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Growth responses of subalpine fir (*Abies fargesii*) to climate variability in the Qinling Mountain, China

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Abstract

Dendroecological techniques have been employed to investigate the relationship between subalpine fir (*Abies fargesii*) growth and climatic variability throughout its elevational range on both south and north aspects in the Qinling Mountain of Shaanxi Province, China. Correlation analyses indicate that early spring and summer temperatures are the principal factors limiting its growth in the low- and middle-elevation distributional areas. In the high-elevation areas, it is the summer precipitation that affects *A. fargesii* radial growth. The previous year August and November temperatures show positive correlation with the radial growth in the low- and middle-elevation distributional areas of the south aspect, and in the high-elevation areas, precipitation in previous November has significantly negative influences on the radial growth. The previous year's temperature and precipitation have no significant effects on the radial growth of the fir trees in the north aspect. Thus, the growth of the subalpine *A. fargesii* responds differently to climatic conditions along the elevational gradient and in different aspects.

Keywords: Growth response; Subalpine fir; Radial growth; The Qinling Mountain

1. Introduction

Dendroecological techniques have been recognized as a useful tool for exploring the relationships between environmental factors such as climatic variables and radial growth of trees (Fritts and Swetnam, 1989; Rigling et al., 2001; Copenheaver and Abrams, 2003; Andreassen et al., 2006). In the subalpine environment, the growth conditions of tree species vary greatly with altitude, tree-rings can provide climatically sensitive records demonstrating different relationships with the vertical changes in climatic conditions (Kienast et al., 1987; Villalba et al., 1997; Yoo and Wright, 2000). Ecotones (i.e., transitional zone between adjacent communities; Odum, 1971) along altitudinal gradient in subalpine environment, such as the lower and upper distributional limits of tree species, have been identified as particularly vulnerable areas that may be the first to reflect changes in local biophysical characteristics (Villalba et al., 1994; Liu et al., 2001a; Takahashi et al., 2003).

Abies fargesii is a subalpine tree species widely distributing in the Qinling Mountain and Daba Mountain of China. It occurs over a wide elevational range and dominates the forests above 2400 m a.s.l. in the Qinling Mountain. Previous studies have utilized dendrochronological techniques to reconstruct past climate conditions (Hughes et al., 1994; Wu and Shao, 1994; Dai et al., 2003; Liu and Shao, 2003). As the region is located in the transitional zone between two macroclimatic regimes (i.e., subtropical and warm-temperate zones) in China, understanding the growth responses of *A. fargesii* along elevation gradient is of great importance for the sustainable forestry in the context of climatic change. In this study, we sampled *A. fargesii* along its distributional range in elevation and in both south and north aspects in the Qinling Mountain, and used dendrochronological techniques (1) to examine the variation in tree-ring growth of *A. fargesii* along the elevational gradient and in south and north aspects; (2) to identify the climatic factors that are responsible for the variation in its radial growth.

2. Methods

2.1. Study area

This study was conducted in the Foping and Zhouzhi National Nature Reserves, located, respectively, in the south and north

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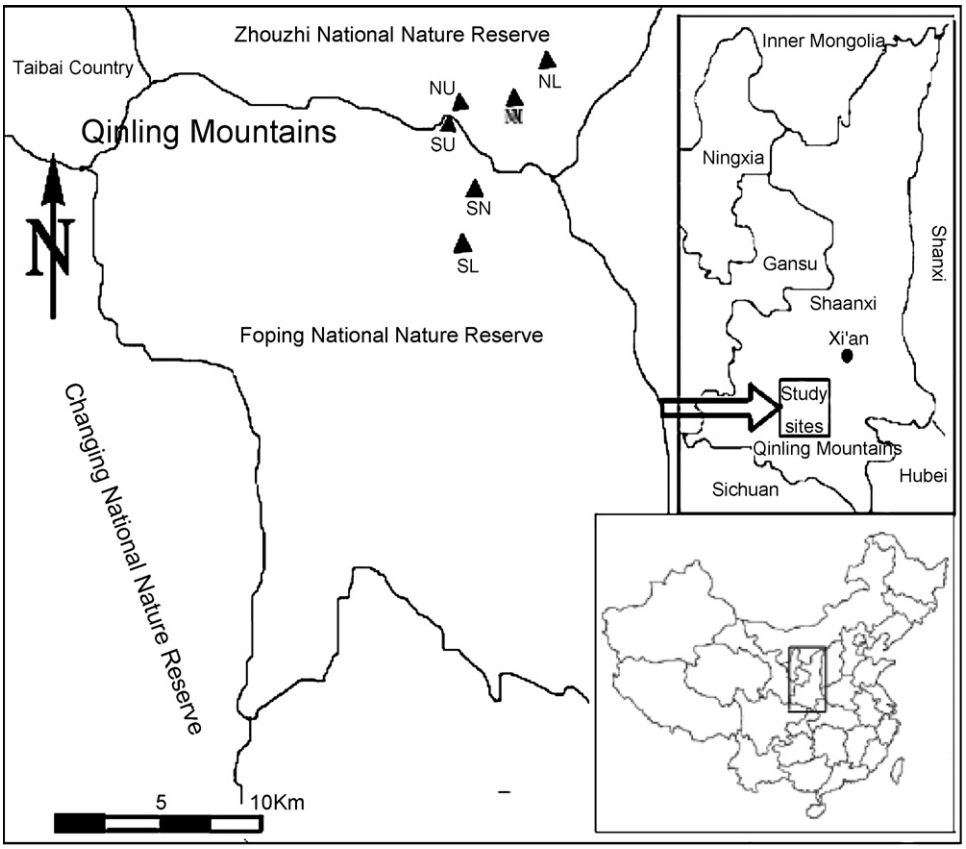

Fig. 1. Locations of the six sampling sites (▲) in the Qinling Mountain of Shaanxi province, China. NL, lower distribution limit in the north aspect; NM, middle distribution zone in the north aspect; NU, upper distribution limit in the north aspect; SL, lower distribution limit in the south aspect; SM, middle distribution zone in the south aspect; SU, upper distribution limit in the south aspect.

aspect of the Qinling Mountain of Shaanxi Province, China (Fig. 1). Elevation in the study area ranges from 980 to 2838 m. The south aspect is of subtropical characteristics with wet summers and warm winters, while the north belongs to warm-temperate zone with relatively dry summers and cold winters (Chen, 1983). Annual precipitation ranges from 950 to 1200 mm, most of which falls between July and September. Snow cover usually lasts five or more months (from November to March), and annual mean temperature ranges from 6 to 11 °C below 2000 m and from 1 to 6 °C above 2000 m a.s.l. (Yue et al., 1999).

Vegetation of the study area comprises of deciduous broad-leaved forests, mixed conifer and deciduous forests, conifer forests and subalpine meadow along the elevational gradient. *Fargesia spathacea* and *Bashania fargesii* are common understory species. Conifers dominated by subalpine fir (*A. fargesii*) occupy the area above 2300 m in elevation, and *A. fargesii* usually develops into mixed forests with birch (*Betula albo-sinensis* var. *septentrionalis*) or forms pure conifer forests above 2300 m. Between the elevation of 1800–2300 m are the mixed conifer and deciduous forests. The deciduous broad-leaved forests grow between the elevation of 980–1800 m. Patchy subalpine meadow occurs above 2600 m a.s.l. (Yue et al., 1999).

2.2. Data collection

In the sampling areas of the Foping and Zhouzhi National Nature Reserves (Fig. 1), subalpine fir (*A. fargesii*) is a dominant or codominant species along the elevational gradient. We have chosen three sites each in the north and south aspects, spanning the elevational range of the subalpine fir: one in the transitional zone between conifer forest and subalpine meadow in the higher elevation, one in the mixed conifer and deciduous forest in the lower elevation, and one in the middle elevation area where the subalpine fir (*A. fargesii*) is the dominant species (Table 1). The vertical distance between the upper and lower sites is 320 m in the south aspect and 400 m in the north aspect. The sampling sites are located in the relatively flat areas with fine to medium-textured substrates.

In each site, a large sample plot ($\geq$100 m $\times$ 20 m) was established, orientating parallel to the isoline to minimize climate variability within each sampling site. All the large and presumably old fir trees within the plots were selected for increment core sampling at breast height (1.3 m above the ground). One or two increment cores per tree were extracted in the direction parallel to the slope contour using increment borers. For a few trees with broken increment core, one additional core from the opposite side was extracted. In total, 223 increment cores were collected from 192 living subalpine fir trees.

2.3. Chronology development

The increment cores were air-dried in the laboratory and mounted on grooved wooden boards. Mounted increment cores