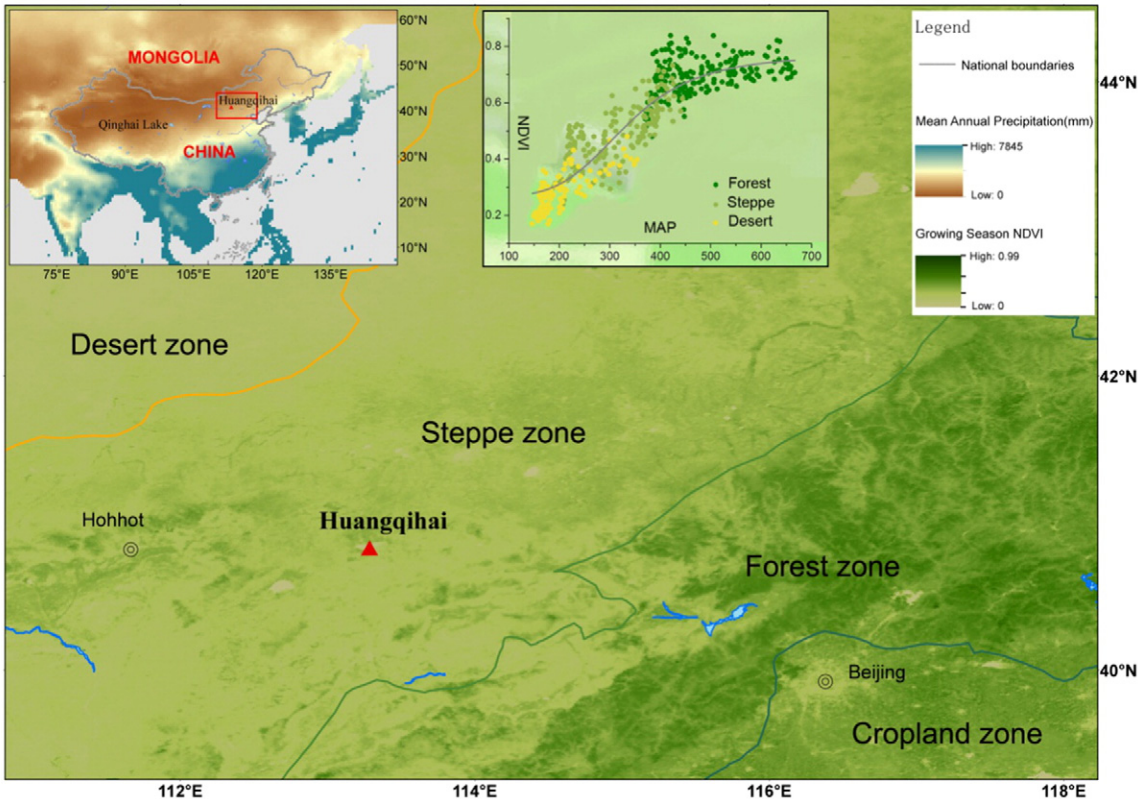

Fig. 1. Geographic features of the study area. (a) Location of Huangqihai Lake in China on the contour map of mean annual precipitation (MAP). (b) Change of vegetation cover as indicated by normalized difference vegetation index (NDVI) of forest, steppe and desert along the MAP gradient in northern China (Liu G et al., 2013). (c) Location of Huangqihai Lake in the vegetation map of the study region and surrounding region. The NDVI can roughly differentiate forest, steppe and desert as indicated in b. Dark green indicates approximate distribution of forest.