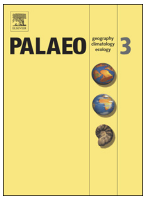
Palaeogeography, Palaeoclimatology, Palaeoecology 446 (2016) 70–77

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo



Pollen-detected altitudinal migration of forests during the Holocene in the mountainous forest–steppe ecotone in northern China

Qian Hao, Hongyan Liu *, Xu Liu

College of Urban and Environmental Sciences and MOE Laboratory for Earth Surface Processes, Peking University, Beijing 100871, China

ARTICLE INFO

Article history:
Received 27 October 2015
Received in revised form 2 January 2016
Accepted 11 January 2016
Available online xxxx

Keywords:
Forest–steppe ecotone
Arboreal pollen
Pinus
Quercus
Betula
Altitude range
Altitudinal migration

ABSTRACT

Distributed on the margin of the influence of the Asian monsoon, the forest–steppe ecotone in northern China is sensitive to climate change. Previous paleovegetation reconstructions in this region have led to inconsistent explanations of paleovegetation dynamics across sites. We hypothesized that the patterns observed are related to altitudinal migration of forests across mountains in this region. We combined eight lake sediment pollen records to explain how three forest types dominated by the tree genera *Pinus*, *Quercus*, and *Betula* changed in response to temporal and spatial monsoon changes within the forest–steppe ecotone during the Holocene. Modern pollen assemblages showed that areas with large altitude range could support more forests, which was further confirmed by the spatial patterns of late-Holocene forest distribution under dry climate. Our results confirmed that altitudinal migration of forests might exist in this region. This kind of altitudinal migration of forests under different altitudinal ranges could help to explain the inconsistent patterns observed in arboreal pollen across sediment cores as well as the non-linear response of horizontal forest distribution in relation to climate change.

1. Introduction

Past forest dynamics, particularly at the edge of the current forest distribution are critical in prediction of future forest distribution under a changing climate. However, paleoecological studies often lead to inconsistent results regarding past forest dynamics, which makes future prediction of forest distribution based on paleoecological studies a big challenge.

Located at the margin of influence of the Asian monsoon, vegetation in the forest–steppe ecotone of northern China is sensitive to the Asian monsoon dynamics (Liu et al., 2002, 2014, 2010). There have been many paleoecological studies of local vegetation dynamics in the forest–steppe ecotone in northern China (Chen et al., 2008a; Jiang et al., 2006; Wang et al., 2012; Xiao et al., 2004; Yin et al., 2015, 2011). However, the inconsistency in the evidence gathered from different sediment cores in this region demonstrates that vegetation dynamics cannot be interpreted by climate conditions alone. For example, arboreal pollen percentages vary greatly among different lake-sediment records even though these lakes are geographically close to each other and have similar climate conditions (Wang et al., 2012), implying that the effect of topographical factors cannot be ignored. In addition, these studies have generally focused on the south–north horizontal migration of the forest in relation to climate change (Cao et al., 2015; Ni et al., 2010; Yu et al., 2000). The effect of altitudinal distribution change on forest distribution and survival has not yet been considered.

Altitude interacts with climate conditions to determine the altitudinal distribution of vegetation. Taking the forest–steppe ecotone of northern China as an example, a mosaic of forest (pine and oak forests) and steppe primarily dominates the lower altitudes, while birch forests are more common at the higher altitudes (Liu, 1996). It is expected that climatic drying will push the forest either to higher altitudes or southward with sufficient moisture (Harsch et al., 2009). However, successful altitudinal migration of vegetation depends on the altitudinal range. We hypothesized that the arboreal pollen fraction in a watershed would be larger if the altitudinal range around a lake is large, because larger altitude range can offer more different types of habitats for forest survival as well as more possibilities for altitudinal migration of forests.

In order to test the above hypothesis, we used previously published sediment pollen records from eight lakes located in the forest–steppe ecotone in northern China to reconstruct temporal and spatial changes of *Pinus*, *Quercus*, and *Betula*. To show the role of altitude range on forest distribution as well as related arboreal pollen deposition, we adopted 63 soil surface pollen records located in the forest–steppe zone to analyze the effect of temperature, precipitation, and topographic factors (altitude and altitude range) on forest type, especially forest occupation. A conceptual model of forest migration in mountainous forest–steppe ecotone during the Holocene was also developed.

2. Study area

The eight lakes used in the study are all located at the southeastern edge of the Inner Mongolia Plateau and their altitude ranges from

---

* Corresponding author.
E-mail address: lhy@urban.pku.edu.cn (H. Liu).

http://dx.doi.org/10.1016/j.palaeo.2016.01.024
0031-0182/

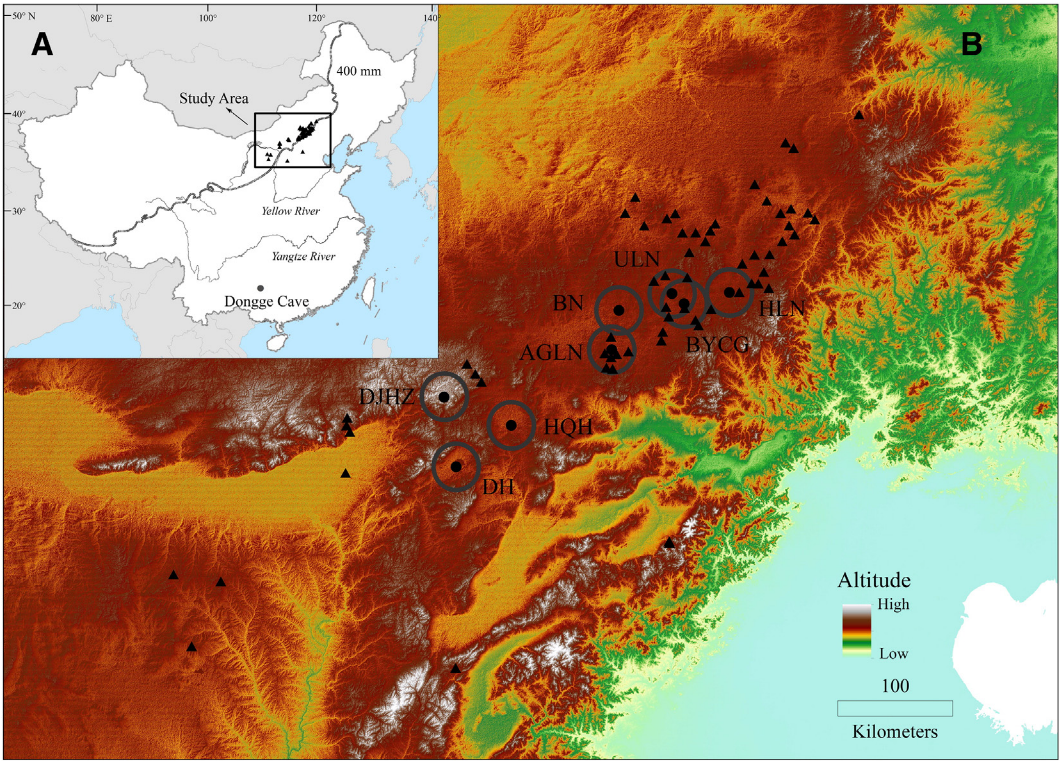


Fig. 1. Location of study area at regional and local scales. (A) Map of China showing location of the study region, Dongge Cave, and the 400-mm isohyet (rectangle area as shown in detail in B). The small black triangles around the study area indicate the soil surface pollen records (n = 63); (B) Digital Elevation Model (DEM) image of the study area showing eight lakes (Daihai, Diaojiaohaizi, Huangqihai Lake, Anguli Nuur, Bayanchagan, Hulun Nuur, Ulan Nuur, and Bai Nuur.). The dark points indicate the location of selected lakes. The gray circles indicate the relevant source area of pollen (20 km) of these lakes (Bradshaw and Webb, 1985; Tarasov et al., 2007; Williams and Jackson, 2003; Xu et al., 2012). The small black triangles around the study area indicate the soil surface pollen records (n = 63).

about 1200 to 2020 m. Hulun Nuur, Bayanchagan, and Ulan Nuur are close to the Otindag Sandy Plain, 70 km northwest of Bai Nuur. Diaojiaohaizi and Daihai Lake are near the Yin Mountains. Anguli Nuur and Huangqihai are located between the above-mentioned lakes (Fig. 1).

Located at the transition between the semi-humid and semi-arid areas in the temperate zone of China, the mean annual temperature (MAT) is about 0–6 °C and mean annual precipitation (MAP) is about 350–450 mm in the region. The climate is mainly controlled by the Siberian–Mongolian high-pressure system in winter, resulting in cold and dry environmental conditions. Warm temperatures and high humidity are brought by the prevailing Asian monsoon in summer (Hao et al., 2014).

Current vegetation types and patterns are similar in the areas around all eight lakes, with forest patches embedded into widely distributed temperate steppe. On the surrounding hills and mountains, three kinds of tree genera, *Pinus*, *Quercus and Betula*, are dominant (Wu, 1980).

In our study area, *Pinus tabulaeformis* is the main representative of its genus. It is an endemic pine species in northern China. The northern edge of its distribution corresponds to the northern margin of the Asian monsoon influence and there have been several detailed studies on this species (Chen et al., 2008b; Liang and Eckstein, 2006; Liu et al., 2009; Shi et al., 2008; Xu, 1990).

The genus *Quercus* is distributed widely in China and is also an important component in many forest ecosystems with coniferous and broad-leaved tree species. In this genus, *Quercus mongolica* is the main species in the mountains in our study areas. *Q. mongolica* lives in warm and humid climate areas, but also has the ability to tolerate lower levels of cold and drought.

Betula phatyphylla and *Betula dahurica* are two species in the genus *Betula* widely distributed in northern China. The two species both prefer

Table 1
Information of 8 lakes fossil pollen profiles in northern China in this study, including the geographical information, climate, altitude range (relevant source area of pollen: 20 km) and sediment pollen data information.

Lake name	Longitude (°)	Latitude (°)	MAT (°C)	MAP (cm)	Altitude (m)	Altitude range (m)	^{14}C age number	Age range (year)	Sample resolution (year)	References
Daihai Lake	112.67	40.55	5.1	423	1216	951	6/8	0–12,000/0–10,500	80/60	Li et al., 2004; Xiao et al., 2004
Diaojiaohaizi	112.60	41.10	0.0	350	2015	864	13	2000–12,000	80	Yang, 2001
Huangqihai	113.28	40.84	4.5	360	1265	573	10	0–8600	50	Hao et al., 2014
Hulun Nuur	115.70	41.70	1.4	426	1375	414	7	0–5700	100	Yin et al., 2015
Anguli Nuur	114.40	41.35	2.6	370	1320	386	9	0–11,500	50	Liu et al., 2010
Bai Nuur	114.52	41.65	1.2	350	1346	339	5	6100–11,000	90	Wang et al., 2012
Bayanchagan	115.21	41.65	3.0	369	1355	339	9	600–12,000	120	Jiang et al., 2006
Ulan Nuur	115.09	41.74	1.2	375	1246	275	4	6000–8600	40	Wang et al., 2012