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ORIGINAL ARTICLE

Responses to climate change in radial growth of *Picea schrenkiana* along elevations of the eastern Tianshan Mountains, northwest China

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ABSTRACT

Tree growth is largely driven by climate conditions in arid and alpine areas. A strong change in climate from warm-dry to warm-wet has already been observed in northwest China. However, little is known about the impacts of regional climate variability on the radial growth of trees along elevations of the eastern Tianshan Mountains. Consequently, we developed three tree-ring width chronologies of Schrenk spruce (*Picea schrenkiana* Fisch. et Mey.) ranging in elevation from 2159 to 2552 m above sea level (a.s.l.), which play an important role in the forestry ecosystem, agriculture, and local economy of Central Asia. In our study, the correlation analyses of growth-drought using the monthly standardized precipitation-evapotranspiration index (SPEI) at different temporal scales demonstrated that drought in growing season was the main factor limiting tree growth, regardless of elevation. The relationships between radial growth of Schrenk spruce and main climate factors were relatively stable by moving correlation function, and the trend of STD chronologies and basal area increment (BAI) also showed a synchronous decline across the three elevations in recent decades. And meanwhile, slight differences in responses to climate change in radial growth along elevations were examined. The drought stress increased as elevations decreased. Radial growth at the higher elevation depended on moisture availability due to high temperature, as indicated by the significant negative correlation with mean temperature in the late growing season of the previous year (August-September, $p < 0.001$). However, radial growth at the lower elevation were restricted by drought stress due to less precipitation and higher temperatures, as demonstrated by the significant negative correlation with mean temperature but positive with total precipitation in the early growing season of the current year (April-May, $p < 0.05$). In addition, the decline of radial growth (BAI) at the higher elevation (3.710 $cm^2\,yr^{-1}$/decade, $p < 0.001$) was faster than that of the middle elevation (2.344 $cm^2\,yr^{-1}$/decade, $p < 0.001$) and the lower elevation (3.005 $cm^2\,yr^{-1}$/decade, $p < 0.001$) since 2000, indicating that the trees at higher elevation of a relatively humid environment were more susceptible to the effects of climate change due to their poor adaptability to water deficit. Therefore, the forest ecosystems would be suppressed as a result of increasing drought stress in the future, especially in the high-elevation forests of arid and semi-arid areas.

1. Introduction

Climate change and its impacts on forest ecosystems are a major force in the twenty-first century (Engelbrecht, 2012; IPCC, 2013). During the past 50 years, the climate in northwest China has changed from warm-dry to warm-wet due to an enhanced global warming and water cycle, most notably in the Xinjiang area (Shi et al., 2007). This climate change is embodied by the increase in total precipitation of 10.15 mm/decade and by a 0.33 °C/decade increase in air temperature during 1960–2010, as measured by 51 meteorological stations in northwest China (Li et al., 2013). This rising trend of annual mean temperature in northwest China was higher than the increasing average of the entire country of China (0.25 °C/decade) and that of the entire globe (0.13 °C/decade) for the same period (Li et al., 2012a). Other climate change results in

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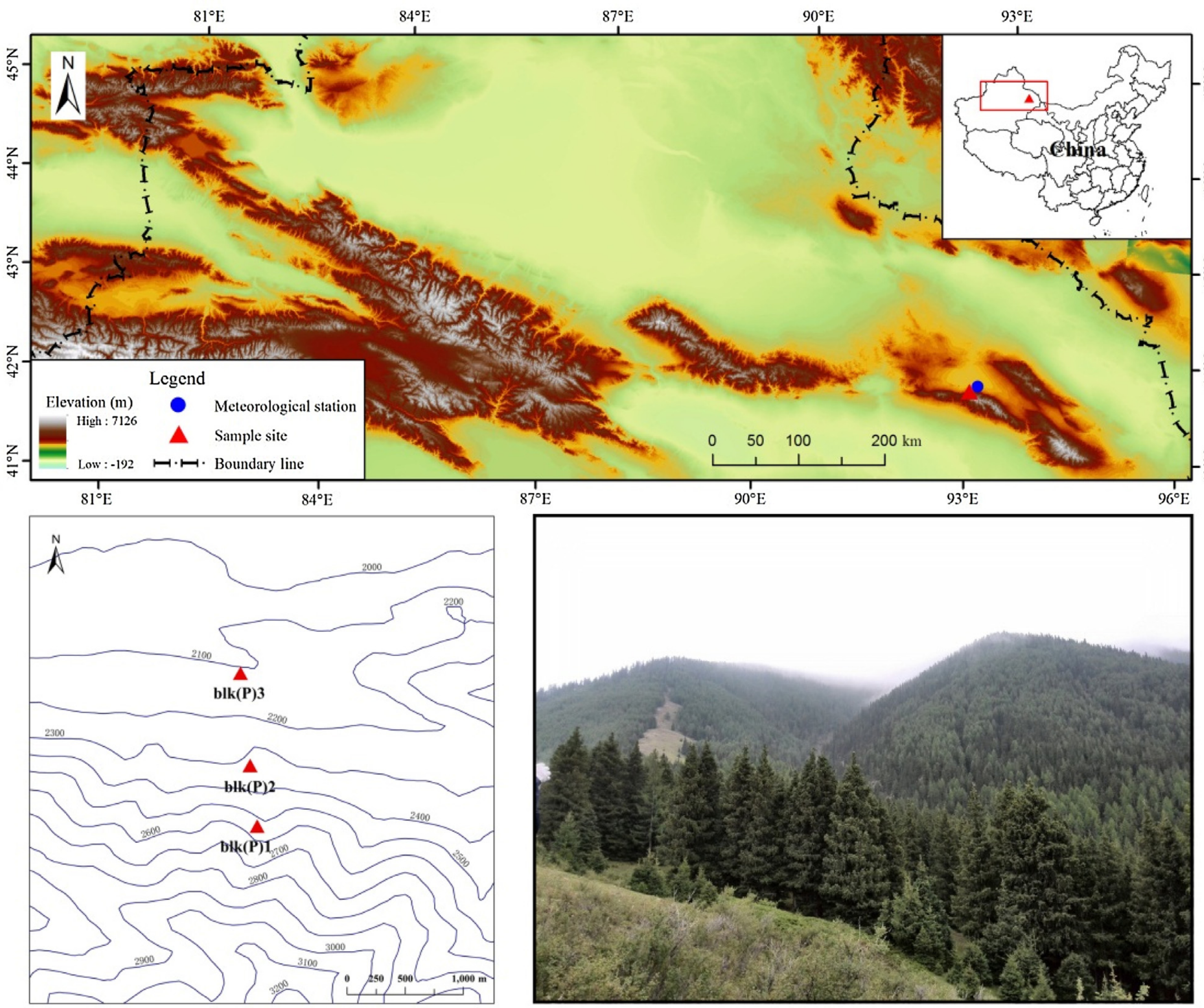

Fig. 1. Locations of the sampling sites and the nearest meteorological station (Tianshan Mountains).

northwestern China include increased glacial melt water, flood disasters, and vegetation cover and the reduction of sand-dust storm days (Shi et al., 2007).

The forest ecosystems, covering approximately 30% of he Earth's total land surface, perform a multitude of the ecological service functions such as terrestrial carbon pools, fresh water cycles, biodiversity, and so on (King et al., 2013). Due to their long life spans and sensitivity to climate factors, forests are considered to have limited adaptability (Lindner et al., 2010). Hence, the spatiotemporal variations of climate have likely impacted the compositions and functions of forest ecosystems in recent decades (Hartl-Meier et al., 2014a). For example, the loss of forest productivity and increase in susceptibility to disturbances in the eastern Alps and the severe degradation in the Normalized Difference Vegetation Index (NDVI) in northern Kazakhstan were shown to be due to drought stress with continued warming during recent decades (Seidl et al., 2011; Gessner et al., 2013). However, vegetation productivity increased in northern Xinjiang after the 1980s according to remote sensing studies (Piao et al., 2005). Therefore, there is still a high degree of uncertainty for the development of forests under climate change, and the effects will depend on the characteristics in different regions and species-specific tolerances (Elkin et al., 2013).

Elevation is an important factor affecting tree growth in mountains with variable climate and terrain, and forest ecosystems in mountains are widely considered to be sensors of climate variability (Malanson et al., 2011; Wang et al., 2015b). In general, radial growth of trees in arid and semi-arid areas correlates positively with temperature at the higher elevation and is limited by drought at the lower elevation (Fritts and Budelsky, 1965). Many dendrochronological studies have confirmed this elevation-dependent response pattern (Wilson and Hopfmueller, 2001; Zhang et al., 2012). In contrast to this general hypothesis, several studies have observed different results along elevations. For example, the spring and summer drought was the emergent limiting factor of *Pinus uncinata* at the higher elevations in the Iberian and of *Betula utilis* in the upper timberlines of the Himalayas (Liang et al., 2014; Diego Galván et al., 2015). Similar correlation patterns of *Sabina tibetica* and *Sabina przewalskii* with climate factors at the high- and low-elevation sites of south and Northeast Tibetan were also shown (Liu et al., 2013; Qin et al., 2013). Based on the radial growth response to climate factors along elevations of dendroclimatology, global warming is believed to have positive effects on forests at the higher elevation but negative effects at the lower elevation, as observed in the Alps of Europe (Paulsen et al., 2000), the Tatra Mountains of Poland (Savva et al., 2006), the western mountains of North America (Salzer et al., 2009), eastern Siberia (Tei et al., 2014), the Andes of northern Patagonia (Álvarez et al., 2015), and the Shennongjia Mountains of central China (Dang et al., 2013).