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Human influence as a potential source of bias in pollen-based quantitative climate reconstructions

Jianyong Li [a], Yan Zhao [b], Qinghai Xu [c, d, e, *], Zhuo Zheng [f], Houyuan Lu [g], Yunli Luo [h], Yuecong Li [d], Chunhai Li [i], Heikki Seppä [a]

[a] *Department of Geosciences and Geography, University of Helsinki, Gustaf Hällströmin katu 2a, P.O. Box 64, Helsinki 00014, Finland*
[b] *Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Datun Road, Beijing 100101, China*
[c] *Institute of Nihewan Archaeology Research, Hebei Normal University, East Road of Southern 2nd Ring, Shijiazhuang 050024, China*
[d] *College of Resources and Environment Science, and Hebei Key Laboratory of Environmental Change and Ecological Construction, Hebei Normal University, East Road of Southern 2nd Ring, Shijiazhuang 050024, China*
[e] *MOE Key Laboratory of Western China's Environmental System, Lanzhou University, Southern Tianshui Road, Lanzhou 730000, China*
[f] *Department of Earth Sciences, Sun Yat-sen University, Xingang Xi Road, Guangzhou 510275, China*
[g] *Key Laboratory of Cenozoic Geology and Environment, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beitucheng Western Road, Beijing 100029, China*
[h] *Institute of Botany, Chinese Academy of Sciences, Xiangshan Nanxincun, Beijing 100093, China*
[i] *State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, East Beijing Road, Nanjing 210008, China*

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ABSTRACT

Human influence on vegetation is a potential confounding factor in pollen-based quantitative climate reconstructions. Here, we examine this issue in China, a region with intensive and long-lasting human influence. We employ modern datasets for human influence index (HII), climate and pollen over continental China to develop quantitative calibration models for HII and two key climate variables (annual precipitation, PANN; annual mean temperature, TANN). We assess the effect of HII on modern pollen assemblages and individual pollen taxa by comparison with climate variables by using constrained ordination methods and boosted regression trees and apply the calibration models to a pollen record spanning the last 6200 years from Lake Tianchi in central China. The results show that HII has smaller influence on the modern pollen data than PANN and TANN, except for in east-central China where the relationship between pollen data and HII is both statistically and ecologically significant. The reconstructed HII from Lake Tianchi remains relatively stable at 6200–2900 cal. yr BP, rises gradually at 2900–1100 cal. yr BP, and increases abruptly 1100 years ago. These HII trends are roughly concordant with Holocene charcoal and historical population records. The climate reconstructions change in tune with the HII, with an abrupt decline of PANN and a rise of TANN after 1100 cal. yr BP. Other palaeoclimatic data contradict the reconstructed patterns of PANN and TANN during the last millennium, suggesting that the climate reconstructions over the last 11 centuries are seriously biased due to the marked increase of human influence. Such a bias likely exists in other pollen-based climate reconstructions from other regions with strong and long-lasting human influence on vegetation.

1. Introduction

Quantitative climate reconstructions using pollen data are a significant source of information on past climatic variability in different areas of the world (e.g., Peyron et al., 1998; Davis et al., 2003; Kerwin et al., 2004; Viau et al., 2006; Brewer et al., 2008; Tonello et al., 2009; Herzschuh et al., 2010; Xu et al., 2010a, b; Bartlein et al., 2011; Klemm et al., 2013). Such reconstructions are based on modern pollen samples which are collected for developing pollen–climate

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[*] Corresponding author. Institute of Nihewan Archaeology Research, College of Resources and Environment Science, and Hebei Key Laboratory of Environmental Change and Ecological Construction, Hebei Normal University, East Road of Southern 2nd Ring, Shijiazhuang 050024, Hebei Province, China.

E-mail address: xuqinghai@mail.hebtu.edu.cn (Q. Xu).

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calibration models. These samples are selected to reflect regional natural vegetation which is assumed to be predominantly determined by regional climate (e.g., Birks et al., 2010). Human influence, for example, deforestation, irrigation, plant introduction, cultivation and urbanization, potentially blurs the natural vegetation–climate relationship and confounds the precision of pollen–climate calibration models (e.g., Seppä and Bennett, 2003; Birks and Seppä, 2004; Xu et al., 2010a). Therefore the aim in the constructions of pollen–climate calibration models is to avoid pollen samples from sites with strong human influence (e.g., Seppä et al., 2004; Li et al., 2007; Bjune et al., 2010). However, human influence is pervasive in most ecosystems of the world, and it has been estimated that more than 75% of the Earth's ice-free area has been modified by human influence and can be considered as ‘anthropogenic biomes’ (Ellis and Ramankutty, 2008). Human influence on ecosystems has occurred not only in the contemporary time but also during the Holocene, especially since the expansion of Neolithic agriculture mostly in Europe and Asia (e.g., Kirch, 2005; Dearing, 2006; Ruddiman et al., 2008; Zeder, 2008; Li et al., 2009). Consequently, it is often impossible to completely rule out human influence when collecting modern and fossil pollen samples. To quantify the extent of human influence, Sanderson et al. (2002) developed a modern global dataset for human influence index (HII) by integrating the weighted sum of human population density, land-use, infrastructure, and accessibility. This dataset has been used recently in many biogeographical studies, for example, for modeling the distribution of animal species (e.g., Adams et al., 2010; Fløjgaard et al., 2011; Hu and Jiang, 2011) and vegetation types (Greve et al., 2011). In palaeoecology, this dataset makes it possible to quantify the importance of HII for the distribution and abundance of pollen types in modern pollen datasets and to construct calibration models for HII that can be used for numerical human influence reconstructions.

In China, pollen-based quantitative climate reconstructions have been mostly conducted in the monsoon-influenced regions, for example, in Inner Mongolia (e.g., Jiang et al., 2009; Xu et al., 2010a,b; Sun and Feng, 2013), and in the Tibetan Plateau (e.g., Tang et al., 2000; Shen et al., 2006; Herzschuh et al., 2009, 2010; Tang et al., 2009; Lu et al., 2011). These studies have shown that the prevailing Holocene patterns of vegetation changes reflected in the pollen diagrams concur with the variations in insolation-driven monsoon intensity. However, China is the most populated country of the world with a long history of agriculture dating back to the early Holocene (e.g., An, 1989; Barton et al., 2009; Lu et al., 2009). The intensity of human influence on natural vegetation has enhanced since the mid-Holocene and has been particularly strong in northern China where the forest cover has declined by 50% from the mid-Holocene to the present (e.g., Ren, 2000, 2007). It is therefore likely that HII is an important factor influencing both modern pollen samples and fossil pollen records in China.

Here, we quantify and assess the bias caused by human influence on pollen-based quantitative climate reconstructions. For this purpose, we utilize the recently-compiled continental-scale surface pollen–climate dataset that covers the whole China from the regions with the highest human population density in the east to the extremely sparsely populated mountains and deserts in the west (Zheng et al., 2008, 2010), combined with the modern HII dataset (Sanderson et al., 2002). We use these data to (1) evaluate quantitatively the effect of HII on modern pollen data in comparison with key climate parameters, and to (2) assess the reliability of pollen-based climate reconstructions by comparing the reconstructions with a quantitative HII reconstruction from a mid- to late-Holocene pollen record from a lake in central China. We further discuss the bias caused by human influence on other pollen-based climate reconstructions in China and other regions with long-lasting and intensive human influence on vegetation.

2. Materials and methods

2.1. Modern calibration data

The surface pollen dataset employed here was initially compiled by Zheng et al. (2008) and contains 1374 samples from continental China (Fig. 1a). The detailed information about the sample types, pollen characteristics, data contributors, and laboratory treatments have been described by Zheng et al. (2008, 2010). Pollen percentages were calculated from the total sum of terrestrial pollen grains. The dataset spans all biogeographical regions and all zonal vegetation types in China: cold-temperate needleleaf deciduous forest and temperate mixed needleleaf and deciduous broadleaf forest in north-eastern China; warm-temperate deciduous broadleaf forest in east-central China; subtropical broadleaf evergreen forest and tropical monsoonal rainforest in southern China; temperate steppe and desert in north-western China; alpine vegetation on the Tibetan Plateau (Fig. 1a; Hou, 2001; Fang et al., 2011).

Human influence index values for individual pollen samples were derived from the global HII dataset with a spatial resolution of 1 km^2 (Fig. 1b; Sanderson et al., 2002; WCS/CIESIN, 2005). This dataset has been produced by synthesizing several indices that reflect the intensity of human influence, such as the human population density, infrastructure including built-up areas and land-use, and accessibility such as coastlines, roads, railroads, and navigable rivers. HII values vary from 0 to 64, from minimum to maximum (WCS/CIESIN, 2005). Modern site-specific climate data were extracted from the WorldClim dataset with a spatial resolution of 30 arc-seconds (Hijmans et al., 2005). Two key climate parameters, annual precipitation (PANN; Fig. 1c) and annual mean temperature (TANN; Fig. 1d), were used. TANN values were corrected according to the standard lapse rate of 0.6 °C/100 m (Domrös and Peng, 1988) to account for the altitudinal differences between the sites and the WorldClim-based data.

2.2. Fossil record from Lake Tianchi

Lake Tianchi (latitude 35°15′53″N, longitude 106°18′33″E; altitude 2430 m a.s.l.) is a small lake (2×10^4 m^2), situated in the Liupan Mountains on the Loess Plateau, Gansu Province, China (Fig. 1a). The modern values of TANN and PANN are 3.4 °C and 615 mm, respectively, and most of the precipitation falls in the summer (Zhao et al., 2010). The current vegetation surrounding the lake is characterized by steppe and shrub plants, chiefly by *Artemisia*, *Rosa*, *Salix*, *Berberis*, *Hippophae*, *Rubus*, *Ostryopsis*, *Fargesia*, and *Lonicera*, and farmland terraces (Zhao et al., 2010). The sediment core (GSA07-1, 11 m in length) extracted from the lake has been dated with 19 AMS ^{14}C dates from terrestrial plant remains (tree leaves). The age–depth model was constructed by using a second-order polynomial curve (Zhao et al., 2010). All AMS ^{14}C dates are in chronological order and exhibit a highly consistent time series. The chronology shows that the Tianchi sediment core covers the past 6200 years and the sediment accumulation rate is consistent at ca 1.85 mm/yr (Zhao et al., 2010; Sun et al., 2011). 72 fossil pollen samples with a temporal resolution of ca 85 years have been previously used to investigate the vegetation history (Zhao et al., 2010).

2.3. Numerical analyses

Prior to numerical analyses, the modern pollen dataset for the whole China (WC) was divided into five subsets, east-central China (ECC; 185 samples), southern China (SC; 455 samples), north-eastern China (NEC; 133 samples), north-western China (NWC; 453 samples), and the Tibetan Plateau (TP; 148 samples)