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Original article

Intra-annual radial growth of Schrenk spruce (*Picea schrenkiana* Fisch. et Mey) and its response to climate on the northern slopes of the Tianshan Mountains

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ABSTRACT

Schrenk spruce (*Picea schrenkiana* Fisch. et Mey.) is widely distributed in the Tianshan Mountains. In this study, four Schrenk spruce trees were continuously monitored with dendrometers from 27 April to 30 September 2014 on the northern slopes of the Tianshan Mountains in northwest China. The goal of this monitoring study was to determine the main growing season of Schrenk spruce and to analyze intra-annual radial growth variability and its relation to daily meteorological factors. Our studies have shown that the critical growing season of Schrenk spruce is from late May to late July and that the rapid growth stage is from mid-June to early July. Meanwhile, in the growing season, changes in the radial growth of Schrenk spruce were negatively correlated with daily temperature, evaporation, sunshine hours and vapor pressure deficit (VPD), and were positively correlated with precipitation and relative humidity (RH). The correlation coefficient between radial growth and RH can be as high as 0.750 (Pearson, $p < 0.0001$, $n = 60$). Dates in which precipitation occurred corresponded to periods of rapid growth. The results of the climate-growth analysis show that changes in radial growth reflect the effect of water stress on tree growth, whether or not the changes are positively or negatively correlated with the above climatic factors. This indicates that moisture plays a major role in the growth of Schrenk spruce. We suggest that precipitation between late May to late June is a limiting factor for radial growth of Schrenk spruce on the northern slopes of the Tianshan Mountains.

1. Introduction

In the context of global warming, a clear assessment of the response of radial growth in trees to climate at different time scales is important for an in-depth understanding of the physiological mechanisms of tree growth and its response to the environment. The understanding of physiological processes and their effects on tree growth are the basis of dendroclimatology (Fritts 1976). Both short- and long-term changes in environmental conditions have a distinct effect on the development of trees (Schweingruber et al., 2006). Therefore, a more detailed mechanistic understanding of tree growth physiology and of the registration of environmental and climatic signals in tree rings is required (Gričar et al., 2011).

The automatic dendrometer is an important instrument in the study of tree growth because it allows monitoring of tree radius variations at high temporal and spatial resolution without invasive sampling of the cambium (Deslauriers et al., 2011). In the past decades, high-precision dendrometers have been used with different species across a variety of environments, from the tropics to boreal regions, to describe stem radius growth phenology and/or to assess growth–climate relationships (Downes et al., 1999; Tardif et al., 2001; Zweifel et al., 2000; Deslauriers et al., 2007; Mäkinen et al., 2008; Bräuning et al., 2009; Biondi and Hartsough, 2010; Oberhuber and Gruber, 2010; Stahl et al., 2010; Krepkowski et al., 2011). Deslauriers et al. (2003) found that precipitation played an important role in stem radius growth of *Abies balsamea*, while nighttime temperature was more important than daytime temper-

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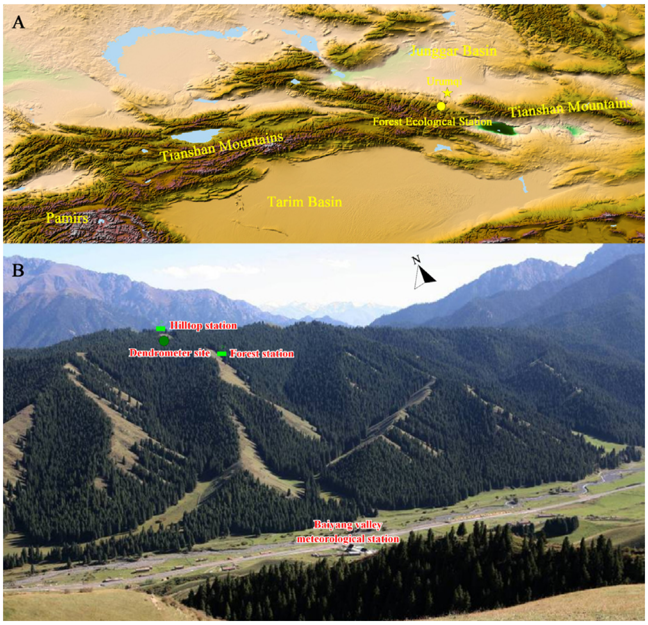

Fig. 1. Map and photo showing the location of the research site on the northern slopes of the Tianshan Mountains.

ature in controlling radius growth. Zweifel et al. (2006) also found that tree growth was related to precipitation in three species in a boreal ecosystem. These studies have improved our understanding of intra-annual growth dynamics and their association with climatic factors.

The Tianshan Mountains cover a large portion of Central Asia, which is one of the most important water source areas in China. Schrenk spruce (*Picea schrenkiana Fisch.* et Mey.) is a long-lived species growing in the Tianshan Mountains of arid Central Asia. This species is grows in shady areas at elevations of 1200–3500 m, usually in pure forests. Studies have shown that the tree-ring of Schrenk spruce growing in arid and semi-arid mountainous environments is climate-sensitive making this species very suitable for reconstructing past climate (Zhang et al., 2016a,b). Many studies have shown that, at the lower treeline, moisture (as measured by precipitation, Palmer Drought Severity Index, standardized precipitation-evapotranspiration index, relative humidity and snow cover) before the growing season and during early wood formation limits radial growth (Yuan et al., 2001, 2003; Li et al., 2006; Zhang et al., 2009, 2016a,b; Chen et al., 2013; Qin et al., 2012, 2016). However, previous studies in this area focus on individual local areas and regional climate reconstructions. Few studies have investigated the physiological mechanisms of radial growth of Schrenk spruce in response to climate. At the same time, the growth season of Schrenk spruce remains unknown. Here, we present a 1-year long data series based on four dendrometers that measured Schrenk spruce and data from synchronous meteorological stations to (1) assess the growing season and rapid growing phase of Schrenk spruce, and (2) reveal the response of variations in stem radius to meteorological factors.

2. Data and methods

2.1. Study area

The study area is located on the northern slopes of the central Tianshan Mountains (43°25′58″N, 87°11′52″E), in the upper reaches of the Urumqi River Basin in northwestern China (Fig. 1A). The investigation was conducted near the Baiyang Valley Meteorological Station, in a remote area with a mountainous environment. Apart from a few herdsmen who occasionally pass through the area while looking after their livestock, there is very little human influence at this site, which is located in virgin forest with abundant vegetation. The tree species analyzed here, Schrenk spruce, often grows on north-facing slopes with elevations ranging from 1800 to 2600 m in the Urumqi River Basin. Schrenk spruce is a dominant species in the study area and plays an important role in preventing soil erosion and soil water loss and in regulating the local climate, as well as in protecting the ecological stability of this inland river drainage area (Wu et al., 2015). The study site is located slightly below the treeline at an elevation of 2250 m a.s.l. with a mean slope of 10°, and represents the lower limit of the elevational distribution of this species (Fig. 1B).

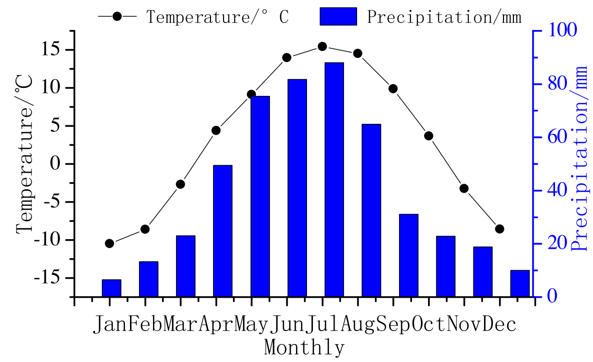

Fig. 2. Climate diagram for the Baiyang valley meteorological station during 2003–2014.

The typical dry-continental climate has relatively cold winters and warm summers. Climatic data from the meteorological station closest to the study site (Baiyang Valley, 43°27′N, 87°11′E, 1933 m a.s.l.; collected in 2003–2014) show that the average annual precipitation between 2003 and 2014 was 485.1 mm, of which 70% fell from May to September. The annual mean temperature was 3.14 °C, with July as the warmest month (15.41 °C) and January as the coldest month (−10.50 °C) (Fig. 2). Four Schrenk spruce were monitored during the 2014 growing season using dendrometers.

2.2. Dendrometric records

Automated high-resolution point dendrometers (Ecomatik GmbH, Munich, Germany; type radius dendrometer (DR), accuracy < 2 μm, temperature coefficient\0.1 l m/K) were installed on four Schrenk spruce trees at the study site. The point dendrometers measured changes at a single point (radius) of the tree. Deslauriers et al. (2007) suggested that several difficulties exist when using slow-growing trees to identify crucial events. However, many coniferous species have been successfully analyzed with dendrometers (Deslauriers et al., 2003; Wang et al., 2012, 2015). We therefore chose trees that were approximately 100 years old (the mean age of Schrenk spruce in this area is about 300 years, although individuals can live as long as 700–800 years). Healthy, upright trees with circumferences ranging from 78 to 134 cm at breast height were selected. The dendrometers were usually installed at breast height on a stem (Table 1); however, the measuring heights had to be adjusted in a few cases to avoid the influence of dense branches. To reduce the influence of the expansion and shrinkage of the bark, small portions of the outer bark were removed without wounding the cambial zone. Variations in the stem radius of the analyzed trees were automatically recorded from 27 April to 1 October at 30-min intervals (48 data points/day); these data were saved by dendrometer data loggers (Ecomatik).