Tree Radial Growth and Its Response to Climatic Factors in the Altai Mountains of Kazakhstan: Postprint

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Abstract

A tree-ring study was conducted on Siberian spruce (Picea obovata) and Siberian larch (Larix sibirica) on the southern slopes of the Altai Mountains in Kazakhstan, establishing tree-ring chronologies, calculating mean annual tree-ring width values and mean annual basal area increment (BAI), and analyzing the trends in tree-ring width indices of these two species before and after the warming shift that occurred in 1988, as well as their radial growth responses to climatic factors. The results indicate that before and after the warming shift, the trends in tree-ring width indices of the two species were consistent. However, after the warming shift, their trends changed from non-significant increases to significant decreases; that is, tree radial growth slowed down. After the warming shift, the radial growth responses of both species to precipitation weakened, while their responses to temperature strengthened, and a "positive-negative reversal" in the correlation between tree-ring indices and climatic factors occurred.

Full Text

Preamble

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1 Introduction

1.1 Study Area

The research area is located on the southern slope of the Altay Mountains in Kazakhstan, where the main forest species include *Picea obovata*, *Larix sibirica*, and *Abies sibirica*. The elevation of *Picea obovata* stands ranges from 1200 to 2100 m, with a semi-humid climate. *Larix sibirica* is distributed across a wider elevation range of 1300–2600 m, with relatively dry site conditions. The region experiences 5 months of winter, with growth occurring from June to July and cessation in September-October [14].

1.2 Tree-Ring Data Collection and Chronology Development

Two standardized tree-ring width chronologies were developed [Figure 1: see original paper]. The standardization (STD) method was applied to establish the chronologies [15]. In 2017, 8 increment cores were collected from each of 20 *Larix sibirica* trees and 20 *Picea obovata* trees to construct the tree-ring width chronologies for the two species (*Larix sibirica* denoted as LDL; *Picea obovata* as LDY).

1.3 Basal Area Increment Calculation

The basal area increment (BAI) was calculated to quantify radial growth trends. The two tree-ring width chronologies were standardized, and the BAI for each species was computed using the formula:

$$BAI_t = BA_t - BA_{t-1} = \pi[(R_{t-1} + TRW_t)^2 - (R_{t-1})^2]$$

where BAI_t is the basal area increment in year t, BA_t is the basal area in year t, R_{t-1} is the radius in year $t-1$, and TRW_t is the tree-ring width in year t [18].

Tree-ring widths were measured using a LINTAB measuring system with 0.001 mm precision. Cross-dating quality was verified using the COFECHA program [16], and the ARSTAN software was employed to develop the final chronologies through detrending and averaging [17]. The Gleichläufigkeit (GLK) statistic was calculated to assess the synchronicity between the two species' growth patterns [21]. For two chronologies x and y, GLK is computed as:

$$GLK(x, y) = \sum_{i=1}^{n-1} G_i/(n-1)$$

where $G_i = 1/2$ if the sign of the difference between consecutive years matches for both series, $G_i = 0$ if either series shows no change, and $G_i = -1/2$ if the signs differ [22].

TABLE:1 provides detailed information about the sampling sites and statistical characteristics of the tree-ring width chronologies for the common period 1910–2010.

1.4 Climate Data and Statistical Analysis

Climate data (monthly precipitation and temperature) for the period 1960–2016 were obtained from the Kazakhstan meteorological station network within the study area (50°–51°N, 83°–84°E). The expressed population signal (EPS) exceeded 0.85 for both chronologies, indicating reliable representation of the population growth patterns.

Correlation analysis was performed using Pearson correlation coefficients between the tree-ring chronologies and monthly climate data from the previous August to current September [24]. The Mann-Kendall test was applied to detect trends and abrupt changes in climate variables [Figure 4: see original paper]. The analysis was conducted for two periods: 1960–1988 and 1989–2016, separated by the identified temperature shift in 1988.

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2 Climate Characteristics and Tree Growth Trends

During 1960–2016, annual precipitation and mean temperature showed increasing trends, with Mann-Kendall test statistics of 0.414 ($P < 0.01$, $n = 107$), 0.532

($P < 0.01$, n = 107), and 0.846 ($P < 0.01$, n = 107) for different climate parameters. The GLK value between the two species' BAI chronologies was 0.732 (n = 56, $P < 0.001$), indicating highly synchronous radial growth patterns.

The tree-ring width index for both species showed consistent variation trends before and after the 1988 temperature rise. Prior to 1988, the index increased significantly despite slowly decreasing precipitation and gradually rising temperatures. However, after 1988, both species exhibited significant declining trends in ring-width index as precipitation and temperatures continued to increase, suggesting a negative impact of climate change on tree growth.

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3 Species-Specific Climate Responses

The response of radial growth to climatic factors differed between the two species and varied across time periods. During 1960–1988, *Larix sibirica* growth showed significant negative correlation with May precipitation and previous August temperature. *Picea obovata* exhibited significant positive correlation with July precipitation but negative correlation with previous August temperature.

During 1989–2016, the growth response patterns shifted. *Larix sibirica* no longer showed significant correlation with May precipitation; instead, significant negative correlations emerged with May and previous August temperatures. The correlation with growing-season temperatures weakened or shifted from positive to negative. *Picea obovata* lost its significant positive correlation with July precipitation, while negative correlations with temperature strengthened, particularly for previous August and October temperatures.

Overall, the positive response to precipitation decreased while the negative response to temperature increased after the 1988 temperature rise for both species. The response of *Larix sibirica* to temperature was slightly stronger than that of *Picea obovata*, though the difference was not statistically significant ($P = 0.342$).

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4 Discussion

The results demonstrate that temperature is the primary limiting factor for radial growth of both *Picea obovata* and *Larix sibirica* under global warming, with precipitation playing a relatively minor role. The divergence in climate-growth relationships before and after the 1988 temperature threshold suggests that continued warming may further constrain forest productivity in the Altay Mountains region. The high GLK values indicate consistent growth patterns between species, reflecting common regional climate signals.

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Note: Figure translations are in progress. See original paper for figures.