Quaternary Science Reviews 30 (2011) 1173–1184

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Holocene vegetation and climate histories in the eastern Tibetan Plateau: controls by insolation-driven temperature or monsoon-derived precipitation changes?

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A R T I C L E I N F O

Article history:
Received 22 June 2010
Received in revised form
15 February 2011
Accepted 23 February 2011
Available online 21 March 2011

Keywords:
Holocene
Forest decline
Peatlands
Pollen
Peat
Summer monsoon
Insolation
Zoige Basin
Eastern Tibetan Plateau

A B S T R A C T

The climates on the eastern Tibetan Plateau are strongly influenced by direct insolation heating as well as monsoon-derived precipitation change. However, the moisture and temperature influences on regional vegetation and climate have not been well documented in paleoclimate studies. Here we present a well-dated and high-resolution loss-on-ignition, peat property and fossil pollen record over the last 10,000 years from a sedge-dominated fen peatland in the central Zoige Basin on the eastern Tibetan Plateau and discuss its ecological and climatic interpretations. Lithology results indicate that organic matter content is high at 60–80% between 10 and 3 ka (1 ka = 1000 cal yr BP) and shows large-magnitude fluctuations in the last 3000 years. Ash-free bulk density, as a proxy of peat decomposition and peatland surface moisture conditions, oscillates around a mean value of 0.1 g/cm^3, with low values at 6.5–4.7 ka, reflecting a wet interval, and an increasing trend from 4.7 to 2 ka, suggesting a drying trend. The time-averaged mean carbon accumulation rates are 30.6 gC/m^2/yr for the last 10,000 years, higher than that from many northern peatlands. Tree pollen (mainly from *Picea*), mostly reflecting temperature change in this alpine meadow-forest ecotonal region, has variable values (from 3 to 34%) during the early Holocene, reaches the peak value during the mid-Holocene at 6.5 ka, and then decreases until 2 ka. The combined peat property and pollen data indicate that a warm and wet climate prevailed in the mid-Holocene (6.5–4.7 ka), representing a monsoon maximum or "optimum climate" for the region. The timing is consistent with recent paleo-monsoon records from southern China and with the idea that the interplays of summer insolation and other extratropical large-scale boundary conditions, including sea-surface temperature and sea-level change, control regional climate. The cooling and drying trend since the mid-Holocene likely reflects the decrease in insolation heating and weakening of summer monsoons. Regional synthesis of five pollen records along a south–north transect indicates that this climate pattern can be recognized all across the eastern Tibetan Plateau. The peatland and vegetation changes in the late Holocene suggest complex and dramatic responses of these lowland and upland ecosystems to changes in temperature and moisture conditions and human activities.

1. Introduction

Summer monsoon intensity in East Asia has varied at multiple timescales. During the Holocene it is hypothesized that the strongest monsoon during the early Holocene was induced by peak summer insolation (Kutzbach, 1981; Ruddiman, 2008). This hypothesis has been confirmed in a general term by increasing empirical evidence from cave deposits (Wang et al., 2005, 2008), lake sediment records (e.g., Shen et al., 2005) and peat-based records (e.g., Hong et al., 2003; Zhou et al., 2004). However, the timing of Holocene monsoon maximum appears to vary in different regions and from various records (e.g., Overpeck et al., 1996; Xiao et al., 2004; Jiang et al., 2006; Griffiths et al., 2009; Yang and Scuderi, 2010; Yang et al., 2010). For example, pollen records from Daihai Lake in the monsoonal region of north China suggest a mid-Holocene monsoon maximum (Xiao et al., 2004). The speleothem records from Indo-Pacific region show that the maximum monsoon occurred after 7 ka (1 ka = 1000 cal yr BP) after sea level rose and stabilized (Griffiths et al., 2009). Further analysis based on Chinese cave records suggests that the lowest oxygen isotope values that were recorded during the Holocene may not reflect maximum precipitation, as the maximum precipitation intensity seemed to have occurred much later after the summer insolation maximum in the region between Dongge and Heshang caves (Hu et al., 2008). The roles of sea level in

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0277-3791/$ – see front matter
doi:10.1016/j.quascirev.2011.02.006

tropical southeastern Asia (Griffiths et al., 2009) and extratropical boundary conditions (ice sheet and sea-surface temperature) have been proposed to explain the inconsistencies in timing of monsoon maximum (Overpeck et al., 1996; Herzschuh, 2006). Furthermore, it is unclear whether temperature or precipitation changes have been dominant features of the observed regional climate and environmental changes.

The eastern Tibetan Plateau is strongly influenced by Asian summer monsoons, including both the East Asian and Indian monsoons. However, its high-altitude (>3000 m above sea level) settings should make it also sensitive to direct insolation heating and other extratropical influences, like many high-latitude regions, in addition to monsoon-driven precipitation changes. Peatlands (alpine marshes) on the eastern Tibetan Plateau are the largest highland peatland in the world. Multiple proxy data from peat-core records would potentially provide information to evaluate the relative importance of monsoon-derived precipitation and temperature changes during the Holocene. Palynological data from peatlands can be used to reconstruct regional vegetation and its spatial and temporal patterns. Peat properties, including organic matter content and degree of peat decomposition, can be used to infer hydrological conditions on the peatland surface. Combining these proxies would allow us to evaluate local and regional vegetation changes and their potential climate controls. During the last decade, several studies have been published on peatlands from this region, mostly for pollen analysis and regional vegetation and climate reconstructions (e.g., Yan et al., 1999; Joosten et al., 2008; Zhou et al., 2010). However, few studies have used peat properties to infer paleoclimatic changes (but see Zhou et al., 2002). Furthermore, the regional patterns of Holocene vegetation changes and their climate controls are still poorly understood.

There is also a debate about the relative importance of climate and human activities in causing the observed vegetation changes, especially forest decline, on the Tibetan Plateau during the mid- and late Holocene (e.g., Miehe et al., 2009; Schlütz and Lehmkuhl, 2009; Herzschuh et al., 2010). For example, studies from south-central Tibet by Miehe et al. (2009) and Schlütz and Lehmkuhl (2009) suggest that human activities, especially grazing, have had significant impacts on vegetation since as early as 8000 years ago. However, on the basis of pollen-based precipitation reconstructions at a site in the northeastern Tibetan Plateau, Herzschuh et al. (2010) concluded that monsoon-induced precipitation changes could explain the forest decline during the last 6000 years and that human activities are not necessary. Obviously additional records from other regions in the Tibetan Plateau would provide useful information on this topic.

In this study, we present a Holocene record of peat properties and fossil pollen data from a rich fen peatland in the central Zoige Basin. The objectives of this study were (1) to reconstruct regional vegetation and peat accumulation histories using multiple proxy data from a peat core; (2) to evaluate the relative importance and influence of the monsoon-driven precipitation and insolation-driven temperature on peatland dynamics, regional vegetation and climate changes; and (3) to investigate the potential different responses and sensitivities of regional vegetation along a south–north transect in the eastern Tibetan Plateau to Holocene temperature and moisture changes.

2. Study region and site

The Zoige Basin is a low-relief plateau in the eastern Tibetan Plateau at 32°10′–34°10′N latitude and 101°45′–103°25′E longitude, with an altitude of ca 3350–3450 m above sea level (Figs. 1A and 2A). The basin contains a long lake sedimentary deposit, going back to 800 ka (Chen et al., 1999). The peatland area is ca 4500 km^2,

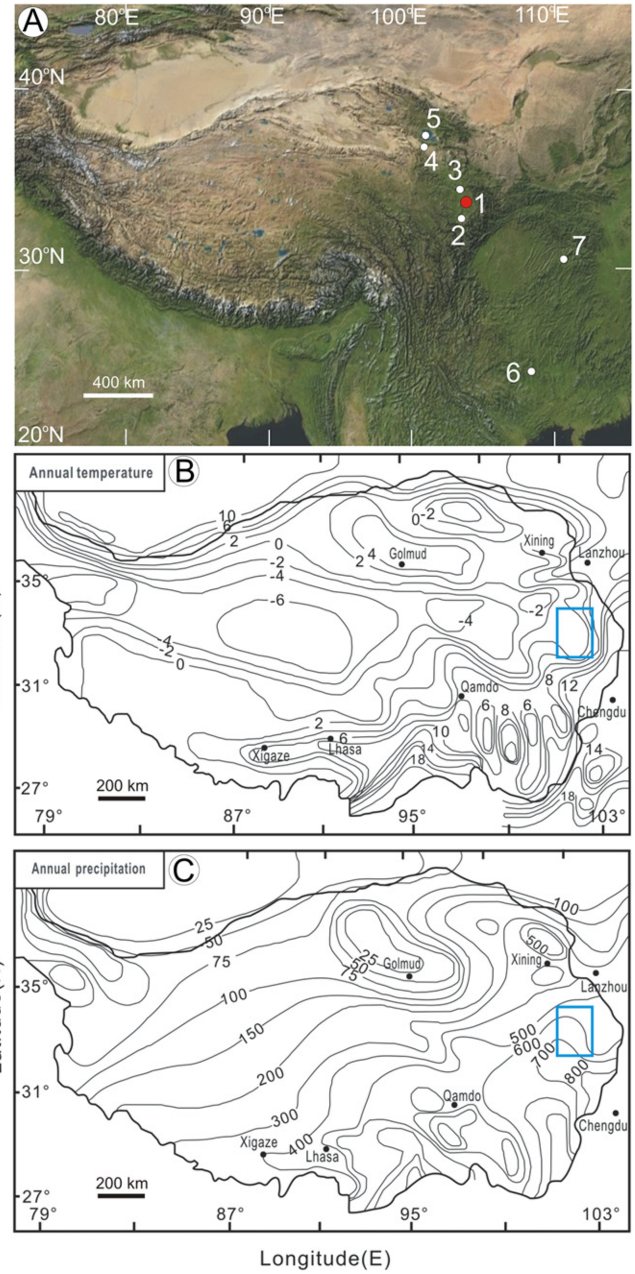

Fig. 1. Location map and climate settings. A. Satellite image map of the Tibetan Plateau and surrounding regions showing the locations of paleo study sites discussed in the text: 1. Zoige peatland (core ZB08-C1, this study; red large dot); 2. Hongyuan peatland sites (Yan et al., 1999; Zhou et al., 2010); 3. Zoige core RM (Shen and Tang, 1996); 4. Dalianhai Lake (Cheng, 2006); 5. Qinghai Lake (Shen et al., 2005); 6. Dongge Cave (Wang et al., 2005); and 7. Heshang Cave (Hu et al., 2008). B and C. The mean annual temperature and mean annual precipitation of the Tibetan Plateau, respectively (from Institute of Geography, 1990). The rectangle in B and C shows the study region as detailed in Fig. 2.

with average peat depth of 2–3 m and a maximum peat depth of up to 9–10 m (Thelaus, 1992; Joosten et al., 2008).

Mean annual precipitation (MAP) at nearby Zoige meteorological station (at 3439 m a.s.l.) is 648.5 mm for the period 1971–2000. Most precipitation falls as rain during the summer months (June–September; Fig. 3C), owing to the influence of the Asian summer monsoons. Mean annual temperature (MAT) is 1.1 °C, with July temperature of 10.8 °C and January temperature of −10.2 °C. We also plotted the climate diagrams from meteorological stations