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Vegetation successions in response to Holocene climate changes in the central Tibetan Plateau

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ABSTRACT

Alpine vegetation in the central Tibetan Plateau is vulnerable to climate change. Nine lacustrine pollen records with well-constrained chronologies and high-resolution data were reviewed to document regional and local patterns of alpine vegetation succession in this region, and to understand the climatic driving forces for these changes. According to the relationship between modern pollen distribution and climate condition in the central Tibetan Plateau, Cyperaceae is a moisture-favored and cold-resistant component in both the vegetation and pollen assemblages in the region, while *Artemisia* is a drought-tolerant and temperate component. Within an east–west transect across contemporary alpine steppe zone and alpine meadow zone of the central Tibetan Plateau, *Kobresia* (Cyperaceae)-dominated alpine meadow expanded westwards to invade the alpine steppe (dominated by *Artemisia* and Poaceae), and to replace the *Artemisia*-rich temperate steppe on a regional scale during the mid-Holocene, probably driven by the enhanced precipitation. Vegetation within a south–north transect, covered by alpine steppe and temperate steppe, underwent a turnover in steppe composition from a predominance of *Artemisia* during the first half of the Holocene to a predominance of Cyperaceae in the latter half on a regional scale, caused by a decline in the temperature. Furthermore, altitudinal vegetation belts in the central Tibetan Plateau shifted downwards in response to cooling climate since the early Holocene. Therefore, monsoonal precipitation and insolation-driven temperature changes may be the key climate driving forces for the Holocene vegetation successions in the central Tibetan Plateau.

1. Introduction

The central Tibetan Plateau (TP) covers the vast interior plateau at an average elevation of 4500–5200 m (27°23′–33°30′N, 86°–95°E) to the south of the Kunlun Mountain and north of the Himalaya Mountains (Tibetan Investigation Group, 1966). The central TP is located close to the northern boundary of the modern Asian Summer Monsoon system (Ren et al., 1979; Chinese Academy of Sciences (1984); Yao et al., 2013), and is characterized by alpine vegetation types including alpine meadow, alpine steppe and temperate steppe (Hou, 2001). Vegetation changes in the region during the Holocene are attracting increasing attention due to the sensitivity of alpine vegetation to climate change (Herzschuh et al., 2006; Shen et al., 2008) and human activity (Miehe et al., 2006). Among numerous paleoenvironmental proxies, lacustrine pollen records with continuous sedimentation and high resolution have become one of the major archives for paleovegetation and paleoclimate reconstructions in the region (Sun et al., 1993; Shen, 2003; Herzschuh et al., 2006; Tang et al., 2009; Li et al., 2011).

Palynological research has figured some patterns of vegetation change in the central TP, including: 1) Alpine meadow had expanded westwards at the expense of alpine steppe and temperate steppe since the mid-Holocene (Shen, 2003; Herzschuh et al., 2009). 2) Vegetation changed from *Artemisia*-rich steppe to Cyperaceae-dominated steppe in the mid-Holocene as documented by pollen spectra in Lake Zigetang (Herzschuh et al., 2006). 3) Marsh meadow developed around lake basins in the late Holocene (Sun et al., 1993; Gu et al., 1994). 4) Altitudinal vegetation belt

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shifted downward on the north slope of Nyainqentanglha Mountains since the mid-Holocene (Li et al., 2011).

However, questions remain open regarding the vegetation changes on different spatial scales, their different responses to changes in Holocene climate in terms of temperature and precipitation, and as well as the impacts from human activity. For example, precipitation changes may have played a major role in the westward shifts of alpine meadow in Co Ngion area (Shen et al., 2008), and in the vegetation change from temperate steppe to alpine meadow in Koucha area (Herzschuh et al., 2009). However, temperature is also assumed to be responsible for vegetation transition between alpine meadow and forest (Zhao et al., 2011). A few studies suggested that human activity is one reason for forest decline and meadow expansion in the central and southern TP in the early Holocene (e.g., Miehe et al., 2009), whereas other paleovegetation records showed no evidence of anthropogenic impacts on vegetation (Herzschuh et al., 2006, 2011).

Here, we introduce the relationship between climate condition and modern pollen distributions of major pollen taxa in the central TP, and synthesize nine Holocene lacustrine pollen records with reconstructed paleovegetation and paleoclimate changes from an east–west transect and a south–north transect (Fig. 1). This review compiles pollen-based paleovegetation successions with independent records of monsoon intensity and climate changes to expand the understanding on the response of alpine vegetation to climate change, and to verify the hypotheses about climatic driving for vegetation successions in the central TP.

2. Study region, data source, and analysis methods

The modern climate of the central TP is characterized by a latitudinal gradient of temperature and a near-longitudinal gradient of monsoonal precipitation. The mean annual temperature (MAT) descends from 8 to 10 °C in the south to −6~0 °C in the north. The mean annual precipitation (MAP) decreases from more than 600 mm in the east to 100~200 mm in the west (Hou, 2001; Lu et al., 2011). Vegetation in the central TP shows a distinct southeast-northwest gradient, from alpine meadow zone and temperate subalpine steppe zone, to alpine steppe zone (Fig. 1) (Hou, 2001; Editorial Committee of Vegetation Map of China (2007)).

1) Temperate subalpine steppe zone. In the central–southern TP (MAT of 0~3 °C, MAP of 250~400 mm), river valleys and lake basin areas below 4400 m are covered by temperate steppe dominated by *Artemisia* spp., *Stipa bungeana*, *Aristida triseta* and shrub of *Sophora moorcroftiana*. The areas above 4400~4600 m are occupied by grasses of *Stipa purpurea*, *Artemisia wellbyi, A. younghusbandii*, *Orinus thoroldii*, and shrubs like *Caragana versicolor* and *Dasiphora parvifolia*.
2) Alpine steppe zone. It occurs in the central–western TP at elevations of 4500~5100 m (MAT of −6~0 °C, MAP of 150~300 mm). Alpine steppe in Changtang Plateau, northern region of central TP, is dominated by Poaceae (e.g. *S. purpurea*) and *Artemisia* spp., while in the western region it is dominated by *S. purpurea*, *Carex moorcroftii* and *Ceratoides compacta*.
3) Alpine meadow zone. This vegetation type occurs in the central–northeastern TP at elevations of 3300~4500 m (MAT of −3~4 °C, MAP of 350~700 mm). It mainly consists of *Kobresia pygmaea*, and shrubs like *Rhododendron* spp., *Salix* spp., *Dasiphora* spp. and *Sibiraea anngustata*. The associated taxa include *K. humilis*, *Stipa aliena*, *S. capillacea*, *S. purpurea*, *Festuca ovina*, *Polygonum* spp., *Carex* spp., *Thalictrum* spp. and *Potentilla anserina*. Alpine meadow usually occurs as an altitudinal vegetation belt on mountain slopes with an upper elevation limit of 4700~5600 m and an elevation extent of 500~800 m, between alpine steppe belt and alpine sparse vegetation belt (Zhang et al., 1981; Miehe and Miehe, 2000).

There are many paleoclimate records from the central TP. However, there are large differences in their age-controls and temporal resolutions. This study examines five lacustrine fossil pollen records from Selin Co, Xuguo Co, Co Ngion, Ahung Co and Koucha Lake within an east–west transect across modern alpine meadow zone and alpine steppe zone, and the other four pollen records from lake Zigetang, Nam Co, Chen Co and Hidden Lake within a south–north transect across temperate subalpine steppe zone and alpine steppe zone in the region (Fig. 1, Table 1). Uncalibrated radiocarbon dates from the record of Selin Co were calibrated to calendar years before present (BP = before 1950 AD) by using Calib7.0.2 based on the IntCal13 dataset (Reimer et al., 2013). An age–depth model for this site was established by linear interpolation.

Published palynological climatic proxies cited here, including

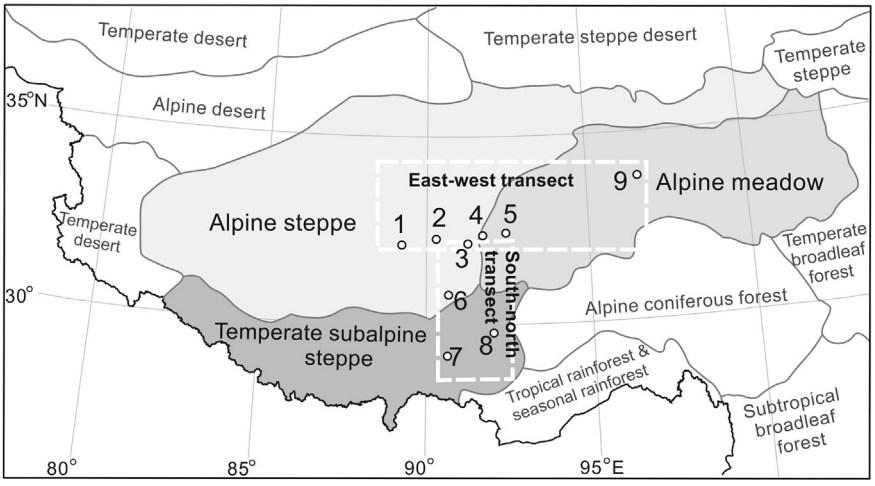

Fig. 1. Vegetation distribution on the Tibetan Plateau (Hou, 2001; Editorial Committee of Vegetation Map of China (2007)). Numbers 1 to 9 indicate sites of selected lacustrine pollen records in central TP. In an east–west transect: 1. Selin Co, 2. Xuguo Co, 4. Co Ngion, 5. Ahung Co, 9. Koucha Lake. In a south–north transect: 3. Lake Zigetang, 6. Nam Co, 7. Chen Co, 8. Hidden Lake. See Table 1 for site information and references.