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Modern pollen assemblages and their relationships to vegetation and climate in the Lhasa Valley, Tibetan Plateau, China

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ABSTRACT

Forty-seven surface pollen samples and 141 vegetation quadrats were investigated in the Lhasa Valley in order to assess the relationships between local modern pollen assemblages and vegetation and climate. The regional climatic data for each sample are mean annual precipitation (P_{ann}), mean annual temperature (T_{ann}), summer temperature (T_{summer}), actual evapotranspiration (AET), potential evapotranspiration (PET), and moisture index (MI), estimated by co-kriging using meteorological data from 16 climate stations in or near the Lhasa Valley. Cluster analysis, principal components analysis (PCA), Procrustes analysis, and co-correspondence analysis (Co-CA) were used to evaluate the relationship between modern pollen assemblages and contemporary vegetation. Linear regression was used to examine the relationships between pollen ratios (*Artemisia*/Chenopodiaceae (A/C), *Artemisia*/Cyperaceae (A/Cy), *Artemisia* + Chenopodiaceae/Cyperaceae (AC/Cy)), aridity pollen index, total arboreal pollen (AP), and the climatic variables. Cluster analysis and PCA results are generally consistent, and differentiate between pollen assemblages from arid conditions and those from more humid conditions. However, the PCA results distinguish pollen assemblages from shrubland slightly more clearly than the cluster analysis does. The PCA results show a general agreement between the modern pollen assemblages and contemporary vegetation types, but pollen assemblages from coniferous (*Juniperus*) woodland cannot be distinguished from shrub grassland, meadow, or shrub meadow pollen assemblages in the PCA results. Both Procrustes analysis and associated permutation tests and Co-CA show a strong statistically significant relationship between modern pollen and vegetation composition. Analysis of the relationship between the climatic variables and vegetation types suggests that humidity (P_{ann} and MI) is the main variable related to the vegetation types within the restricted areas of the Lhasa Valley. Neither the A/C ratio nor the aridity pollen index is a reliable aridity indicator in the Lhasa Valley. The AP sum may be a weak precipitation indicator, whereas the A/Cy and AC/Cy ratios appear to be robust indicators of precipitation, aridity, and temperature at the scale of the Lhasa Valley.

1. Introduction

Assessing the relationship between modern pollen assemblages and present-day vegetation is an essential step for the interpretation and reconstruction of vegetation history from pollen data due to differential pollen production, dispersal, deposition, and preservation (Birks and Berglund, 2017; Birks and Birks, 1980). These relationships may vary between different areas (Chang et al., 2017). A strong relationship between modern pollen records and climatic variables is also a critical prerequisite for past climate reconstruction from fossil pollen assemblages (Birks et al., 2010). Research on these relationships has been carried out in many regions around

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the world, including the Tibetan Plateau (e.g. Cour et al., 1999; Herzschuh, 2007; Lu et al., 2004, 2006, 2008, 2010, 2011; Yu et al., 2001; Zhang, 2013; Zhang et al., 2013, 2015b; Zhao and Herzschuh, 2009), but no study has been made in the Lhasa Valley of central-southern Tibet. The Lhasa Valley is an important transitional zone between the humid south-eastern region and the arid north-western part of the Tibetan Plateau (Duo, 2008). Human activities here are intensive and have greatly influenced the composition and structure of vegetation compared to many other regions of the Plateau. The present study is therefore designed to provide new information relevant to the reconstruction of past vegetation and regional climate within the Lhasa Valley.

Different pollen ratios, such as the arboreal pollen sum (AP), the *Artemisia*/Chenopodiaceae (A/C) ratio, the *Artemisia*/Cyperaceae (A/Cy) ratio, and the aridity pollen index have been developed as semi-quantitative and/or quantitative proxies in the reconstruction of past climate in arid areas such as the Tibetan Plateau. AP and the A/C ratio are widely used as indicators of temperature and aridity variability, respectively, in several mountainous and semi-arid areas (e.g. Chen et al., 2006; Cour et al., 1999; Herzschuh, 2007; Qin et al., 2015; Wei et al., 2011; Yan et al., 1999; Yu et al., 2001). Using lake sediments, Herzschuh et al. (2006) introduced the *Artemisia*/Cyperaceae (A/Cy) ratio. Herzschuh (2007) examined its reliability in the central-eastern Tibetan Plateau and showed that the A/Cy ratio in her study is positively and significantly correlated with summer temperature, and has a weak correlation with annual precipitation. Fowell et al. (2003) proposed an aridity pollen index, which is the sum of *Artemisia* and Chenopodiaceae (= Amaranthaceae) pollen percentages divided by Poaceae values. *Artemisia* and Chenopodiaceae pollen characterise dry environments whereas Poaceae pollen is more abundant in comparatively moist conditions in north-central Mongolia. This aridity pollen index was developed to distinguish pollen assemblages of dry steppe from moist meadow steppe and forest steppe. Here we present another pollen ratio AC/Cy, [ratio of (*Artemisia* + Chenopodiaceae) to Cyperaceae], because in the Lhasa Valley and much of the Tibetan Plateau, *Artemisia* and Chenopodiaceae pollen characterise dry environments as in north-central Mongolia. *Artemisia* plus Chenopodiaceae pollen should be more reliable in characterising dry environments than *Artemisia* pollen itself. Cyperaceae pollen is generally more abundant in moist conditions compared to Poaceae pollen which is more abundant in relatively dry environments in the Lhasa valley. Xu et al. (2005) and Luo et al. (2010) also suggest that Cyperaceae pollen could indicate a semi-humid environment on the Tibetan Plateau. Therefore, we hypothesise that the AC/Cy ratio might be a more reliable aridity indicator than the A/Cy ratio or the aridity pollen index.

We examine modern pollen assemblages of surface samples from the Lhasa Valley and explore their relationships with vegetation and climate to investigate the following questions: 1. How well do the modern pollen assemblages distinguish the contemporary vegetation types? 2. What climate variables have strong relationships with the vegetation and with the pollen assemblages? 3. How reliable are the pollen ratios discussed above, especially the AC/Cy ratio introduced here, as proxy climate indicators in the Lhasa Valley?

2. Materials and methods

2.1. Study area

The Lhasa Valley is located on the central-southern Tibetan Plateau (Fig. 1), from 90°05′ E to 93°20′ E and from 29°20′ N to 31°15′ N (Comprehensive Scientific Expedition Team of Chinese Academy of Sciences in Qinghai-Tibet Plateau, 1984). Mean annual temperature is 6.7 °C and annual precipitation is 468 mm in Lhasa, of which 400 mm falls in June to September (Miehe et al., 2001). The Lhasa Valley is located in the transition climate zone between the moist south-eastern region and the arid north-western part of the Tibetan Plateau, and is also in the vegetation ecotone between the south-eastern subtropical zone and the north-western alpine zone. The vegetation distribution is largely influenced by the summer monsoon rainfall (Hou et al., 2015), characterised by alpine meadows, alpine grasslands, sub-alpine

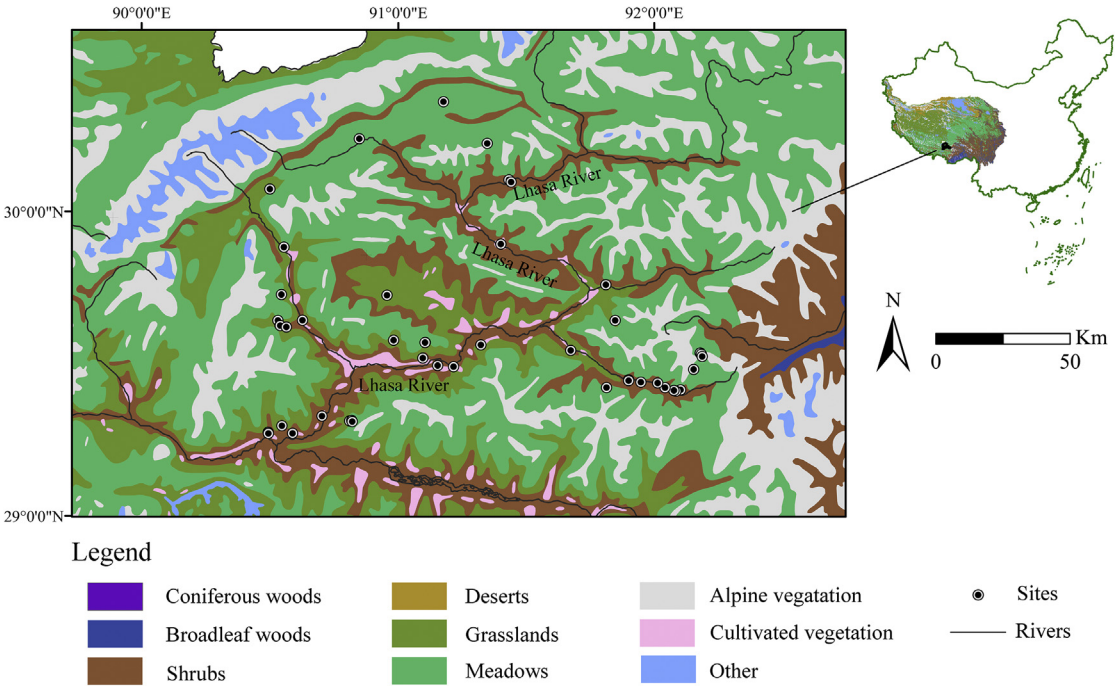

Fig. 1. Vegetation zones within the study area and locations of the 47 sample sites in the Lhasa Valley.

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