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Relation between modern pollen rain, vegetation and climate in northern China: Implications for quantitative vegetation reconstruction in a steppe environment

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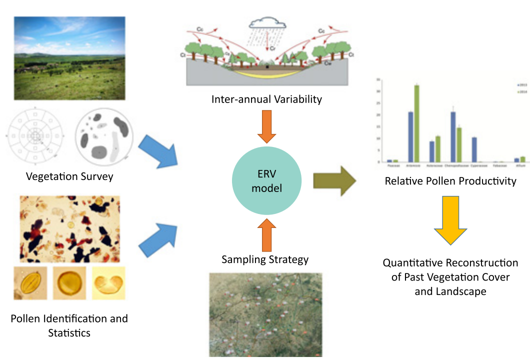
HIGHLIGHTS

- Pollen assemblages can reflect the characteristics of typical steppe vegetation well in northern China.
- 2 years' results of RSAP and RPP estimates for common herb taxa in northern China.
- The effects of inter-annual climate variability on pollen-vegetation relationship are considerable in typical steppe.
- Pollen signal in the soil samples is dominated by the pollen of the most recent growing season instead of several years.
- Random sample selection is the best strategy for obtaining robust RSAP and RPP estimates.

GRAPHICAL ABSTRACT



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ABSTRACT

Vegetation reconstructions from palaeoecological records depend on adequate understanding of relationships between modern pollen, vegetation and climate. A key parameter for quantitative vegetation reconstructions is the Relative Pollen Productivity (RPP). Differences in both environmental and methodological factors are known to alter the RPP estimated significantly, making it difficult to determine whether the underlying pollen productivity does actually vary, and if so, why. In this paper, we present the results of a replication study for the Bashang steppe region, a typical steppe area in northern China, carried out in 2013 and 2014. In each year, 30 surface samples were collected for pollen analysis, with accompanying vegetation survey using the "Crackles Bequest Project" methodology. Sampling designs differed slightly between the two years: in 2013, sites were located completely randomly, whilst in 2014 sampling locations were constrained to be within a few km of roads. There is a strong inter-annual variability in both the pollen and the vegetation spectra therefore in RPPs, and annual precipitation may be a key influence on these variations. The pollen assemblages in both years are dominated by herbaceous taxa such as *Artemisia*, Amaranthaceae, Poaceae, Asteraceae, Cyperaceae, Fabaceae and *Allium*. *Artemisia* and Amaranthaceae pollen are significantly over-represented for their vegetation abundance. Poaceae, Cyperaceae and Fabaceae seem to have under-represented pollen for vegetation with correspondingly lower RPPs. Asteraceae seems to be well-represented, with moderate RPPs and less annual variation. Estimated Relevant Source Area of Pollen (RSAP) ranges from 2000 to 3000 m. Different sampling designs have an effect both

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on RSAP and RPPs and random sample selection may be the best strategy for obtaining robust estimates. Our results have implications for further pollen-vegetation relationship and quantitative vegetation reconstruction research in typical steppe areas and in other open habitats with strong inter-annual variation.

1. Introduction

Quantitative reconstructions of past vegetation cover are important inputs for the testing of regional and global climate models, and also valuable for addressing a range of other scientific questions concerning human-environment interactions in the Anthropocene and Holocene, biodiversity dynamics, earth system processes, and nature conservation (Seddon et al., 2014). Among palaeoecological proxies, pollen records are the most effective data source for reconstructing past vegetation cover (Davis, 2000; Seppä and Bennett, 2003), however, the pollen-vegetation relationship is complex and depends on species-specific variation in pollen productivity, transport mechanisms, deposition and preservation (Bradshaw and Webb, 1985; Faegri and Iversen, 1989; Nascimento et al., 2015). Thus, understanding modern pollen-vegetation relationship and quantifying it based on proper methods are necessary and significant.

Pollen assemblages occurring in arid or semi-arid environments as found in the steppe region are transported to sedimentary contexts from wider surrounding landscape, and this adds complication for obtaining reliable relations between pollen and vegetation since the signal contains multiple spatial components, from local vegetation within or on the sedimentary system, from the nearby landscape, and from a regional or background pollen rain. The pollen signal from any one taxon could include grains from all three spatial components, and therefore extracting a spatially useful reconstruction in this region is more challenging.

Steppe in northern China lies at the edge of the temperate continental monsoon climate region and is a climatically sensitive area also subject to disturbance by human activity. Previous modern pollen studies for this region are preliminary and largely qualitative or semi-quantitative (Herzschuh et al., 2003; Li et al., 2005a,b; Ma et al., 2008; Wei et al., 2009; Zhao et al., 2012a; Tian et al., 2014). For instance, Li et al. (2005a) suggested that pollen assemblages show similar characteristics even when they are collected from different types of steppe vegetation by analysing 39 sites covering various types of steppe in China. Ma et al. (2008) collected 104 pollen surface samples along a south–north transect across five vegetation zones in Mongolia and established the spatial and statistical relationships between modern pollen and vegetation based on discriminant analysis and hierarchical cluster analysis.

However, more comprehensive and quantitative studies are needed to support better reconstruction of past vegetation from pollen records. An approach that seems promising is to use mathematical models of the pollen-vegetation relationship (e.g. Prentice, 1985, 1988; Sugita, 1993, 1994, 2007a,b; Bunting et al., 2008; Broström et al., 2008), but these models depend on empirical estimates of a few key parameters, including pollen productivity. This is usually expressed as Relative Pollen Productivity (RPP), the amount of pollen produced per unit amount of vegetation (e.g. m^2 of ground cover using vertical projection) expressed relative to the amount produced by a named reference taxon. The reference taxon is chosen based on data characteristics; the selected taxon is one which appears consistently and abundantly in both pollen and vegetation data sets (Li et al., 2015). RPP can be estimated empirically from a dataset of paired modern pollen and vegetation records, most commonly using the Extended R-Value (ERV) approach (e.g. Parsons and Prentice, 1981; Prentice and Parsons, 1983; Broström et al., 2004; Nielsen and Sugita, 2005; Soepboer et al., 2007; Mazier et al., 2008; Poska et al., 2011; Abraham and Kozáková, 2012; Xu et al., 2014; Li et al., 2015; Niemeyer et al., 2015).

In order to reconstruct past vegetation, RPP is treated as a constant in time within broadly defined spatial regions. Intraregional comparison of RPP values in north-west Europe (e.g. Broström et al., 2008; Mazier et al., 2012) shows very large differences in the empirical estimates, which might mean that the assumption of consistency over time is flawed, and therefore that the pollen signal itself is not a consistent reflection of vegetation. However, the studies included in these comparisons used a very wide range of methods, and were designed for a range of different purposes. Part of the observed variation seems to result from differences in methods used to record the necessary vegetation data for comparison with the modern pollen records (e.g. Bunting and Hjelle, 2010; Bunting et al., 2013).

Actual pollen production is known to show inter-annual variation, as plant flowering and pollen production varies in response to short-term changes in climate (e.g. Hicks, 1999) or local land management (e.g. coppicing - Waller et al., 2012). Most published research assumes that these variations are smoothed out by expressing pollen productivity as a ratio against a reference taxon, and using pollen samples collected from "natural traps" which reflect multiple years of pollen deposition (e.g. lake surface sediments - Soepboer et al., 2007, moss polsters - Mazier et al., 2008 or soil samples - Duffin and Bunting, 2008). Vegetation survey is typically carried out only once, or at a small number of occasions during a single year, due to the high cost in terms of field time incurred, and the likely variation over the course of a year may have important effects on estimates of RPP in some habitats (Broström et al., 2008; Mazier et al., 2008; Farrell et al., 2016). Thus, there is a clear need for further research on variation and controls on RPPs to avoid potential problems of inaccurate vegetation quantification through poor input parameters to mechanistic modelling based approaches (von Stedingk et al., 2008). Any inter-annual fluctuation in estimated RPP values may be more obvious in sensitive arid or semi-arid environment where both climate and environment conditions show strong inter-annual changes, and plants show marked annual changes in areal coverage unlike the forest and woodland more commonly studied. So far, few attempts have been made to measure RPP in this region (Li et al., 2011; Wang and Herzschuh, 2011; Xu et al., 2014), and no investigation into variability of estimates has been made.

This paper presents the results of a replication study carried out in two consecutive years, estimating RPP using a consistent methodology from soil samples collected in a typical steppe environment, where inter-annual climate variability is both normal and known to have a strong effect on the vegetation abundance of the main pollen-producing plant taxa. Our aims are: (1) to determine the relation between pollen rain, vegetation and climate in a typical steppe, northern China; (2) to explore the effects of inter-annual variability and methodological modification in pollen and vegetation datasets on estimates of RPPs and thus on parameterisation of the pollen-vegetation models used to reconstruct past land cover quantitatively; (3) to consider the implications of our findings for future investigation and use of the quantified pollen-vegetation relationship in these environments and others.

2. Study area

The chosen study area is a 200 km × 200 km area in the south of Inner Mongolian Plateau, within the typical steppe biome, and is referred to as Bashang steppe in this paper. It is located (see Fig. 1) at the border of Hebei Province and the Inner Mongolia Autonomous Region in northern China (114°10′-116°10′E, 41°10′-42°50′N), taking in