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Differential response of vegetation in Hulun Lake region at the northern margin of Asian summer monsoon to extreme cold events of the last deglaciation

Shengrui Zhang [a, b], Jule Xiao [a, b, c, *], Qinghai Xu [d], Ruilin Wen [a], Jiawei Fan [a], Yun Huang [a, b], Hideki Yamagata [e]

[a] Key Laboratory of Cenozoic Geology and Environment, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China
[b] College of Earth and Planetary Sciences, University of Chinese Academy of Sciences, Beijing 100049, China
[c] CAS Center for Excellence in Life and Paleoenvironment, Beijing 100044, China
[d] College of Resources and Environment, Hebei Key Laboratory of Environmental Change and Ecological Construction, Hebei Normal University, Shijiazhuang 050024, China
[e] Paleo Labo Co., Ltd., Saitama 335-0016, Japan

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ABSTRACT

The response of vegetation to extreme cold events during the last deglaciation is important for assessing the impact of possible extreme climatic events on terrestrial ecosystems under future global warming scenarios. Here, we present a detailed record of the development of regional vegetation in the northern margin of Asian summer monsoon during the last deglaciation (16,500–11,000 cal yr BP) based on a radiocarbon-dated high-resolution pollen record from Hulun Lake, northeast China. The results show that the regional vegetation changed from subalpine meadow-desert steppe to mixed coniferous and deciduous forest-typical steppe during the last deglaciation. However, its responses to the Heinrich event 1 (H1) and the Younger Dryas event (YD) were significantly different: during the H1 event, scattered sparse forest was present in the surrounding mountains, while within the lake catchment the vegetation cover was poor and was dominated by desert steppe. In contrast, during the YD event, deciduous forest developed and the proportion of coniferous forest increased in the mountains, the lake catchment was occupied by typical steppe. We suggest that changes in Northern Hemisphere summer insolation and land surface conditions (ice sheets and sea level) caused temperature and monsoonal precipitation variations that contributed to the contrasting vegetation response during the two cold events. We conclude that under future global warming scenarios, extreme climatic events may cause a deterioration of the ecological environment of the Hulun Lake region, resulting in increased coniferous forest and decreased total forest cover in the surrounding mountains, and a reduction in typical steppe in the lake catchment.

1. Introduction

As the principal component of terrestrial ecosystems, vegetation plays a crucial role in sustaining the global carbon cycle, regulating greenhouse gas concentrations and influencing regional climates (Bonan et al., 1992; Schimel, 1995). Therefore, the response processes and feedback mechanisms of vegetation to climate change have been a major focus of global change research (e.g. Lashof et al., 1997). The last deglaciation was punctuated by several abrupt climatic events in high northern latitudes that had a major influence on global atmospheric circulation and terrestrial ecosystems (Denton et al., 2010; Clark et al., 2012). Thus, understanding vegetation succession and its response to abrupt climatic events during the last deglaciation in different regions is important for assessing the impact of future global warming and possible extreme climatic events on terrestrial ecosystems.

Previous studies have shown that the vegetation composition changed significantly in Europe (Huntley, 1990; Binney et al., 2017),

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[*] Corresponding author. Institute of Geology and Geophysics, Chinese Academy of Sciences, No. 19, Beitucheng Western Road, Chaoyang District, 100029, Beijing, China.

E-mail address: jlxiao@mail.iggcas.ac.cn (J. Xiao).

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North America (Prentice et al., 1991; Williams et al., 2002) and the tropics (Hughen et al., 2004) during the last deglaciation: during the Bølling-Allerød warming event (B/A) and the early Holocene, forest expanded at low latitudes (Hughen et al., 2004) and horizontal vegetation zones migrated northward and inland in mid-high latitudes (Huntley, 1990; Williams et al., 2002; Dyke, 2005). In contrast, during the Heinrich event 1 (H1) and the Younger Dryas event (YD), forest shrank and dry grassland dominated at low latitudes (Hughen et al., 2004), while cold-resistant species increased at mid-high latitudes (Yu and Eicher, 1998). These observations indicated that the vegetation responded rapidly and sensitively to abrupt climate change, but that the changes in vegetation communities and the extent and rate of migration of vegetation zones varied significantly at different latitudes.

Vegetation change in East Asia during the last deglaciation has received much research attention in recent years (Demske et al., 2005; Stebich et al., 2009; Park and Park, 2015; Wu et al., 2016a, 2016b). It is well established that the vegetation responded dramatically to millennial- and centennial-scale climatic fluctuations during this period (Stebich et al., 2009; Park and Park, 2015; Wu et al., 2016a). However, most of the previous studies have focused on mountain lakes or small lakes (e.g., Sihailongwan Lake - Stebich et al., 2009; Hanon Maar paleolake - Park and Park, 2015; Moon Lake - Wu et al., 2016a; and Gonghai Lake - Xu et al., 2017) which are significantly affected by factors such as lake basin shape, topography, and altitude. Consequently, such records tend to reflect variations in local vegetation or vertical migration of mountain vegetation zones (Jacobson and Bradshaw, 1981; Sugita, 1994) and they provide less information about changes in regional vegetation. In addition, existing high-resolution paleo-vegetation records mainly came from low-middle latitudes and there is a dearth of records from higher latitudes of East Asia. Therefore, there is a need for a greater number of regional paleo-vegetation records from mid-high latitudes to provide a more comprehensive understanding of the vegetation response to extreme cold events during the last deglaciation.

Hulun Lake is in a climatically sensitive region, on the northeastern edge of the current monsoon margin, and therefore is well suited for reconstructing regional climate and vegetation change (Xiao et al., 2009; Wen et al., 2010). In this study, we reconstructed the vegetation history of the Hulun Lake region during the last deglaciation (16,500–11,000 cal yr BP) based on AMS ^{14}C dating and pollen analysis. Our aims were to determine the response of the regional vegetation at the northern margin of Asian summer monsoon to abrupt climate change, with the focus on the extreme cold events of H1 and YD. It was hoped that the results would provide insights into the possible regional vegetation response to future global warming and associated extreme climatic events.

2. Hulun Lake and its environment

Hulun Lake (48°30′40″ to 49°20′40″N, 117°00′10″ to 117°41′40″E, 543 m a.s.l.) is located ca. 30 km south of Manchuria, Inner Mongolia, in an inland graben basin that formed in the late Pliocene (Fig. 1A). The Hulun Lake has a catchment of 37,214 km^2 within the borders of China, and two major rivers enter the lake, the Herlun River (more than 1000 km long) flowing from the southeastern part of the Hentiy Mountains and the Urshen River (about 220 km long) flowing from the western part of the Great Hinggan Range (Xu et al., 1989).

Hulun Lake is in the semi-arid region of the middle temperate zone. The climate of the region is controlled by the East Asian Summer Monsoon (EASM) and continental polar air masses. Summers are short and warm and winters are long and cold (Xu et al., 1989). The regional mean annual temperature ranges from −0.7 to 1.1 °C, with a July average of 18.3 to 20.1 °C and a January average of −21.3 to −19.3 °C. Mean annual precipitation ranges from 248 to 292 mm, with 70% falling in summer (June-July- August). Mean annual evaporation ranges from 1500 to 1800 mm (Yan et al., 2012).

The modern natural vegetation of the Hulun Lake catchment is middle temperate steppe, and the plant communities consist mainly of *Stipa grandis*, *Stipa krylovii* and *Leymus chinensis* grass steppe, dominated by Gramineae, Asteraceae and Rosaceae species. The intrazonal vegetation includes psammophytes growing on the eastern shore of Hulun Lake and in the Chagang sandy land. Halophytes are distributed in the lowland areas or in areas with alkaline saline soils, and meadow occurs in the river valleys and wetlands (Inner Mongolia–Ningxia Integrated Survey Team, Chinese Academy of Sciences, 1985). On the western slopes of the Great Hinggan Range, coniferous forest is prevalent above 1000 m; it is dominated by *Larix gmeliai*, *Betula platyphylla* and *Populus davidiana*, *Pinus pumila*, *Pinus sylvestris* and *Picea koraiensis* which occur sporadically. Between 800 and 1000 m, the vegetation is forest steppe with mesophytic meadows, with the sporadic occurrence of islands of birch and poplar forest and dense shrub land (Inner Mongolia–Ningxia Integrated Survey Team, Chinese Academy of Sciences, 1985). On the eastern slopes of the Hentiy Mountains, subalpine meadow occurs above 2000 m and is composed of cryophilous species (mainly of Cyperaceae, Asteraceae and Polygonaceae); between 1600 m and 2000 m, coniferous forest is present, dominated by *Larix sibirica* with the frequent occurrence of *Betula platyphylla*, *Picea obovata* and *Pinus sylvestris.* A forest-steppe belt occurs from 800 to 1600 m, with Gramineae, *Artemisia* spp., Chenopodiaceae, *Populus* spp. and *Ulmus pumila* (Hilbig, 1995).

3. Materials and methods

3.1. Core HL08

In January 2008, drilling was conducted on the ice at the depocenter of Hulun Lake using a TOHO (Japan) drilling system (Model D1-B). Sediment cores were extracted to a maximum depth of 921 cm beneath the lake floor and are designated HL08 (49°06′52.4″N, 117°31′56.0″E) (Fig. 1C). The core sections were split, photographed and described on site and then cut into 1–cm segments, resulting in 921 samples.

3.2. ^{14}C dating

Bulk samples were collected from organic-rich horizons from the upper 375 cm of core HL08 for accelerator mass spectrometry (AMS) ^{14}C dating. All samples were measured with a Compact-AMS system (NEC Pelletron) by Paleo Labo Co., Ltd (Japan). Organic carbon was extracted from each sample and dated following the methods described by Nakamura et al. (2000).

3.3. Pollen analysis

Pollen grains were extracted using a modified HCl-NaOH-HF procedure (Fægri et al., 1989). Before pretreatment, one tablet of *Lycopodium* spores (27,637 ± 563 grains) was added to each sample to calculate the pollen concentration. Pollen identifications were made under an Olympus BX 41 microscope with the aid of the *Pollen Flora of China* (Wang et al., 1995) and *Palynomorphs of Japanese Plants* (Shimarkura, 1973). More than 600 terrestrial pollen grains were counted for each sample.

Pollen percentages of terrestrial plants were based on the sum of total terrestrial pollen grains, while the percentages of aquatic pollen types and fern spores were based on the sum of terrestrial