



Pollen–climate transfer functions intended for temperate eastern Asia



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ABSTRACT

Pollen data of 646 surface samples from northern China and Mongolia and climatic data from the relevant meteorological stations were collected in this study to develop more reliable pollen–climate transfer functions for temperate eastern Asia. Canonical correspondence analysis (CCA) was used to examine the pollen–climate relationships, and mean summer precipitation (MSP) and mean January temperature (MJaT) were inferred to be the first and second important factors controlling the spatial distribution of the surface pollen in the study area. The original dataset was screened with CCA for MSP and MJaT separately to detect anomalous samples that show the extreme values. The first screened dataset was established after excluding those anomalous samples, and the initial transfer function was generated using the weighted averaging partial least squares (WAPLS) method. The jackknife test was then applied to the WAPLS model for determining the optimum transfer function and for detecting large-residual samples, and the final transfer function was generated after removing the large-residual samples from the first screened dataset. The final dataset for MSP and MJaT consists of 428 and 419 samples, respectively. The root mean square errors of prediction for both WAPLS models are 34 mm and 2.7 °C, and the coefficients of determination are 0.85 and 0.73. This study suggests that the values of climatic parameters could be better estimated and the reliability of pollen–climate transfer functions would be significantly improved through removing anomalous and large-residual samples from the original dataset with mathematical methods.

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1. Introduction

Since Imbrie and Kipp (1971) introduced the algorithm to reconstruct environmental variables on biological proxies, pollen–climate transfer functions have been widely attempted for quantitatively reconstructing climatic parameters of the geological past (Bartlein et al., 1984; Guiot, 1987; ter Braak and Juggins, 1993; Birks, 1995). Pollen–climate transfer functions are normally developed based on the relationships between the surface pollen and the modern climate of sampling sites along certain climatic gradients. However, the developed transfer functions are often less reliable because many factors might have complicated or even distorted the expected relationship between the pollen and the climate. Among these factors, two are outstanding in most cases: (1) locally-resulted deviation of plant growth from climate equilibrium-resulted plant growth and (2) inadequate bioclimatic coverage of

sampling sites. The local vegetation inferred from pollen assemblages of some surface samples may not closely related to the regionalization of natural vegetation under modern climatic conditions due to possible human disturbance or/and the effect of local topography. Such samples must be recognized and removed while the pollen–climate transfer functions are developed to improve the reliability of the transfer functions. In addition, the directional length or/and the areal coverage of ecological and climatic gradients along which the surface samples were obtained is also important. For example, a small length or/and a small coverage of bioclimatic gradients of surface pollen sampling is absolutely inadequate in developing pollen–climate transfer functions if the transfer functions are used to reconstruct paleoclimate of the past during which large shifts in climatic and associated vegetation zones occurred. A large coverage of surface pollen samples is therefore required to enhance the adaptability of the transfer functions.

Temperate eastern Asia is currently under the combined influence of the mid-latitude westerlies and the low-latitude monsoons (Chinese Academy of Sciences, 1984; Zhang and Lin, 1985). It covers

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a large gradient of climatic conditions and associated vegetation landscapes and is thus an ideal region for developing pollen–climate transfer functions. In this study, we collected both pollen data of 646 surface samples from northern China and Mongolia and climatic data from the relevant meteorological stations. With the aid of statistical methods of canonical correspondence analysis and weighted averaging partial least squares, we attempt to develop reliable pollen–climate transfer functions for the quantitative reconstruction of paleoclimatic conditions in temperate eastern Asia.

2. Study area

The 646 surface samples used in this study are distributed in northern China and Mongolia, and display a latitudinal coverage of ~2000 km (33.6°–51.5°N) and a longitudinal coverage of ~3000 km (88.3°–128.1°E) (Fig. 1). The elevation of the sampling sites ranges from 228 to 3600 m above sea level. A total of 323 meteorological stations were collected for modern climatic data from the sampled region and the surrounding area (Fig. 1).

In the sampled area, the modern natural vegetation spans from deciduous broadleaved forests in the warm temperate zone to mixed conifer–broadleaved forests, steppes and deserts in the temperate zone, and conifer forests in the cold temperate zone (Fig. 1). Mean annual precipitation varies from 0 to 900 mm with a summer (June, July and August) average ranging from 0 to 500 mm and a winter (December, January and February) average from 0 to 40 mm. Precipitation decreases northwestwards in northern China and then increases northwards in Mongolia. Mean annual temperature ranges from –8 to 13 °C with a July average from 7 to 26 °C and a January average from –32 to –1 °C. Temperature declines with increasing latitudes and altitudes of the sampling sites.

3. Data and methods

3.1. Pollen data

Pollen data used in the present study are from 646 surface samples collected in northern China and Mongolia in the years 1998–2009 (Fig. 1). The sites of the surface samples were selected from localities more than 500 m far away from road. To ensure the even representation of surface samples in northern China, 3–5 sub-samples of moss or surface litter leaves or soil were randomly collected from a plot of 10 m × 10 m and then mixed into one sample. In Mongolia, each sample was a composite of 10–20 sub-samples of surface soil obtained randomly from an area of 20 m². Some samples from Mongolia contained a small amount of moss and litter material. The latitude, longitude and elevation of the sampling sites were determined with a receiver of Global Positioning System. Pollen was extracted from the surface samples following the HCl–NaOH–HF-sieving-acetolysis procedure described by Fægri et al. (1989) and more than 300 pollen grains were identified and counted for each sample. Aquatic pollen in the samples was not considered in this study because the growth of aquatic plants is closely related to local environments rather than the regional climate.

In order to eliminate undesirable effects of pollen types with occasional occurrences in the samples and/or with divergent identifications among different researchers, 25 major pollen taxa were selected from all the surface samples as representative pollen types in the present study (Table 1). These pollen types occur frequently and have higher percentages in different samples. They also show typical features in morphology and unambiguous implications in ecology. These pollen types include coniferous trees of *Pinus*, *Picea*, *Abies* and *Larix*, broadleaved trees of *Betula*, *Alnus*, *Quercus* and

Ulmus, shrubs of *Corylus*, *Ostryopsis*, *Ephedra*, *Nitraria*, Rosaceae, Elaeagnaceae and Tamaricaceae, and herbs of *Artemisia*, Chenopodiaceae, Poaceae, Asteraceae, Cyperaceae, *Thalictrum*, Caryophyllaceae, Asclepiadaceae, Labiatea and Liliaceae. The pollen percentages were based on the sum of the 25 pollen taxa in a sample.

Table 1
Statistics of 25 representative pollen types in 646 surface samples from northern China and Mongolia. The percentages of pollen types are based on the sum of the total terrestrial pollen in a sample.

Pollen type	Occurrence	Maximum (%)	Mean (%)	Standard deviation (%)
<i>Pinus</i>	622	96.56	16.07	21.52
<i>Picea</i>	222	78.62	2.47	9.72
<i>Abies</i>	93	54.92	0.60	4.14
<i>Larix</i>	173	26.42	0.63	2.44
<i>Betula</i>	547	90.12	6.90	14.01
<i>Alnus</i>	194	4.67	0.19	0.48
<i>Quercus</i>	338	74.05	3.12	9.38
<i>Ulmus</i>	258	19.83	0.34	1.17
<i>Corylus</i>	134	20.74	0.21	1.08
<i>Ostryopsis</i>	245	63.71	0.86	4.16
<i>Ephedra</i>	417	63.16	1.25	4.79
<i>Nitraria</i>	312	39.34	0.90	3.16
Rosaceae	427	30.79	1.14	2.67
Elaeagnaceae	243	88.70	0.82	4.68
Tamaricaceae	58	37.66	0.30	2.16
<i>Artemisia</i>	623	94.42	28.55	21.94
Chenopodiaceae	621	94.11	16.87	20.61
Poaceae	609	41.06	4.67	5.89
Asteraceae	569	27.29	2.35	3.80
Cyperaceae	442	78.08	3.06	8.68
<i>Thalictrum</i>	201	12.31	0.26	1.01
Caryophyllaceae	229	53.21	0.68	2.68
Asclepiadaceae	102	8.72	0.20	0.79
Labiateae	305	17.76	0.53	1.36
Liliaceae	259	27.61	0.40	1.43

3.2. Climate data

Climate data used in this study include mean summer (June, July and August) precipitation (MSP), mean winter (December, January and February) precipitation (MWP), mean annual precipitation (MAP), mean July temperature (MJuT), mean January temperature (MJaT), and mean annual temperature (MAT). These data are based on the 30-year averages of instrumental observations of the years 1961–1990 at 323 meteorological stations (data source: <http://cdc.cma.gov.cn/>) (Fig. 1). For each sampling site, the six climate parameters were yielded from observed data of the surrounding stations within a radius scope of three latitudinal or longitudinal degrees by inverse distance squared interpolation using the program Polation version 1.0 (T. Nakagawa, unpublished software). Altitudinal temperature corrections were conducted according to the universal temperature lapse rate of 0.6 °C per 100 m.

The accuracy of the interpolation method was tested with the leave-one-out method. The correlation coefficients between estimated and observed values of the six climate parameters for the 323 meteorological stations all are higher than 0.95. The estimated values of MSP, MWP, MAP, MJuT, MJaT and MAT for the 646 sampling sites range from 28 to 485 mm, 1 to 38 mm, 45 to 828 mm, 7.0 to 26.0 °C, –31.7 to –0.1 °C and –7.3 to 12.6 °C, respectively.

3.3. Canonical correspondence analysis

The collinearity among climatic variables was assessed through examining the variance inflation factors (VIFs). One variable would be assumed to be almost perfectly correlated with the other variables in the dataset if it has a VIF value higher than 20 (ter Braak, 1988). Our results show that MAP, MJuT, MJaT and MAT have VIF

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