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Changes in plant richness and evenness since Marine Isotope Stage 2 on the Chinese Loess Plateau

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ABSTRACT

The warming period from Marine Isotope Stage 2 (MIS 2) to the mid-Holocene provides a useful analog for assessing the impact of global warming on plant diversity. Previously published pollen records from ten loess sections across the Chinese Loess Plateau (CLP) have shown that herbs were dominant during both MIS 2 and the mid-Holocene. During MIS 2, the vegetation in the eastern part was characterized mainly by *Artemisia*, together with *Taraxacum*-type, *Echinops*-type and Chenopodiaceae; and by *Echinops*-type, Chenopodiaceae, *Nitraria*, *Ephedra* and *Picea* in the western part. During the mid-Holocene, *Artemisia* remained dominant, while *Echinops*-type, Chenopodiaceae, *Nitraria*, *Ephedra* and *Picea* decreased, and Poaceae became more prevalent. From west to east during the mid-Holocene, *Corylus*, *Quercus* and *Pinus* increased, while *Artemisia* and *Taraxacum*-type decreased. In the present study, two indices of plant diversity (richness and evenness) were analyzed using these published pollen data. The results demonstrate that from MIS 2 to the mid-Holocene, plant richness increased at most of the studied sites, while plant evenness decreased. The increase in plant richness during the warming interval is in accordance with numerous geological records, but differs from modern observations of the response of biodiversity to ongoing global warming. The decrease in plant evenness is attributed to the increase in precipitation, associated with the intensification of the East Asian summer monsoon, which resulted in an increase in the dominance of *Artemisia*, and the corresponding inhibition in the growth of other species. Therefore, our results imply that plant richness in northern China would be expected to increase in a climate warming scenario, while changes in plant evenness would largely depend on interspecific competition within a plant community.

1. Introduction

The reality of global warming is beyond dispute and with increasing atmospheric CO_2 concentrations, global temperature is predicted to continue to rise during the 21st century (IPCC, 2013), with potentially severe impacts on global ecosystems. Since the dynamics, functioning and ability of ecosystems to provide humans with essential goods and services depend to a significant degree on biological diversity (Cardinale, 2011; Tscharntke et al., 2012; Brown and Williams, 2016), it is necessary to evaluate possible future biodiversity trends in a warming world.

A large number of numerical modelling results (Thomas et al., 2004; Pounds et al., 2006; Ghosn et al., 2010; Zhang et al., 2015), as well as several modern observations (Parmesan, 1996; Hughes, 2000; Root et al., 2003; Seifert et al., 2015), indicate that climatic warming is already leading to increasing extinction rates and loss of biodiversity. However, some other modern observations suggest that warming leads to increasing biodiversity (e.g. Weslawski et al., 2010; Jiang et al., 2013a). Apparently, therefore, the impacts of global warming on future biodiversity are unclear.

The East Asian monsoon is an important component of the global climate system and plays a crucial role in global hydrological and energy cycles (Cai et al., 2010). The plentiful water supply delivered by the summer monsoon sustains hundreds of millions of people and makes the East Asian monsoon region a unique terrestrial ecosystem (Ito et al., 2016). The Chinese Loess Plateau is located on the northwestern margin of the East Asian summer monsoon region. At present, the mean annual precipitation and temperature of the plateau increase from ~300 mm and ~8 °C in the northwest to ~700 mm and ~14 °C in the southeast. The vegetation of the plateau is very sensitive to climate, changing from forest-grassland into grassland and desert-grassland, from southeast to northwest (Zhang, 2007). Since MIS 2, the Earth has experienced a cold extreme (the Last Glacial Maximum), and a warm period (the Holocene Optimum), and this warming trend provides a useful analog for future warming.

Pollen grains in sediments are the most abundant and well-dispersed fossil plant remains. Pollen analysis is one of the most powerful methods for reconstructing past vegetation (Meltsov et al., 2011) and fossil pollen data has been widely used to infer past changes in plant

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diversity (Odgaard, 1999; Fredh et al., 2012; Giesecke et al., 2012; Berglund et al., 2008a, 2008b; Reitalu et al., 2015). In the present study, ten pollen records, spanning the interval from MIS 2 to the present, from the Chinese Loess Plateau, were chosen to reconstruct past plant diversity (richness and evenness), and to attempt to predict future biodiversity trends in the region.

2. Materials and methods

Ten loess sections, located at Jingtai, Huining, Weiyuan, Jingbian, Pingliang, Heshui, Fuxian, Jixian, Xiangfen and Lantian, were logged (Fig. 1). Detailed location information is given in Jiang et al. (2013b, 2014) and Yang et al. (2015b). All sections include soil unit S_0, loess unit $L_{1\text{-}1}$ and the upper part of the weakly-developed soil $L_{1\text{-}2}$. Previous research has shown that $L_{1\text{-}2}$ was deposited during late marine isotope stage (MIS) 3 (~40–28 ka), $L_{1\text{-}1}$ was deposited during MIS 2 (~28–11 ka) and S_0 developed during the early-mid-Holocene (~11–4 ka) (Ding et al., 2002; Yang and Ding, 2008, 2014; Lu et al., 2007; Yang et al., 2012). Therefore, these sections span the entire interval from MIS 2 to the mid-Holocene. Magnetic susceptibility and grain-size results indicate that soil units S_0 and L_{1-2} are characterized by higher magnetic susceptibility values and finer grain sizes than loess unit $L_{1\text{-}1}$, and that all ten loess sections can be reliably correlated in detail (Fig. 2). Pollen grains were extracted using the heavy-liquid method (Li et al., 2006) and identified at ×400 magnification using a Nikon ECLIPSE 50i microscope. A total of 204 pollen samples were analyzed for the ten loess sections, and the results have been published previously (Jiang et al., 2014; Yang et al., 2015b).

Biological diversity is mainly measured by two parameters: richness and evenness (Magurran, 2004, Soininen et al., 2012). In this study, we use two indices for richness: species richness and the rarefaction curve. Species richness is defined as the number of pollen types in sediment samples (Birks and Line, 1992), and is one of the simplest and most widely used techniques for reconstructing past vegetation diversity (Seppä, 1998; Veski et al., 2005; Saarse et al., 2009; Meltsov et al., 2011; Matthias et al., 2015). Rarefaction curves allow us to compare species richness among fossil pollen samples with different numbers of pollen grains identified (Birks and Line, 1992; Birks et al., 2016). Evenness (E) describes the distribution of pollen types within the pollen assemblage (Keen et al., 2014). Here we use evenness defined by Buzas and Gibson (1969), which has been widely used in analysis of biodiversity (Small and McCarthy, 2002; Leponce et al., 2004; Hayek and Buzas, 2010; Tuomisto, 2012; Gagnarli et al., 2015; Fattorini et al., 2016). It is calculated as

$$E = e^{-\sum_i P_i * \ln(P_i)/S}$$

where E is evenness, P_i is the proportion of pollen type i, and S is the number of pollen types in a fossil sample. Species richness, rarefaction curves and evenness were computed using the PAST software package (Hammer et al., 2001).

3. Results

3.1. Vegetation changes on the Chinese Loess Plateau since MIS 2

The pollen results indicate that during MIS 2, vegetation in the western Loess Plateau was dominated by *Artemisia* and several drought-tolerant taxa such as *Echinops-type*, Chenopodiaceae, *Nitraria*, and *Ephedra*, while coniferous forest (mainly *Picea*) flourished in nearby river valleys (Yang et al., 2015b). The vegetation in the eastern Loess Plateau was characterized mainly by *Artemisia*, together with *Taraxacum*-type,

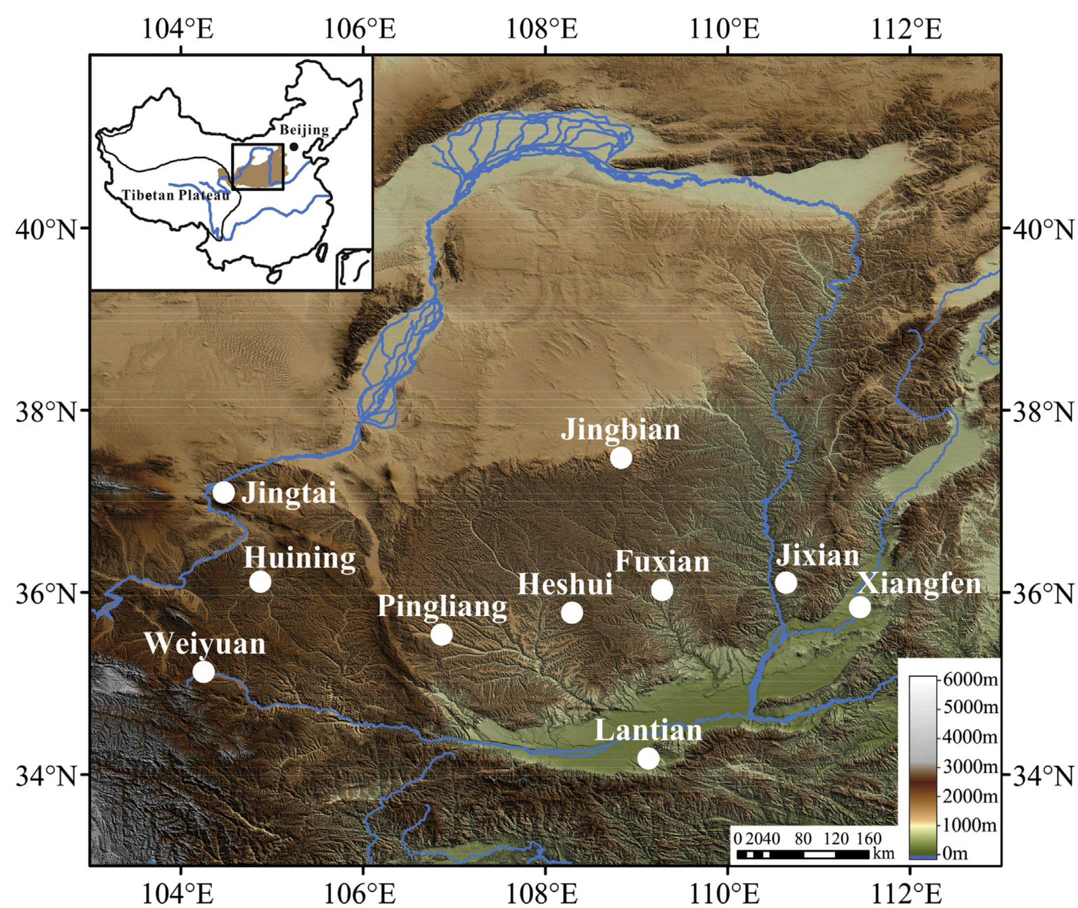

Fig. 1. Location of the Chinese Loess Plateau. White circles indicate locations of the ten sites investigated in this study.

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