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Spatial variation and temporal instability in the climate–growth relationship of Korean pine in the Changbai Mountain region of Northeast China

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ABSTRACT

Tree radial growth in mountainous areas is subject to complex environmental influences, and the response of radial growth to climate varies with elevation. To detect spatial variation and temporal instability in the climate–growth relationship for Korean pine (*Pinus koraiensis* Sieb. et Zucc) in Northeast China, we used dendrochronological analyses to examine radial growth–climate relationships along an altitudinal gradient in different forests on Changbai Mountain. Results confirmed the general conclusion that the climate–growth relationship varies with altitude. More specifically, at lower elevations Korean pine radial growth was controlled mainly by precipitation, while at the upper limit of its higher elevation zone it was much more affected by minimum temperature. Furthermore, these effects have become stronger since the temperature began increasing more rapidly in 1970 than before. In effect, radial growth decreased at lower elevations under climate change characterized by warming and drought, but increased at higher elevations. These results showed that long-term climate sensitivity varies strongly across altitudinal gradients and may be characterized by abrupt temporal shifts and differing trends in drought. The findings of this study will assist in simulating radial growth and distribution dynamics for Korean pine under various global climate change scenarios.

1. Introduction

The effects of global warming are expected to be most apparent at mid- to high-latitudes in the Northern Hemisphere, especially on sites located in the continental interior (Serreae et al., 2000). Accumulating evidence has revealed that in China the Northeast has experienced the greatest increase in temperature since the 1950s (Wang et al., 2010). This rapid rise in temperature has contributed to an obvious climatic warming–drying trend since the 1970s (Wang et al., 2008, 2009). There is also considerable evidence that contemporary changes in global climate are altering the phenology and distribution of many species in the region (e.g. Mérian et al., 2011). In the context of climatic change, questions have arisen concerning forest composition, survival and growth in response to annual climate variability in Northeast China.

To date, forest succession models have predicted that distributions of the dominant conifer tree species in Northeast China under global warming scenarios will be manifest via northward geographic and upward altitudinal shifts (e.g. Shao, 1996; Zhao et al., 1998; Xu and Yan, 2001; He et al., 2005). If such models are realistic, these shifts should be reflected in variations in forest composition and structure, which in turn would concurrently be reflected in tree radial growth. The spatial distribution of a given conifer species would be extended geographically at its upper northernmost limit and recede from its lower or southernmost limit. Forest composition and structure will change as the dominance of tree species in a given forest type will be magnified or reduced depending on its response to climate change. Such responses have contributed to the basic assumptions and preconditions of most models (Yan et al., 2000; Hao et al., 2001; He et al., 2005).

Dendrochronological studies at broad spatial and temporal scales could provide useful information on the spatiotemporal variation of tree growth (Tardif et al., 2003). These studies are also essential to validate climate model simulations in climate-sensitive areas such as the higher-latitude region of Northeast China. Many studies have found that climate–growth relationships vary with latitudinal and elevational differences (e.g. Yu et al., 2005, 2006, 2011; Liang et al., 2010; Zhang et al., 2012; Griesbauer and Green, 2012). In general trees have been found to suffer more from water stress at their southern-most geographic and lowest altitudinal distributions and from temperature at their northern-most geographic and highest altitudinal distributions. However, a number of recent tree-ring studies have highlighted a decreasing

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response to temperature of forest ecosystems at their northernmost latitudes and high elevations since around the mid-20th century (D'Arrigo et al., 2008; Oberhuber et al., 2008; Zhang and Wilmking, 2010); as well as an increasing sensitivity to summer water balance as affected by temperature at these same latitudes and elevations (Andreu et al., 2007), suggesting a temporal instability in climate–growth relationships (D'Arrigo et al., 2008; Oberhuber et al., 2008). These areas characterized by climate warming and dry climatic trends are found at similar latitudes to those of Northeast China. In this light, analyzing the variation of climatic influences on radial growth may provide a powerful tool to yield valuable information about forest sustainability in this region.

Korean pine (Pinus koraiensis Sieb. et Zucc), the dominant species in the Korean pine and broad-leaved mixed forest, is widely distributed in the temperate zone (middle and lower latitudes) of Northeast China. Previous findings have identified Korean pine as a moisture-loving species, but with a narrow ecological capacity for adaption to moisture (Wei et al., 1995). Several studies of the climate–growth relationship of Korean pine in this region have identified both precipitation and temperature as limiting factors with respect to tree growth, with precipitation more important at more southern geographic and lower altitudinal limits (Shao and Wu, 1997; Zhu et al., 2009; Wang et al., 2011), and temperature more limiting at higher latitudes and altitudes (Gao et al., 2011; Yu et al., 2011; Li et al., 2011). However, most studies have focused primarily on single forest sites and few have devoted attention to the effects of climate on tree growth along latitudinal or altitudinal gradients since the onset of the more rapid increase in temperature over the past 40–50 years. While climate warming and increasingly dry climatic patterns will be experienced in the middle and lower latitudes of Northeast China via such limiting factors as increasing low temperatures and drought stress, their effects on Korean pine are uncertain, given that broad scale variations in climate–growth relationships of Korean pine and their temporal evolution remain largely unspecified.

The core area of Changbai Mountain in Northeast China is covered with a large area of undisturbed temperate old-growth forest (Shao and Zhao, 1998). It is characterized by a vertical zonation of three forest ecosystems along the altitudinal gradient. These ecosystems also represent the major forest types in Northeast China along the latitudinal gradient. This makes Changbai Mountain an ideal setting to examine climate–growth relationships. Despite abundant precipitation in the region, dendrochronological studies have suggested that precipitation is a critical factor limiting radial growth on Changbai Mountain (Yu et al., 2007, 2011; Li et al., 2011). With respect to Korean pine, a species with high economic value and widespread distribution in the region, how climate warming and increasingly dry climatic patterns have affected tree growth is still unknown.

In this study we used a dendroecological approach to better understand spatio-temporal changes in climate–growth responses of Korean pine to 20th century climate variability. The following three research questions will be addressed by means of tree-ring growth analysis: (1) What are the most important climatic factors influencing Korean pine growth on Changbai Mountain? (2) To what extent does Korean pine react to climate variability? and (3) Are the observed climate–growth relationships stable over time?

2. Materials and methods

2.1. Study area

The study area is located on the northern slope of the Changbai Mountain Natural Reserve in Northeast China (41°31′–42°28′N, 127°9′–128°55′E) (Fig. 1). The altitudinal vegetation zonation within the study area has been well documented (e.g. Wang et al., 1980). Four altitudinal vegetation zones have been recognized, including Korean pine and broad-leaved mixed forest extending from approximately 750–1100 m asl; spruce-fir forest – from 1100 to 1700 m asl; erman's birch forest, which forms the upper

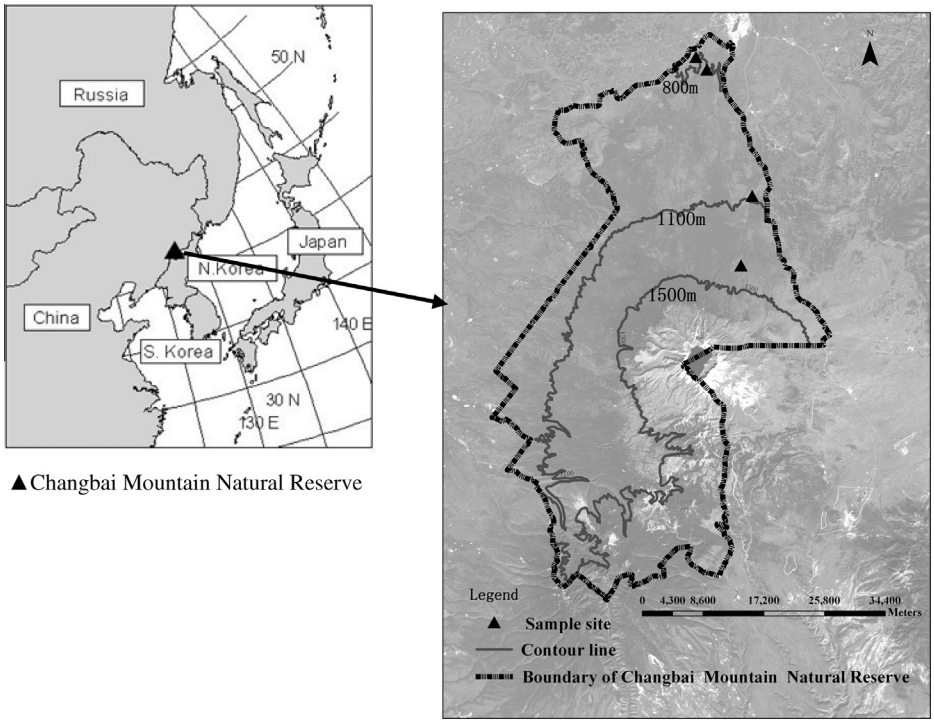

Fig. 1. Location of the Changbai Mountain Natural Reserve in Northeast China.