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Sensitivity of temperate vegetation to Holocene development of East Asian monsoon

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ABSTRACT

Estimating vegetation sensitivity during the Holocene will improve the predictions of future vegetation dynamics. We compiled 52 pollen sequences from the monsoon-influenced northern China to reconstruct the Holocene dynamics of three forest types dominated respectively by *Pinus, Quercus* and *Betula*, as well as steppe and desert indicated respectively by *Artemisia* and Chenopodiaceae. The sensitivities of these vegetation types to changes in intensity of the East Asian monsoon were calculated according to the elevation, temperature and precipitation groupings of sites. Our results show that the Holocene vegetation dynamics differed across vegetation types, with *Pinus* and *Quercus* at lower elevations more sensitive to monsoon-induced precipitation changes and *Betula* at higher elevations more sensitive to temperature changes at the beginning of the Holocene. We also found an increasing sensitivity for forests and steppe within different groups following evident reduction in monsoon intensity since 5 ka BP, caused most probably by climate drying in this drought-determined forest-steppe in northern China. Besides regional scale forest retreat caused by climate drying, elevational movement as well as site expansion and decline are also suggested to explain low vegetation sensitivities in some site-groups. Our study provides insights into the mechanisms of individualistic responses of plant taxa as well as the asymmetrical response of ecotonal vegetation to the Holocene monsoon development in China.

1. Introduction

Forest decline can, through its effect on albedo, evapotranspiration and carbon sequestration, strongly affect the global climate and environment, particularly in middle to high latitudes and in semi-arid regions (Rotenberg and Yakir, 2010; Lee et al., 2011). Simulations by dynamic global vegetation models (DGVMs) have predicted replacement of forest by grassland (ecotone shifting) in the temperate semi-arid regions under the current warming trend, implying potential forest decline in these regions (Lucht et al., 2006). Validating model simulations requires evidence of forest decline under past climate change on decadal to centennials time scales (Freilich and Reich, 2009). Palaeoecological studies focusing on past vegetation dynamics meet this requirement.

Identifying the effects of climatic factors on forest dynamics, however, can be complicated because ecological and anthropogenic factors have also contributed to vegetation dynamics (Miller et al., 2008; Clegg, 2011). Vegetation sensitivity analysis, indicating the stability or instability of vegetation to exotic factors, provides an optimal tool to identify the role of climate in vegetation dynamics (Hosack et al., 2009). High sensitivity of vegetation to change in a climatic factor indicates a rapid response of vegetation to a tiny change of this climatic factor. It has been recognized that vegetation sensitivity to climate change is the greatest and response times are as short as decades near ecotones (Peteet, 2000). Ecotonal vegetation dynamics, however, have been found inconsistent across regions and time periods. Taking temperate forest-grassland ecotone as an example, evidence for the aridity-induced replacement of forests by grasslands (or even deserts) during the Holocene has been found in several different parts of the world, including Asia (Ren, 2007; Shen et al., 2008), North America (Williams et al., 2009) and South America (Mancini, 2010), suggesting a high sensitivity of semi-arid forest to climate drying. However, asymmetric or non-linear responses of the ecotone vegetation to past climate change have also been recognized, implying that a rapid response of forest and grassland biomes to Holocene climate change did not necessarily occur (Liu et al., 2001; Umbanhower et al., 2006; Williams et al., 2010). We hypothesize that these

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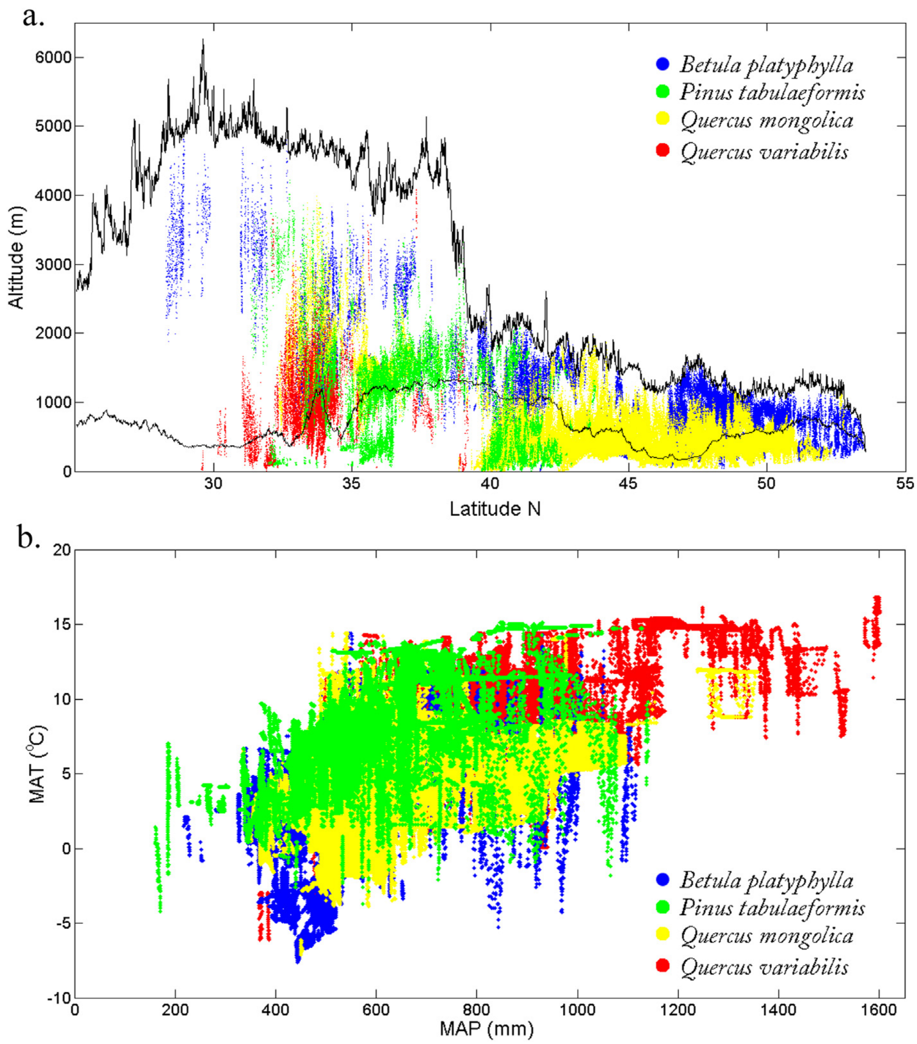

Fig. 1. Distribution of dominant tree species with a) latitude and altitude; and b) mean annual precipitation (MAP) and mean annual temperature (MAT). Maximum and mean elevations with latitude are indicated by a solid line. Data are from reference (Hou, 2001).

contrary behaviors have been caused by forest types with different sensitivities to the selected changing climatic factors in the forest-grassland ecotone.

We selected northern China as our study area to link vegetation sensitivity to vegetation dynamics during the Holocene. Unlike similar latitudes in Europe and North America, northern China was not covered by a continental ice cap during the Last Glacial episode, and was dominated by the monsoon evolution during the Holocene (Ni et al., 2010). Strong correspondence between vegetation dynamics in the eastern part of China and East Asian monsoon dynamics implies that aridity might have been significant to past vegetation dynamics at biome level (Zhao et al., 2009), which is also different from the merely temperature-driven vegetation dynamics (Birks and Birks, 2004). The climate and vegetation patterns in northern China provide a unique opportunity to test whether different tree taxa as well as different vegetation types (forest, steppe and desert) share the same sensitivity to the Holocene monsoon development, although sites with accurate dating are still relatively scarce in this region compared to the well-studied North America and Europe (Williams, 2002; Birks and Birks, 2004; Umbanhower et al., 2006; Williams et al., 2009, 2010). Following the previous estimations of vegetation sensitivity as significant correlation between pollen percentage and value of corresponding climatic parameter (e.g. Barber et al., 1994), we intend to reveal how site-level species sensitivities have contributed to regional vegetation dynamics, particularly the advance and retreat of forests in this study.

2. Study area and methods

2.1. Study area

We selected the monsoon-influenced eastern part of northern China, including the northeastern edge of the Tibetan Plateau, as our study area (Fig. 2). The modern dry timberline in this region is consistent with the 400 mm mean annual precipitation (MAP) isohyet (Liu et al., 2000). To more accurately reconstruct the forest history, we have extended our study area to a modern MAP range of ~100 mm to ~1100 mm, as well as a mean annual temperature (MAT) range of −3.9 °C to 13.7 °C (Fig. 2).

The study area was divided into four regions based on their modern climate and vegetation patterns: an arid desert region with MAP <200 mm; a semi-arid steppe and forest-steppe region with MAP ranging from 200 mm to 400 mm; a semi-humid region dominated by dry temperate broadleaf forest with MAP ranging from 400 mm to 600 mm; and a humid region dominated by humid