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Climate-growth response of Chinese white pine (*Pinus armandii*) at different age groups in the Baiyunshan National Nature Reserve, central China

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ABSTRACT

Climate-growth response of trees at different age groups is less studied in humid regions of central China. In this study, we divided *Pinus armandii* ring-width series collected from the Baiyunshan National Nature Reserve of central China into young and old age groups based on the Hierarchical cluster analysis. Chronology statistics indicate that mean sensitivity (M.S.), signal-to-noise ratio (SNR), and expressed population signal (EPS) are higher in the old age group than that in the young age group. Meanwhile, there is are growth difference between the two age groups during their common period 1966–2014. Trees in the old age group exhibit significant decadal (~10-year) cycles in the 1960s–1980s, while the 2–3-year cycles are more pronounced for the young age group. Correlation analysis between tree-rings and climate factors shows that the old trees generally contain more climatic information and are more sensitive to temperature, precipitation and moisture variability than the young trees, consistent with the chronology statistics. Our findings highlight the importance of considering the "juvenile effect" of young trees on tree-ring based climate reconstructions in the area.

1. Introduction

Tree-rings are one of the most important means for studying global climate change, due to their precise dating, high (annual) resolution, extensive spatial availability, and high sensitivity to hydroclimate at many locations (Fritts, 1976; Gou et al., 2010). Tree growth is not only affected by climate, but also physiological traits of tree species, tree age, and ecological micro-environment (Fritts, 1976; Szeicz and MacDonald, 1994; Ettl and Peterson, 1995). Therefore, tree-ring based climate reconstructions should be built upon a clear understanding of tree growth under different environmental conditions. A reliable reconstruction can only be achieved by incorporating tree-ring sequences that exhibit coherent growth patterns.

With the advancement of tree-ring research, understanding the influence of tree age on growth variability is becoming more and more important. The response of trees at different age groups to climate change is still not fully understood. Although a few studies considered the climate-growth responses between trees of different age groups are similar (Colenutt and Luckman, 1991; Esper et al., 2008; Wilson and Elling, 2004), many others found large discrepancies (Szeicz and MacDonald, 1994; Ettl and Peterson, 1995; Rozas, 2005; Wang et al., 2009; Peng et al., 2014; Zhang et al., 2013; Wang et al., 2011; Li et al., 2016; Zhao et al., 2016), with the underlying mechanisms remaining unclear. Moreover, there is still no uniform standard or method for the classification of tree age groups. Classifications based on diameter at breast height (Li et al., 2016), tree age at breast height (Szeicz and MacDonald, 1994; Zhao et al., 2016), or clustering of samples at different ages (Peng et al., 2014) are likely affected by non-age-related factors that will inhibit the understanding of age-dependent tree growth response. In this study, we propose a more objective classification method based on Hierarchical cluster analysis, which will reduce non-age-related disturbance and preserve the coherency of tree growth at each age group.

Tee-ring studies in China are mostly carried out in arid and semi-arid regions (e.g., Yuan et al., 2003; Liang et al., 2003; Li et al., 2006, 2007; Wang et al., 2008; Zhang et al., 2011; Fang et al., 2010a, 2010b, 2012) and on the Tibetan Plateau (e.g., Zhang et al., 2003, 2015; Gou et al., 2007, 2008; Li et al., 2008; Liang et al., 2008, 2016; Liu et al., 2009; Shao et al., 2010; Peng and Liu, 2013). More studies are emerging in humid and semi-humid regions of central and eastern China in recent years (Shi et al., 2010; Chen et al., 2011; Duan et al., 2012, 2013; Zheng et al., 2012; Cai and Liu, 2013). To help the development of tree-ring based climate reconstructions in the area, the age-related tree grow response needs to be assessed.

Here we report a case study in the Baiyunshan National Nature Reserve on the northern slope of the Funiu Mountain in Luoyang,

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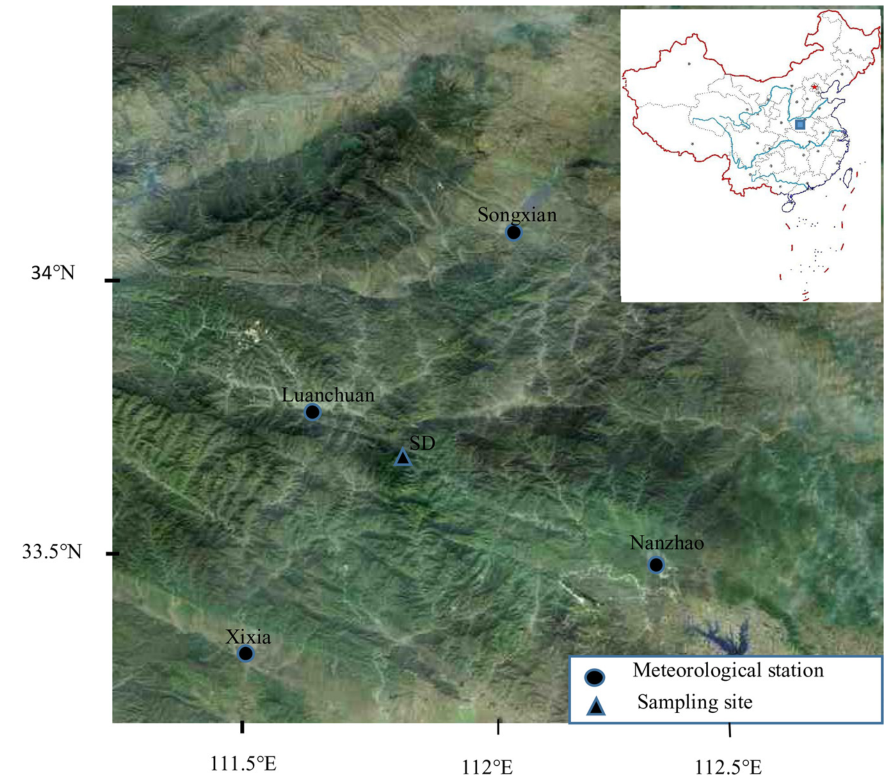

Fig. 1. The map of sampling site and meteorological stations in study area.

Henan Province. The reserve is located in the transition zone of the subtropical-warm temperate in central China, with abundant forest resources. Some dendroecological and dendroclimatological studies have been performed in the area (Shi et al., 2009, 2012; Tian et al., 2009, 2011; Wang et al., 2010; Wang et al., 2014a; Wang et al., 2014b; Liu et al., 2013; Liu et al., 2014a; Liu et al., 2014b) using tree species such as *Pinus tabulaeformis* Carr. and *Pinus armandii,* but none of them discussed the age-dependent tree growth response to climate change. One study assessed the dynamic change of carbon storage from different diameters of *P. armandii* trees in the Baotianman Nature Reserve on the southern slope of Funiu Mountain (Wang et al., 2014a,b). This study aims to study the climate-growth response of *P. armandii* at different age groups in the area, and to assess whether there is age-related growth response for this species.

2. Materials and methods

2.1. Study area and tree-ring sampling

Our sampling site is located in the Baiyunshan National Nature Reserve on the northern slope of the Funiu Mountain, Henan Province (Fig. 1). The peak Yuhuangding, 2216 m above sea level (a.s.l.), is the source region of the White River (a tributary of the Yangtze River), Yi River (a tributary of the Yellow River), and Ru River (a tributary of the Huai River). The Funiu Mountain is an important geographical boundary of warm temperate zone and subtropical zone in China. It is also a complex eco-sensitive area with a high forest coverage (> 90%), with major tree species including *P. armandii*, *P. tabulaeformis*, *Metasequoia glyptostroboides, Larix kaempferi* and some mixed forests. *P. armandii* is mainly distributed within an elevation of 1200–1800 m a.s.l. *P. tabulaeformis* in the study area is already at the southern boundary of its natural distribution. Forest type and structure in the reserve are complex, rich and diversified, making it one of the relatively rare regions with distinct vertical forest distribution zones in central China. The forests are ideal for dendroecological studies as they are less disturbed by human activities.

In November 2014, we collected tree-ring samples of *P. armandii* along a south-north mountain ridge in the Baiyunshan National Nature Reserve (33°40′29″N, 111°51′38″E, 1384 m a.s.l.). Trees with a diameter of 5 cm or above were collected, and tree cores were generally taken at breast height. In total 58 cores from 33 trees were retrieved at the site, with two cores from 25 trees and one core from 8 trees when a second core was hard to collect. The samples were marked as SD.

2.2. Tree-ring pretreatment and measurement

Following standard methods of dendrochronology (Stokes and Smiley, 1968), all the samples were brought back to the lab, mounted, air dried and sanded. After that, the samples were cross-dated with skeleton plot and measured to 0.001 mm precision using a Velmex measuring system. The quality of visual cross-dating was checked with COFECHA (Holmes, 1983; Grissino-Mayer, 2001) program to ensure exact dating for each annual ring. Eventually 55 cores from 31 trees were retained for the study, with the age ranging from 35 to 110 years.

We employed the DPS software (Tang, 2010) to conduct the Hierarchical cluster analysis based on the correlation coefficients between variables and this technique clusters the variables according to their degree of correlations. In the study, the accurately dated raw ring-width sequences were clustered stepwisely based on the degree of their similarity and discrete variance (Fig. 2). Minor adjustments were applied according to the bearing of tree core and the agreement of two cores from the same tree. For example, we will change SD12A (47 years) and SD23A and SD23B (49 years) into young group. Because tree cores SD12A and SD12B of the same tree were separated into two clusters. SD12A (47 years) exhibits high similarity with SD23A and SD23B (49 years) and SD16 (76 years) in the older age trees (see shading in Fig. 2), such that all samplings are divided into the two clusters include young (< 50 years) and old age trees (≥50 years) in order to compare with other study results.

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