

Differential Growth Responses of Natural Mongolian Pine to Climate Change in Southern and Northern Greater Khingan Mountains: A Post-print

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Abstract

Dendrochronological methods were used to establish tree-ring width chronologies for Mongolian pine (*Pinus sylvestris* var. *mongolica*) in the southern and northern parts of the Greater Khingan Mountains forest region, and to investigate differential responses of radial growth to climate change. The results show that tree-ring width in the southern region (Arshan, Hailar) is highly significantly positively correlated with the mean Standardized Precipitation Evapotranspiration Index (SPEI) for April-September of the current year ($r=0.639$, $P < 0.01$), while in the northern region (Mohe, Tahe) it is highly significantly positively correlated with the mean minimum temperature of the same period ($r=0.488$, $P < 0.01$). This indicates that radial growth of Mongolian pine in the southern region is primarily limited by water availability during April-September of the current year, whereas in the northern region it is primarily regulated by the mean minimum temperature of the same period. Tree growth in both regions shows consistent responses to precipitation, but opposite responses to temperature during April-September (except June) of the current year. In recent decades, with significant temperature increase ($P < 0.01$), the negative response of tree growth in the southern region to mean maximum temperature during April-September has continuously strengthened, while trees in the northern region show a more pronounced positive response to mean minimum temperature during the same period. Simultaneously, the growth rate of Mongolian pine in the southern region has rapidly declined ($r=0.612$, $P < 0.001$), while in the northern region it has significantly increased ($r=0.474$, $P < 0.001$). The study found that intensified drought stress caused by high temperatures is the primary reason for the growth decline of Mongolian pine in the southern region, whereas the increased growth in the northern region is influenced by

the interaction between mean minimum temperature and precipitation during April-September. If warming continues, the distribution range of Mongolian pine may shift northward in the future.

Full Text

Different Responses of Natural *Pinus sylvestris* var. *mongolica* Growth to Climate Change in Southern and Northern Forested Areas of the Greater Khingan Mountains

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Abstract

Using dendrochronological methods, we established tree-ring width chronologies for natural *Pinus sylvestris* var. *mongolica* forests in the southern and northern Greater Khingan Mountains to investigate differential radial growth responses to climate change. In the southern region (Arxan and Hailar), tree-ring width showed a highly significant positive correlation with the average Standardized Precipitation Evapotranspiration Index (SPEI) from April to September ($r = 0.639$, $p < 0.01$), indicating that radial growth was primarily constrained by moisture conditions during the growing season. In the northern region (Mohe and Tahe), tree-ring width was significantly positively correlated with mean minimum temperature during the same period ($r = 0.488$, $p < 0.01$), revealing temperature as the main limiting factor. While both regions exhibited consistent positive responses to precipitation, their temperature responses were opposite from April to September (except June). Over the past 54 years, these divergent climate sensitivities have led to contrasting growth trends: southern trees showed a rapid decline in radial growth ($r = 0.612$, $p < 0.001$) at a rate of $0.253 \text{ cm}^2/\text{year}$, whereas northern trees demonstrated a significant increase ($r = 0.474$, $p < 0.001$) at $0.039 \text{ cm}^2/\text{year}$. The primary driver of growth decline in the south was increasing drought stress caused by rising temperatures, while growth enhancement in the north resulted from the combined effects of rising minimum temperatures and precipitation. If warming continues, the natural distribution of *P. sylvestris* var. *mongolica* may shift northward.

Keywords: Greater Khingan Mountains; climate change; *Pinus sylvestris* var. *mongolica*; radial growth; differential response

Introduction

Climate warming has produced divergent effects on tree growth across global forest ecosystems. Many species, including *Pinus sylvestris*, *Pinus nigra*, *Pinus koraiensis*, *Picea crassifolia*, and *Picea meyeri*, exhibit growth divergence along elevational and latitudinal gradients, with declining growth at southern latitudinal or lower elevational limits and increasing growth at northern or upper limits [1-5]. While warming has increased gross primary productivity across the Eurasian continent [6], temperature-induced water stress has simultaneously triggered growth decline and mortality in climate-sensitive regions [8-9]. Even within the same region, tree responses to climate change can be unstable, with both positive and negative responses observed [11-12]. Understanding these differential responses is crucial for accurately predicting future forest ecosystem dynamics.

Pinus sylvestris var. *mongolica*, a geographical variety of Scots pine, is concentrated in the northern Greater Khingan Mountains and the Hulunbuir Sandy Land in southern Inner Mongolia [13]. Previous dendroclimatic studies have identified region-specific limiting factors: precipitation dominates growth in the Hulunbuir region [14-15], while temperature controls growth in northern areas such as Yong'an Mountain [16-17]. Under recent warming, even natural stands in the Mangui area have experienced growth suppression [19]. These findings suggest that *P. sylvestris* var. *mongolica* may exhibit different growth-climate relationships across its distribution. However, comparative studies examining radial growth responses to climate change between southern and northern populations remain limited. This study addresses this gap by sampling at the southern and northern edges of the species' natural range, using dendrochronology to (1) characterize climate-growth relationships in each region, (2) identify growth trends over recent decades, and (3) assess climate impacts on regional growth patterns. Our findings will enrich understanding of growth-climate diversity in the Greater Khingan region and provide a theoretical basis for adaptive management and predicting future distribution shifts of natural *P. sylvestris* var. *mongolica* forests.

1 Study Area Overview

The study area spans 47°25' -53°11' N, 119°30' -124°06' E across the Greater Khingan Mountains, characterized by a cold temperate continental monsoon climate. Southern and northern regions exhibit distinct climatic regimes. The southern area (Hailar and Arxan) features a mid-temperate semi-arid climate with cold, dry winters and hot, short summers. Mean annual temperature is -1.86°C, with monthly temperatures below 0°C for 5-6 months. Average annual precipitation is 397 mm, with 46-49% falling during June-August. Soils are predominantly sandy. The northern area (Mohe and Tahe) represents a cold temperate semi-humid zone with prolonged cold winters and brief warm summers. Mean annual temperature is -3.6°C, with 7 months below 0°C. Annual precipitation averages 444 mm, with 65% concentrated in summer. Terrain consists of low mountains

and hills with brown coniferous forest soils [FIGURE:1, FIGURE:2].

2 Sample Collection and Chronology Development

Sampling sites were established near the natural distribution edges: Hailar (HLZ), Arxan (AEZ), Mohe (MBZ), and Tahe (THZ). Healthy, mature trees were cored at breast height using increment borers. Cores were air-dried, mounted, and sanded until rings were clearly visible under microscopy. Cross-dating was performed both visually and using the Velmex measuring system (0.001 mm precision). The COFECHA program verified dating accuracy, and ARSTAN software [20] was used for detrending (linear or negative exponential functions) and standardization to produce residual chronologies (RES) [21-22].

Statistical analysis revealed strong inter-series correlations within each region ($r > 0.65$, $p < 0.01$), indicating coherent growth patterns. While southern (HLZ-AEZ) and northern (MBZ-THZ) chronologies differed significantly ($p < 0.01$), strong common signals within each zone justified regional pooling. The resulting regional chronologies showed high expressed population signal (EPS > 0.85) and mean sensitivity values suitable for dendroclimatic analysis, with southern chronologies exhibiting greater sensitivity than northern ones .

3 Meteorological Data

Monthly climate data (1960-2013) were obtained from the China Meteorological Data Network (<http://data.cma.cn>) for Hailar, Arxan, Mohe, and Tahe stations. Variables included total precipitation, mean temperature, and mean maximum/minimum temperatures. To minimize single-station bias, data from Hailar and Arxan were averaged for the southern region, and Mohe and Tahe for the northern region, as inter-station correlations were highly significant ($p < 0.01$). Additionally, gridded data for maximum temperature, minimum temperature, and SPEI were downloaded from the KNMI Climate Explorer (<http://climexp.knmi.nl>) for 47°-50°N, 119°-120°E (south) and 52°-54°N, 122°-125°E (north). SPEI, a drought index integrating precipitation and temperature effects [23], was calculated for the period 1954-2013.

4 Statistical Analysis

Pearson correlation analysis assessed relationships between RES chronologies and monthly climate factors from previous October to current September (1960-2013). Basal area increment (BAI) was estimated from raw ring-width measurements, standardized using z-score transformation, and compared between regions using t-tests. Moving correlation analysis (31-year windows) examined temporal stability of climate-growth relationships using gridded data.

1 Climate Change in the Study Area

The study region experienced significant warming from 1960–2013. Mean annual temperature, mean maximum temperature, and mean minimum temperature increased significantly ($p < 0.01$) in both regions, with trends of 0.34, 0.24, and 0.52°C/decade in the south, and 0.44, 0.52, and 0.36°C/decade in the north, respectively. Southern precipitation declined slightly (-1.07 mm/decade, $p > 0.05$), while northern precipitation increased significantly (14.63 mm/decade, $p < 0.05$), particularly after 1980.

2 Relationships Between Chronologies and Climate Factors

Tree growth was primarily influenced by current-year climate conditions. In the southern region, ring width was significantly negatively correlated with mean and maximum temperatures from April–September ($p < 0.01$), but positively correlated with precipitation in May, June, and July ($p < 0.05$). The strongest relationship was with April–September SPEI ($r = 0.639$, $p < 0.01$), confirming moisture as the primary limiting factor. In contrast, northern ring width showed significant positive correlations with April–September mean minimum temperature ($r = 0.488$, $p < 0.01$) and precipitation ($r = 0.376$, $p < 0.05$), indicating temperature limitation. The two regions exhibited opposite temperature responses: southern growth negatively correlated with maximum temperatures, while northern growth positively correlated with minimum temperatures [Figure 3: see original paper].

Moving correlation analysis revealed changing climate sensitivities over time. Southern correlations with maximum temperature strengthened as temperatures rose, becoming increasingly negative. Northern correlations with minimum temperature remained positive and strengthened with warming, with most years showing significant relationships ($p < 0.05$) [Figure 4: see original paper].

3 Changes in Pine Growth and Their Relationship with Climate Change

BAI trends diverged sharply between regions from 1960–2013 (t-test, $p < 0.001$). Southern BAI declined significantly ($r = 0.612$, $p < 0.001$) from 31.68 cm² to 12.78 cm², a 59.6% reduction at a rate of 0.253 cm²/year. Northern BAI increased significantly ($r = 0.474$, $p < 0.001$) from 5.87 cm² to 8.12 cm², a 38.3% increase at 0.039 cm²/year [Figure 5: see original paper].

Climate drivers of these trends differed markedly. Southern BAI was highly significantly negatively correlated with April–September mean maximum temperature ($r = -0.681$, $p < 0.01$), while precipitation showed no significant trend. The divergence between BAI and maximum temperature was stark, with their interannual variations being nearly mirror images [Figure 6: see original paper]. Northern BAI tracked both April–September mean minimum temperature ($r = 0.454$, $p < 0.01$) and precipitation ($r = 0.31$, $p < 0.01$), both of which increased

concurrently with growth.

Discussion

1 Tree Radial Growth Responses to Climate Factors

April–September represents the critical growth period, with growth commencing in late April and ceasing in late September [19]. The consistent positive response to precipitation in both regions reflects the fundamental importance of water availability. However, the opposite temperature responses illustrate distinct limiting factors. In the semi-arid south, abundant solar radiation meets heat requirements, making moisture availability paramount. Elevated maximum temperatures intensify evapotranspiration, exacerbating water stress and reducing growth [24, 35–36]. Conversely, the cold, semi-humid north frequently experiences low-temperature damage [26], making minimum temperature the primary constraint on photosynthesis, respiration, and stem growth [27]. Rising minimum temperatures advance cambial activity [28] and enhance xylem development [29], thereby promoting growth.

The increasing climate sensitivity in both regions aligns with findings for other species [3, 33–34]. The divergent temperature responses likely reflect physiological thresholds: when temperatures exceed optimal limits, respiration increases and photosynthetic rates decline, negatively impacting growth [31]. Southern temperatures may have surpassed these thresholds, particularly given *P. sylvestris* var. *mongolica*'s low heat tolerance [32].

2 Growth Variation and Climate Drivers

The substantial growth decline in the southern distribution edge reflects intensifying drought stress. Despite stable precipitation, rising maximum temperatures have increased evapotranspiration, reducing plant-available water [35–36] and causing earlier cessation of cell division with narrower tracheids [37]. This pattern mirrors growth declines in other water-limited regions [35, 38] and may also involve carbon limitation [39–40].

In contrast, northern growth enhancement reflects beneficial warming effects. Rising minimum temperatures prolong the growing season by advancing spring phenology and delaying autumn senescence [4, 41–42], while increasing precipitation provides adequate moisture to support higher photosynthetic rates. The coupling of warmer temperatures with increased precipitation creates favorable conditions for boreal forest productivity [43–44].

Conclusion

The contrasting growth trends of *P. sylvestris* var. *mongolica* in the southern and northern Greater Khingan Mountains demonstrate divergent climate change impacts. Warming-induced drought stress drives growth decline at the southern range edge, while warming benefits growth in the north. If these trends continue,

the species' natural distribution will likely shift northward, consistent with model projections for northeastern China forests [45].

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