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ORIGINAL ARTICLE

Different responses of Korean pine (*Pinus koraiensis*) and Mongolia oak (*Quercus mongolica*) growth to recent climate warming in northeast China

Shanna Lyu[a], Xiaochun Wang[a,*], Yuandong Zhang[b], Zongshan Li[c]

[a] Center for Ecological Research, College of Forestry, Northeast Forestry University, Harbin 150040, China
[b] Key Lab of Forest Ecology and Environment, State Forestry Administration, Institute of Forest Ecology, Environment and Protection, Chinese Academy of Forestry, Beijing 100091, China
[c] State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China

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ABSTRACT

Different tree species growing in the same area may have different, or even contrasting growth responses to climate change. Korean pine (*Pinus koraiensis*) and Mongolia oak (*Quercus mongolica*) are two crucial tree species in temperate forest ecosystems. Six tree-ring chronologies for Korean pine and Mongolia oak were developed by using the zero-signal method to explore their growth response to the recent climate warming in northeast China. Results showed that Mongolia oak radial growth was mainly limited by precipitation in the growing season, while Korean pine growth depended on temperature condition, especially monthly minimum temperature. With the latitude decrease, the relationships between Korean pine growth and monthly precipitation changed from negative to positive correlation, while the positive correlation with monthly temperature gradually weakened. In the contrary, Mongolia oak growth at the three sampling sites was significantly and positively correlated with precipitation in the growing season, while it was negatively correlated with temperature and this relationship decreased with the latitude decrease. The radial growth of Korean pine at different sites showed a clearly discrepant responses to the recent warming since 1980. Korean pine growth in the north site increased with the temperature increase, decreased in the midwest site, and almost unchanged in the southeast site. Conversely, Mongolia oak growth was less affected by the recent climate warming. Our finding suggested that tree species trait and sites are both key factors that affect the response of tree growth to climate change. In addition, the suitable distribution area of Korean pine may be moved northward with the continued global warming in the future, but Mongolia oak may not shift in the same way.

1. Introduction

For the past one and half centuries (1880–2012), the Earth has been experiencing a changing process mainly characterized by climate warming, with the global average temperature increasing by approximately 0.85 ± 0.15 °C (IPCC, 2013). Global warming is an indisputable fact, and will significantly impact plant growth (Shestakova et al., 2016), phenology (Wolkovich et al., 2012), vegetation distribution (Kelly and Goulden, 2008), and the structure and function of forest ecosystems (Grimm et al., 2013). The magnitude of warming in mid-high-latitude regions is larger than that in low-latitude regions, which means that forests in this area are likely more substantially affected by climate change (IPCC, 2013). Tree growth in high latitude of the northern hemisphere showed the increasing (Leonelli et al., 2009; Borgaonkar et al., 2011; Takahashi and Okuhara, 2012), decreasing (Briffa et al., 1998; Büntgen et al., 2006; Pisaric et al., 2007; Herguido et al., 2016) or invariable (Yu et al., 2005) trends in different areas to the recent climate warming.

Since the 1950s, the Northeast China has been one of the regions with the fastest speed and largest magnitude of warming in China, and experienced the most dramatic climate change since the 1980s (Ren et al., 2005; Zhao et al., 2009; He et al., 2013). The forest region in northeast China is the largest forest distribution area in high latitudes, China, and is also the central distribution area of the broad-leaved Korean pine (*Pinus koraiensis*) forest, which has been impacted substantially by climate warming (Ji, 2010; Wang et al., 2017). Therefore, the radial growth responses of Korean pine and Mongolia oak (*Quercus mongolica*), the two key tree species in the broad-leaved Korean pine forest, to the recent climate warming are crucial to predict the growth variations and dynamic of species composition in the broad-leaved Korean pine forest under the global climate change in the future.

A few of dendroclimatological studies have been conducted in the

* Corresponding author.
E-mail address: wangx@nefu.edu.cn (X. Wang).

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mixed coniferous-broadleaved forests in Xiaoxing'an Mountains, China (Ji, 2010). Climate warming could be causing the growth decline of Korean pine in its marginal distribution areas of Xiaoxing'an Mountains, and the response of Korean pine growth to climate change varied with different regions (Ji, 2010). The recent climate warming decreased the Korean pine growth in the closed forests in Xiaoxing'an Mountains, but accelerated Korean pine growth in forest gaps, although the sampling sites were only limited in one site (Liangshui) (Zhu et al., 2015). The significant warming since 1980 may also be one of the factors causing the growth decline of *Picea koraiensis* in Xiaoxing'an Mountains (Yao et al., 2015). In addition, the growth of *Phellodendron amurense* and *Fraxinus mandshurica* in the northern Zhangguangcai Mountains, China could be conducive to global warming, while *Juglans mandshurica* growth exhibits a "divergence phenomenon" of slowing with the temperature increases (Su and Wang, 2017). The responses of a single coniferous or broad-leaved tree species at a single or different site to climate warming are different. However, there are few studies to identify whether the responses of the coniferous and broad-leaved trees in a gradient environment to recent warming are consistent or divergent.

Therefore, we conduct a study in Xiaoxing'an Mountains, China to understand the divergent effect of climate warming on the radial growth of the coniferous and broad-leaved trees at gradient sites. We use the tree-ring width of Korean pine and Mongolia oak collected from three sites (Hebei, Liangzihe, and Yongxing) in the central and eastern Xiaoxing'an Mountains to answer the following questions. Are there different growth-climate relationships for Korean pine and Mongolia oak growing at different sites? If the radial growth of the two trees species growing at the same site responds differently to the same climatic factors? With recent warming since the 1980s, does the sensitivity of Korean pine and Mongolia oak growth to temperature change?

2. Materials and methods

2.1. Study area

The study sites are located at a natural reserve of old-growth forest barely touched by human activity in the central and eastern region of Xiaoxing'an Mountains. We selected three sampling sites: the Hebei Forestry Bureau (HB), the Daliangzihe National Forest Park (LZH), and the Yongxing Forest Farm of the Dongfanghong Forestry Bureau (YX), respectively (Table 1). The study area is characterized by a temperate continental monsoon climate. The terrain features low mountains and hills. The broad-leaved Korean pine forest is vertically distributed from 300 m to 700 m above sea level (a.s.l.). The scattered Korean pine, however, can be found at 800 m a.s.l., and the lowest edge is at the elevation of 80–100 m a.s.l. The climate is a cold and dry winter and warm, moist, and rainy summer, with annual mean temperatures between −1 and 1 °C. The average temperature in the hottest month (July) is 20–22 °C, and temperatures in the coldest month (January) range from −23 °C to −28 °C. The multi-year average precipitation is 550–700 mm, mainly received in June-August which accounts for approximately 60–80% of the annual total precipitation. The annual frost-free period is 100–120 days. Soil is dominated by mountain dark-brown soil (Liu, 2012).

Two dominant tree species, Korean pine and Mongolia oak, in the natural broad-leaved Korean pine forest of northeast China were chosen. Korean pine is an intolerant conifer tree species with a shallow root system. It is highly sun-loving and has relatively high soil moisture requirements. Korean pine is not suitable to extreme dry or wet soils or a harsh climate, and is sensitive to air humidity. It grows best in a warm and rainy climate with relatively high humidity and in deep and fertile acidic brown forest soil with good drainage.

Mongolia oak is an intolerant broad-leaved tree species, which thrives in a cool climate. It can endure extreme cold and drought, and has no strict soil requirements. Mongolia oak can adapt to a broad range of soil types, although it mainly grows in relatively acidic or slightly acidic dark-brown and brown forest soils. Mongolia oak can endure barren but not wet soils. It is distributed from the top of low hills to ridges and various aspects with gentle inclines due to the developed root systems.

The vegetation of the broad-leaved Korean pine forest in this area is mainly dominated by Korean pine, the broad-leaved trees, such as Mongolia oak, *F. mandshurica*, *P. amurense*, *Juglans mandshurica*, *Ulmus japonica*, *Tilia amurensis*, *Betula costata*, and *Acer mono*, and other conifer trees such as *Abies nephrolepis*, *Picea jezoensis* etc. (Li, 1993).

2.2. Field and laboratory work

In June 2015, we collected tree-ring cores of Korean pine and Mongolia oak in Xiaoxing'an Mountains (Fig. 1). We used an increment borer with an inner diameter of 5.15 mm to take one or two cores at the opposite directions of the breast height (1.3 m) in each tree, and a total of 247 tree-ring cores were collected (Table 1).

All tree-ring samples were brought back to the laboratory, and were pasted, fixed, polished and visually cross-dated by busing the skeleton plot method under a binocular microscope based on the general procedures for processing tree-ring samples (Fritts, 1976; Stokes and Smiley, 1996). Then, we used a Velmex ring width measurement instrument (Velmex TA Tree Ring System, Velmex Inc.) to measure each ring width. The measurement accuracy was 0.001 mm. Finally, the cross-dated results were checked and tested using the quality control program COFECHA (Holmes, 1983), then the wrong cross-dated results were corrected or the unsuccessful cross-dated tree-ring series was eliminated in the subsequent chronology development.

To alleviate the end effect and fitting deviation caused by the dramatic change of tree-ring series, we used the signal-free method to fit the growth trend curve (Melvin and Briffa, 2008). We used the linear or negative exponential functions to fit the growth trend and derive the growth trend of different tree-ring series. Then, we divided the original ring-width series by the fitting growth trend and derived the zero-signal series. Finally, we used the 67% length of each core to fit the zero-signal series and detrend again. After multiple iterations of the processes, we developed the tree-ring chronologies removing the non-climate signals, especially the end effects. The procedures of detrending and chronology development was accomplished using the RCSsigFree 4.5 software

Table 1
Tree-ring sampling information for different sites and tree species in northeast China.

Sampled sites	Sample code	Tree species	Altitude (m)	Latitude (N)	Longitude (E)	Core/tree Numbers
HB	HB-PK	*P. koraiensis*	448	48°02′	130°18′	44/22
	HB-QM	*Q. mongolica*	258	48°11′	130°28′	42/21
LZH	LZH-PK	*P. koraiensis*	451	47°02′	129°41′	41/21
	LZH-QM	*Q. mongolica*	449	47°02′	129°40′	40/20
YX	YX-PK	*P. koraiensis*	161	46°40′	133°42′	40/20
	YX-QM	*Q. mongolica*	161	46°40′	133°42′	40/20

Notes: HB-Hebei, LZH-Liangzihe, YX-Yongxing. PK and QM represent the sampled tree species is *Pinus koraiensis* and *Quercus mongolica*, respectively.