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Quantifying modern biomes based on surface pollen data in China

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ABSTRACT

Large-scale surface pollen records and reconstructions of modern biomes are a necessary prerequisite for the understanding of past vegetation and climate changes, especially in large countries such as China which is subject to a variety of climatic regimes and has experienced long-term intensive anthropogenic disturbances. An updated surface pollen data set consisting of 2324 samples and 737 taxa is used to reconstruct biome distribution in China according to a newly established and well-tested global classification of plant functional types, based on the regional assessment of pollen taxa and the quantitative pollen-biome assignment method of biomization. Nineteen reconstructed types of biome present a reasonable reflection of the latitudinal and altitudinal distributions of modern vegetation in China. Incorrect assignment has previously occurred in some biomes, for example among the cold and cool temperate coniferous forests and mixed forest, among warm-temperate evergreen forest, mixed forest and tropical forests, and among temperate shrubland, grassland, desert and tundra biomes. Mega-biomes, grouped for the same bioclimatic zones, result in a better reconstruction than the nineteen separate biome types. The correct assignments increased from 68.8% to 80.6%. However, comparison of pollen-based biome reconstructions to climate-driven vegetation simulations performed using the global vegetation model BIOME4 indicates a low correlation rate (only 24.8%), suggesting that more needs to be done to combine palaeoenvironmental data with model simulations of past vegetation changes. The misassignment of surface pollen to modern biomes usually occurs in areas which have similar bioclimatic features and vegetation types and for biomes which share the same plant functional types. These mis-matches often occur in mountainous regions where transitional vegetation zones occur on hill slopes at mid-altitudes. Our new modern biome reconstruction for China is more robust and reliable; however continued analysis of pollen records is required in the remote areas of western China and the Tibetan Plateau, as well as in regions of central and eastern China which have suffered from high levels of anthropogenic activity. This type of anthropogenic biome reconstruction presents a new challenge.

1. Introduction

Modern pollen assemblages, related to the current distribution of vegetation, land use and climate, provide a framework for inferring spatial and temporal variations in palaeovegetation and palaeoclimate from fossil pollen records (e.g. Overpeck et al., 1985; Prentice, 1985; Gajewski et al., 2002; Whitmore et al., 2005; Watrin et al., 2007). Modern pollen records, especially across broad regions, are therefore very useful for evaluating current pollen–vegetation relationships and for calibrating reconstructions of past vegetation and climate. In local and regional studies, modern pollen are closely related not only to vegetation and climate, but also to anthropogenically induced land use (e.g. Gaillard et al., 1994, 2008; Hjelle, 1999; Broström et al., 2004; Court-Picon et al., 2006). However, at extra-regional and continental scales, analysis of the distribution of modern pollen taxa is more focused on vegetation–pollen–climate relationships (e.g., Anderson et al., 1991; Gajewski et al., 2002; Whitmore et al., 2005; Watrin et al., 2007; Minckley et al., 2008), on pollen–vegetation relationships (e.g. Newsome, 1999; Markgraf et al., 2002; Ma et al., 2008) and on pollen–climate relationships (e.g. Seppä et al., 2004; Finsinger et al., 2007). These studies are all based on statistical approaches used to investigate pollen distributions and to reconstruct past changes in vegetation and climate. Less attention is paid to the impact of large-scale land use change on modern pollen spectra (Liu et al., 2006, 2008).

The quantitative reconstruction of the large-scale geographical distribution of vegetation from pollen data using the concept of plant functional types (PFTs) is a commonly accepted method called 'biomization' (Prentice et al., 1996; Prentice and Webb, 1998). Continental and modern global biomes that can be used to compare and validate past vegetation changes during the mid-Holocene and at

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the last glacial maximum have been reconstructed from modern pollen records worldwide (see Prentice et al., 2000, and papers from two Special Features of Journal of Biogeography in 1998 and 2000, for the northern Hemisphere and Africa). Modern pollen-based large-scale biome reconstructions have recently been extensively compared to natural vegetation in, for example, SE Asia, Australia and the Pacific (Pickett et al., 2004), Africa (Vincens et al., 2006; Lebamba et al., 2009), Latin America (Marchant et al., 2009) and Indian Continental (Sutra et al., unpublished). However these comparisons used potential modern biomes, i.e. by assigning vegetation types based on field observations and from various vegetation maps of natural biomes (all cultivated vegetation types were assigned to potential natural biomes in the same bioclimatic zones) in order to compare to the reconstructed biomes. Whilst modern pollen samples are normally taken from areas subject to minimal amounts of disturbance by human activity, this does not discount any influence from vegetation change and the impact of human activity in the past. Conversely, the biomization method can be used to reconstruct modern disturbed vegetation in highly disturbed regions such as Japan (Gotanda et al., 2008). This provides a method for investigating the impact of humans on vegetation during the late Holocene in Japan (Gotanda et al., 2008) and in other regions such as China, where there has been long-term human activity and historical land use changes.

Understanding the environmental history of China during the Quaternary has been of special interest to Earth System scientists. This is not only due to its large area, the diverse vegetation and broad climate regimes, but also due to the long history of human activities in China, including irrigated agriculture and forest clearance, in addition to the current environmental problems (Liu and Diamond, 2005). Addressing these problems requires a quantitative understanding of past environmental change and climate variability. A study of modern pollen, climate and vegetation is therefore a fundamental requirement for investigating these issues.

Studies of surface pollen at local and regional scales in China date back to the 1960s, but more comprehensive and quantitative research has only been conducted during the last decade. The Tibetan Plateau (Cour et al., 1999; Yu et al., 2001; Li et al., 2005; Shen et al., 2006, 2008; Herzschuh, 2007; Lu et al., 2008), the arid and semi-arid areas of northern and western China (Liu et al., 2006, 2008; Li et al., 2007; Xu et al., 2007, 2009), and areas of eastern China which have been highly disturbed by human activity (Zheng et al., 2007), are three major target regions for modern pollen studies. On a national level, the only studies which have been reported are those of arboreal pollen–vegetation relationships (Yu et al., 2004) and the biome reconstructions (Yu et al., 1998, 2000; Ni et al., 2010) using the biomization technique (Prentice et al., 1996, 2000; Prentice and Webb, 1998). Quantifying and reconstructing China's modern biomes from pollen data has been the basis for past biome reconstructions (Yu et al., 2000; Ni et al., 2010). However, the limited number of pollen records and the uneven distribution of sampling sites in previous studies (the maximum is 806 samples only) has restricted the accurate interpolation of modern biomes to past vegetation and climate, as well as limited our understanding of biome boundaries. Disturbed modern vegetation types were treated as potential natural biomes, leading to inaccurate comparisons between reconstructed and observed modern biomes (Ni et al., 2010).

In this paper we use an extensive collection of new modern pollen records to quantitatively reconstruct modern biomes using the biomization method. We use a new global scheme of PFTs (Harrison et al., 2010, in preparation) that has been proven in China (Ni et al., 2010), and also conduct a more precise assignment of pollen taxa to PFTs based on newly published floras and online resources. The aims of this work are (1) to investigate the spatial variation of modern pollen–vegetation relationships in China, (2) to compare surface pollen-based biome reconstructions with modern vegetation including natural, potential and simulated biomes, and (3) to more precisely reconstruct modern biome distribution in order to better calibrate past vegetation changes.

2. Data and methods

2.1. Modern pollen data

The modern pollen data set comprises 2324 samples including 1770 raw pollen counts and 554 digitized ones (Fig. 1, Appendices A and B). Of them, 802 samples (764 raw and 38 digitized) were taken from previous publications of Chinese pollen biomization (Yu et al., 1998, 2000; Ni et al., 2010). Another 437 raw pollen samples were downloaded from the Eastern Asia Surface Pollen Dataset (http://eapd.sysu.edu.cn/2/eapd.html). The remaining 569 raw samples were obtained from recent publications and unpublished resources. 516 digitized samples were hand-measured from pollen diagrams published largely between 2000 and 2008. Modern pollen samples were taken from a variety of deposition types, including soil surface (1589), moss polster (295), lake sediment surface (220), sediment core or profile tops (100), dust flux (80), marine sediment surface (19), and snow, ice and glacier (21). More detailed site information can be found in Appendix A.

The new expanded surface pollen data set has nearly three times the number of pollen samples than the previous one (Ni et al., 2010). Whilst geographical gaps in pollen sampling still exist, especially in the northern and northwestern desert areas, non-settlement areas of the Tibetan Plateau, mountainous regions of middle-southern China and some highly populated areas of eastern China, the current data set is the most updated version available. It comprises 181 more pollen taxa and 34 more taxon combinations compared to the previous data set.

2.2. Biomization procedure

The biomization procedure requires a list of pollen taxa, and the classifications of PFTs and biomes. In total we obtained 737 pollen taxa (species, genera and families) from the surface pollen dataset (Table 1). We cross-checked and standardized the different nomenclature used by various authors according to the Floras of China (ECFC, 1959–2002), and Dictionaries of Families and Genera of Chinese Seed Plants (Hou, 1998) and Ferns (Wu et al., 1992). The classification of PFTs in China adopted a newly established global scheme for PFTs (Harrison et al., 2010, in preparation) based on four principles: bioclimatic control (e.g. tropical, warm-temperate, temperate, boreal and arctic), phenology (e.g. evergreen or deciduous), leaf form (e.g. needle-leaved, broad-leaved, small-leaved and micro-leaved) and life form (e.g. tree, shrub, liana or vine, forb, climber, and fern). This scheme has been tested in a previous biomization of China based on limited surface pollen samples and fossil pollen records (Ni et al., 2010). The eurythermic mesic and xeric drought-deciduous malacophyll low or high shrubs were modified to tropical ones because in China taxa from these two PFTs are restricted in tropical zones. Two additional PFTs, the warm-temperate drought-intolerant liana or vine, and climber were added. In total, 78 PFTs were used to establish the modern biomization of China (Table 1).

The recent biomization of China (Ni et al., 2010) used a total of 19 biomes, including 11 forest biomes, one shrubland, one grassland, one desert and five tundra biomes (Tables 2 and 3), and was based on the previous biome classifications of the world (Prentice et al., 1992; Kaplan, 2001; Kaplan et al., 2003) and of China (Yu et al., 1998, 2000). This type of biome scheme has its disadvantages, for example having overly complex biomes in cold- and cool-temperate zones and too few biomes in the warm-temperate (subtropical) zones (Ni et al., 2010). However, to date it is so far the best biome classification for palaeovegetation study in China and is comparable with the world biome system. Therefore we use this scheme in this study. Further