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The responses of dominant tree species to climate warming at the treeline on the eastern edge of the Tibetan Plateau

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ABSTRACT

Tree growth at boreal/alpine treelines is generally expected to be stimulated by climate warming. However, tree growth has been shown to have changed insignificantly or reduced in numerous studies. Tree response to climate warming also varies among species in the same eco-region. The Tibetan Plateau has experienced rapid warming in the past several decades. It remains unknown how the dominant species in this region have responded to this warming, which is expected to significantly influence treeline dynamics. We obtained 288 tree cores from fir (*Abies faxoniana* and *Abies squamata*) and spruce (*Picea purpurea* and *Picea baifouriana*) at six treeline sites on the eastern edge of the Tibetan Plateau to detect their growth trends and climate responses. The results showed that the growth of fir did not change significantly at any site, whereas spruce growth increased, especially at the Songpan and Luhuo sites. The strong negative temperature or positive moisture controls of April on fir growth indicated spring drought stress. The radial growth of spruce was positively related to June and July temperature; at the Songpan and Luhuo sites, it was also positively related to the temperature from February to April. The results indicate that both pre-growing season temperature and growing season temperature accelerate spruce growth, whereas pre-growing season temperature causes drought stress to fir. The tree species composition at the alpine treeline on the eastern edge of the Tibetan Plateau will change as warming continues.

1. Introduction

Climate warming varies over time, and over the half past century, it has been unprecedented (IPCC, 2014). Climate warming is generally expected to stimulate tree growth at boreal/alpine treelines (Körner 2003; Holtmeier & Broll, 2005). However, numerous studies have found no increase in tree radial growth under warming or even decreases in such growth in both circumpolar northern latitude sites and the Alps (Wilmking et al., 2004; Silva and Anand, 2013; Girardin et al., 2016). A previous study reported that the growth of white spruce increased in the western part of Alaska's treeline but decreased in the eastern part under recent warming (Wilmking and Juday, 2005). Peng et al. (2011) found that Canada's boreal forests in the western regions were more sensitive to climate change than were those in the eastern regions. Additionally, the responses of trees to climate change can vary among species even in the same eco-region due to differences in their physiological properties (Reich et al., 2015). For example, white spruce is more sensitive to warming than are other species in the circumpolar north (Lloyd and Bunn, 2007; Subedi and Sharma, 2011; Jiang et al., 2016).

The Tibetan Plateau has experienced persistent warming recently (Liu and Chen, 2000; Duan and Zhang, 2015). The warming rate in this region has exceeded the rates elsewhere in the Northern Hemisphere and at the same latitudinal zone (Liu and Chen, 2000; Duan and Xiao, 2015). Moreover, the ongoing warming is amplified with elevation in the Tibetan Plateau (Liu and Chen, 2000). Liang et al. (2009) found significantly a positive correlation between *Abies georgei* growth and mean summer temperature at the timberline in the southeastern Tibetan Plateau. Trends of increased growth in *Abies fabri* at higher elevations were also found by Wang et al. in the eastern Tibetan Plateau (2017). *Abies* spp. and *Picea* spp. are the main tree species in the Tibetan Plateau, which tend to constitute mixed forests in this region. Their

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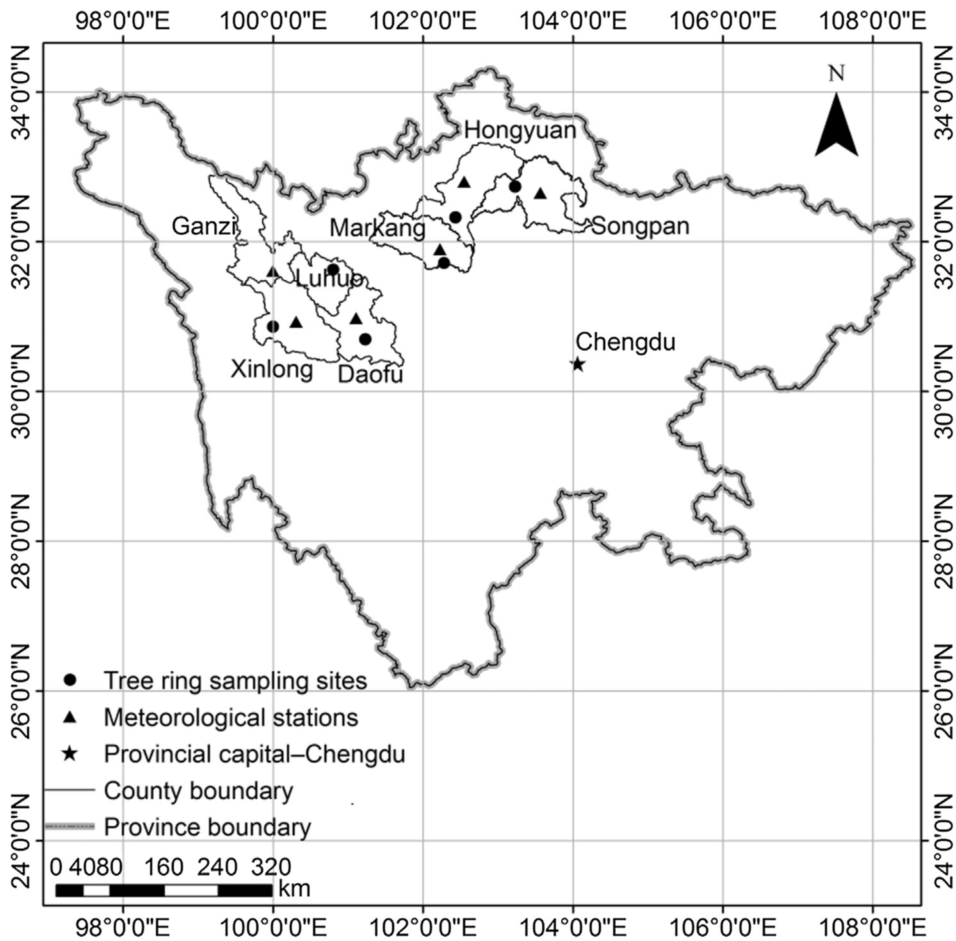

Fig. 1. Sampling sites and meteorological stations.

responses to rapid warming can affect forest dynamics. However, it remains unclear how treeline species respond to rapid warming at large regional scales and whether they respond consistently.

In this study, we collected tree ring cores of *Abies* spp. and *Picea* spp. within six treeline sites on the eastern edge of the Tibetan Plateau. The objectives were (1) to detect the growth trends of *Abies* spp. and *Picea* spp. in the treeline and (2) to identify the responses of the different species to climate change. We hypothesized that warming accelerates the growth of both spruce and fir and that the growth of these trees shows positive response to growing season temperature.

2. Materials and methods

2.1. Study area and climate data

The study was conducted along the eastern edge of the Tibetan Plateau and covered six counties of Sichuan Province (26°03′–34°19′N, 97°21′–108°33′E), namely, Markang, Songpan, Hongyuan, Xinlong, Daofu and Luhuo (Fig. 1). The dominant tree species in Markang, Songpan and Hongyuan are *Abies faxoniana* Rehd. and *Picea purpurea* Mast., whereas *Abies squamata* Mast. and *Picea likiangensis* var. *balfouriana* are the dominant species in Xinlong, Daofu and Luhuo. These species are distributed mainly from 2800 to 4000 m. Based on weather station observations (1961–2012), the mean annual temperature of the study region varies from 1.52 °C (Hongyuan) to 8.67 °C (Markang), and the annual total precipitation ranges from 601.41 mm (Daofu) to 778.30 mm (Markang) (Fig. 2). The mean annual temperature at all sites has increased significantly over time ($P < 0.01$), whereas the annual total precipitation has shown no significant change ($0.06 < P < 0.87$). The climate variables considered in this study were monthly average temperature (Tmean), monthly average minimum temperature (Tmin), monthly average maximum temperature (Tmax) and monthly total precipitation (P). The earliest available climate data for these regions is from the 1960s; thus, our analysis considers data since 1960. As there is no meteorological station in Luhuo, we used the data from the nearest station in Ganzi.

2.2. Tree ring sampling and chronology development

A. faxoniana tree ring cores were collected from the treeline sites in Markang and Hongyuan, and *P. balfouriana* cores were collected from those in Xinlong and Luhuo. We collected *A. faxoniana* and *P. purpurea* tree cores in mixed forest at the treeline site in Songpan and sampled *A. squamata* and *P. balfouriana* in Daofu. Sampling was conducted in 2013 (Markang), 2014 (Songpan) and 2016 (Hongyuan, Xinlong, Luhuo and Daofu). No evidence of fire, insect outbreaks or human disturbance was found at any site. At each site, a belt transect (50 × 100 m) was employed to obtain a sufficient number tree ring cores; in the mixed forests in Daofu and Songpan, the transects were 50 m × 200 m. Within each transect, more than 30 live trees per species were selected for core sampling. One 0.51 mm diameter increment core was extracted perpendicular to the slope from each tree at breast height. In the laboratory, each core was mounted on a wooden support, air-dried and sanded following standard dendrochronology techniques (Fritts, 1976). After visually cross-dating under a binocular microscope, the tree rings were measured to a precision of 0.01 mm using LINTAB TM–6 (Germany). Then, we used COFECHA software to assess the quality (Holmes, 1983). To remove the effects of age and size-related trends in