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Contrasting effects of winter and summer climate on alpine timberline evolution in monsoon-dominated East Asia

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ABSTRACT

Alpine timberline is particularly sensitive to global climate change, with the danger of losing essential ecosystem services in high elevational regions. Its evolution is generally linked to annual average thermal regimes, and is regarded as an indicator of climate warming. However, the effect of uneven seasonal climate change stressed by the Hijioka et al. (2014) on alpine timberline dynamics in terms of both position migration and species composition remains unclear. Here, we documented approximately 6000 years of postglacial alpine timberline evolution on Mt. Tabai in the monsoon-dominated East Asian subtropical–temperate transition. We analyzed three high-resolution lacustrine sediment sequences located below, within, and above the current alpine timberline, an ecotone between the forest line and treeline, respectively. The timberline position appears to have varied coincidently with the temperature effect of cold East Asian Winter Monsoon (EAWM), implying that enhanced EAWM shortened the duration of the growing season and reduced forest survival at the alpine timberline. Unlike position migration, however, timberline species composition depends on summer precipitation. We found that drought-tolerant herb and shrub species were much more sensitive to variations in the water-bearing East Asian Summer Monsoon (EASM) than mesophytic trees at the alpine timberline. Our results suggest that prediction of future timberline dynamics should consider uneven seasonal climate changes.

1. Introduction

Mean annual temperatures have risen globally over the past century, with the most pronounced and rapid changes occurring at high altitudes and latitudes (Solomon et al., 2007). These trends are expected to cause timberlines to migrate to higher elevations and to more northerly latitudes (Grace et al., 2002; Tinner and Kaltenrieder, 2005; Holtmeier and Broll, 2005). The observed change in climate over the period 1901–2009 has emphasized that the warming trend is particularly strong in the cold season between November and March, with an increase of 2.4 °C in mid-latitude continental Asia (Hijioka et al., 2014). The uneven seasonal climate change in East Asia, which is closely related to the East Asian monsoon (EAM), the strongest and most active monsoon system on the planet, will inevitably influence timberline dynamics. The contrast between winter and summer monsoons represents the contrast between the Siberian high and tropical Pacific climate systems, and the resulting climatic patterns largely explain the distribution of natural vegetation in East Asia (Su et al., 2013; Leipe et al., 2015; Xu et al., 2013) (Fig. 1a). Therefore, understanding how past alpine timberline evolution responds to changes of the EAWM and EASM is critical for improving estimates of future impacts of uneven seasonal climate change on vegetation dynamics in East Asia.

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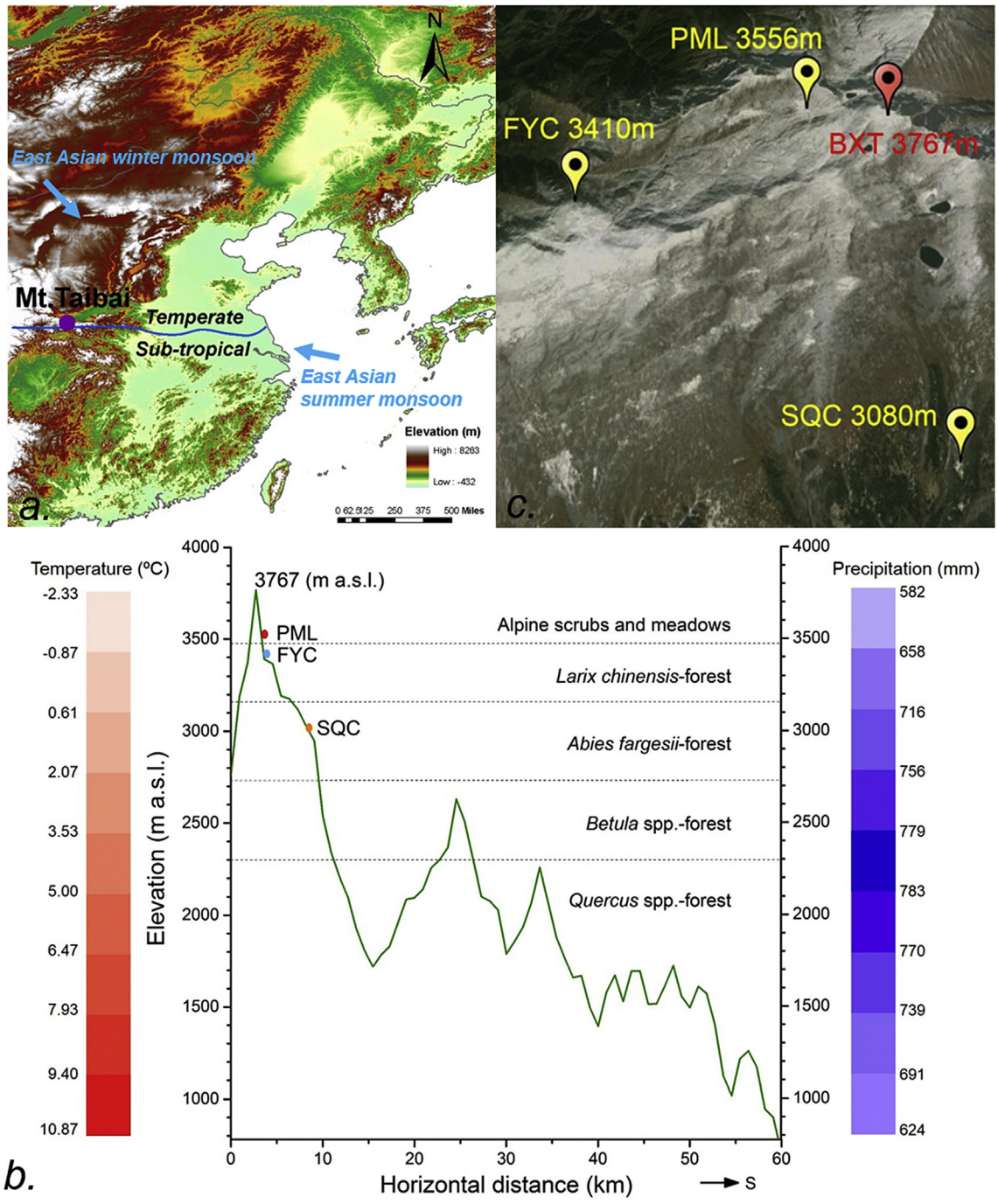

Fig. 1. a) Location of Mt. Taibai, as well as the Asian subtropical–temperate transition, and its relation with the East Asian winter monsoon and East Asian summer monsoon; b) Changes in mean annual temperature (MAT), mean annual precipitation (MAP), and vegetation with altitude, and the three study sites, Sangongdian Swamp (PML), Foye Chi (lake) (FYC), and Sanqing Chi (lake) (SQC), on Mt. Taibai; c) Three study sites, Sangongdian Swamp, Foye Chi and Sanqing Chi in relation to the treeline, timberline ecotone, and modern forest line.

The Asian subtropical–temperate transition is strongly affected by both the EAWM and the EASM (Fig. 1a and b). However, the alpine timberline is a sensitive indicator of vegetation dynamics, and how it responded to EAWM and EASM in the past remains a challenge due to limited paleoecological records that would allow reconstruction of long-term timberline evolution, particularly in the subtropics. Mt. Taibai, the only mountain with alpine flora and a timberline south of 35°N in monsoon-dominated continental East Asia, appears to be an ideal site for investigating responses of the alpine timberline to past climate change.

The alpine timberline is an ecotone between the forest line (upper boundary of continuous forest) and the treeline (uppermost altitude of isolated trees) (Holtmeier, 2009), and is composed of a mixture of trees, shrubs and herbaceous species (Körner, 2012). It is important to distinguish two types of timberline response to climate change: position migration and species change. The EASM, closely linked to the North Pacific atmospheric circulation, is responsible for summer precipitation and temperature (Li et al.,