Climate–Growth Relationships of Mongolian Pine (Pinus sylvestris var. mongholica) along an Altitudinal Gradient of Northeast China

Xinrui Wang 1, Zhaopeng Wang 1, Dongyou Zhang 1,2,*, Taoran Luo 1, Xiangyou Li 1, Bingyun Du 1 and Shubing Zhong 1

1 Heilongjiang Province Key Laboratory of Geographical Environment Monitoring and Spatial Information Service in Cold Regions, Harbin Normal University, Harbin 150025, China; wxhxs0928@stu.hrbnu.edu.cn (X.W.); wzphsd0503@stu.hrbnu.edu.cn (Z.W.); luotaoranhashida@stu.hrbnu.edu.cn (T.L.); 17855027656@163.com (X.L.); duby@stu.hrbnu.edu.cn (B.D.); zhongshubing@stu.hrbnu.edu.cn (S.Z.)

2 Heilongjiang Wuyiling Wetland Ecosystem National Observation and Research Station, Yichun 153000, China

* Correspondence: zhangdy@hrbnu.edu.cn

Abstract: To study the radial growth of Mongolian pine (Pinus sylvestris var. mongholica, MP) trees in response to climatic factors against the global warming background in the northeast part of the Greater Kheingan Mountains (GKM), 101 tree cores were collected at contrasting altitudes (1100 and 650 m) in the Mordoga area, a tree-ring width chronology of MP was established for that region at both altitudes, and the relation between climatic factors and ring width trends at different time scales was investigated. The results revealed four major findings. (1) The ring width chronology of MP in the low-altitude area has better quality. (2) The growth of MP at high (low) altitude was mainly influenced by temperature (precipitation) factors. (3) Before a sudden change in temperature, there was a decreasing trend in the annual indices of MP's at higher altitudes. The chronological coefficients of MP's at both altitudes showed a significant upward trend after the increase in temperature. (4) The sliding analysis results showed that the stability of the relationship between MP growth and its response to climatic factors at both altitudes was also mostly similar. MP growth is relatively stable and sensitive to climatic factors as temperatures increase.

Keywords: tree rings; Mongolian pine; climate response; altitudinal trends

1. Introduction

Global climate warming has continued to have significant impacts on natural ecosystems [1]. According to the Intergovernmental Panel on Climate Change (IPCC), the global surface temperature has increased 1.1 °C in 2011–2020 when compared to the temperatures for 1850–1990 [2]. The increase in global temperature is not a steady increase at the same rate every year but rather a sudden change in temperature over a period of time [3]. As the mainstay of terrestrial ecosystems, forests are a huge terrestrial carbon sink [4]. With their high productivity and species diversity, they play a major role in maintaining the global carbon and water cycle and in mitigating climate change [5]. However, in the context of global warming, climate change has profound impacts on forest ecosystems, such as loss of biodiversity and changes in species ranges and ecosystem structure and function [6]. Accordingly, in order to better understand the relationship between climate change and forest vegetation, it is important to properly assess that impact. This will facilitate the anticipation of future forest cover changes and optimize forestry management strategies to ensure the longevity and sustainability of forest ecosystems.

Tree annual rings typically have many characteristics. Examples include broad coverage, precise resolution, accurate chronological localization, and ease of obtaining consistent samples [7]. Furthermore, the width of a tree ring can faithfully record the favorable or
unfavorable climatic factors of each passing year; hence, ring data are now widely used to reconstruct the paleoclimate or paleoenvironment and have emerged as a key source of proxy data for climate and environmental change [8]. Climate change can affect the biological processes in trees, which in turn can alter their growth, reproduction, and species distribution [9]. It has been shown that rapid climate warming increases both tree growth and forest productivity [10–12]. Interactions between forest ecosystems and climate are difficult to understand because of the coexistence of many biotic and abiotic factors, but environmental differences along altitudinal gradients could be a vital factor influencing tree growth dynamics [13,14]. Altitude is recognized as a pivotal ecological factor that often drives the redistribution of thermal and hydrological conditions and affects the tree growth of tree species [15]. It is generally accepted that at high altitudes, growth is mainly influenced by temperature, whereas at low altitudes, that growth is more controlled by water conditions [16,17]. For example, the radial growth of high-altitude snow ridge spruce (Picea schrenkiana) in the western Tianshan mountains of northwest China is likewise limited by temperatures, while at low altitudes, it is affected mainly by precipitation [18]. Yet the climatic factors limiting growth vary across regions, and the response of tree growth to climatic factors may remain remarkably consistent at different altitudes [19]. For example, long-bracted fir (Abies georgei) at different altitudes on Jade Dragon Snow Mountain is limited by both temperature and precipitation [20], while Yunnan pine (P. yunnanensis) growing at different altitudes showed the same response pattern to climatic factors [21]. Therefore, clarifying the stabilizing tree reaction to climate change at different altitudes under a warming climate and elucidating the responsible mechanisms involved are both of great scientific value to dendroclimatology.

The northeast part of the Greater Khingan Mountains (GKM) is at one of the highest latitudes in China, with the most pronounced warming and the most sensitivity to climate change [22]. As the only cold-temperate coniferous forest ecosystem in China, GKM is an ideal area for conducting research on dendrochronological research [23]. Mongolian pine (Pinus sylvestris var. mongholica, MP) is a coniferous species sensitive to climate change. The variation of its annual ring width can reflect climate change well and has been heavily used to study climate change impacts and for climate reconstruction in many countries and regions [24–26]. In recent years, many scholars have conducted a series of dendrochronological studies of MP in the GKM. For example, Zhang et al. [27] investigated the response of its radial growth in plantation forests in different-aged stand ages to climate change, as well as differences in their capacity to cope with extreme droughts in Zhanggutai Town, Liaoning Province, China. Bao et al. [28] simulated the growth patterns of MP in Hulunbeier by using the Vaganov–Shashkin model at four sampled sites; Lv et al. [29] examined the growth of MP trees in the Ali River area of the GKM and went on to reconstruct the average precipitation there since 1809, from the December of the previous year to January of the current year; and Li et al. [30] reported that the growth of MP plantations in China has been influenced by both precipitation and humidity, with sensitivity to both abiotic factors decreasing with increasing moisture content. All these cited studies investigated the relationship between climate change and MP’s growth in different areas of the GKM, albeit from different perspectives. Recent studies have shown that trees at higher altitudes experience faster climate change compared to lower altitudes [31,32]. This divergence may alter tree growth and forest productivity along differing altitudinal gradients of climate change [33]. It is thus prudent to consider how importantly altitude affects MP growth–climate response patterns and future species distributions. Therefore, this study had two main objectives: (1) detecting major climatic limiting factors affecting MP radial growth at different altitudes and (2) analyzing the similarities and differences in the correlations and dynamics of MP radial growth at two altitudes with climate factors at different time spans.
2. Materials and Methods

2.1. Study Area

The study area is located in the northwestern foothills of the GKM of the Inner Mongolia Autonomous Region. The area (51°03′16″–52°06′00″ N, 120°00′26″–121°19′31″ E) is located in the city of Ergun in northeastern China, across the Ergun River from Russia (Figure 1). The study area has a forested area of 5484 km², the vegetation type being mainly deciduous and coniferous; the forest coverage rate is 94.7%, rendering Mordoga a key ecological function area of the GKM, Inner Mongolia. The region is located in a cold-temperature zone that belongs to the continental monsoon climate zone, being characterized by a large seasonal difference in temperature: cold and snowy winters versus warm and rainy summers. The area has a mountainous, shallow, grayish loam and a zonal brown coniferous forest soil. Its zonal vegetation type is Xing’an larch forest, whose main coniferous species are Xing’an larch (Larix gmelinii (Rupr.) Kuzen), Betula platyphylla, and MP. The vegetation type changes along the altitude gradient, with mixed conifer-larch forest being dominant. In this paper, the main conifer species growing naturally in this area, MP, was selected and sampled at two altitudes: 650 ± 20 m (low) and 1100 ± 20 m (high) (Figure 1).

2.2. Tree Ring Sampling and Dendrochronology Development

Based on the basic principles of dendrochronology [34], samples of tree annual rings were collected from the primary forest at the two altitudes (650 m and 1100 m a.s.l.) in July 2023. Tree cores were drilled from well-grown MP less affected by human activities and likely better recording the climatic signal. Two cores were drilled at breast height (1.3 m) along different directions with an incremental drill, with a total of 101 cores collected. These consisted of 48 cores at low altitudes (MLZ) and 53 cores at high altitudes (MHZ) (Table 1).
Tree rings samples were collected and sent to the laboratory, air-dried there at room temperature, fixed in U-shaped wooden troughs, and then sanded and polished successively with 120, 600, 800, and 1200 grit sandpaper until the annual rings were clearly visible. After the samples were pre-treated by fixation, air-drying, and fine sanding, they were dated visually under a microscope, and the tree-ring widths were then measured by a LINTAB 6 tree annual ring analyzer (accuracy: 0.001 mm) [35]. These measurements were corrected by running the COFECHA program [36] to eliminate individual sequences that were poorly dated, had low correlation with the main sequence, or had a high number of outliers. Tree growth trends were removed using the negative exponential function in the Arstan_44xp software program, and standard and residual chronologies were created [37]. The final retention after these treatments was 24/51 (number of trees/cores) at high altitudes (MHZ) and 23/45 at low altitudes (MLZ).

2.3. Meteorological Data

Historical climatic data for this study were obtained from the China Meteorological Science Data Sharing Data Network (http://data.cma.cn/site/index.html (accessed on 13 April 2024)). Based on the proximity principle, the climatic data were selected from the meteorological station in Genhe (50°79′ N, 121°52′ E) (Figure 2), which is 300 km away from the sampling site. The monthly maximum temperature ($T_{\text{max}}$), monthly mean temperature ($T$), monthly minimum temperature ($T_{\text{min}}$), and monthly precipitation ($P$) from the 1958–2020 period were used in this study. Figure 2A shows the monthly precipitation and air temperature conditions in the study area during the year. Evidently, the distribution of both is regular, and their peaks occur in the same time period in July; rain and heat coincided, leading to pronounced wet and dry seasons. The highest average temperature was 17.45 °C, and the maximum precipitation was 122.37 mm, the latter accounting for 27.63% of the annual precipitation. in the area. We checked for temporal variation in the mean annual temperature and total precipitation at meteorological stations. The inter-annual variability in climate had a flat trend with respect to annual precipitation from 1958 to the present day (Figure 2C; $Y = 0.086X - 272.815, R^2 = 0.001, p = 0.893$), in contrast to the clear rise in average annual temperatures (Figure 2B; $Y = 0.053X - 109.921, R^2 = 0.618, p < 0.01$).

Table 1. Data from sampling the core of tree rings.

<table>
<thead>
<tr>
<th>Site Code</th>
<th>High Altitude (MHZ)</th>
<th>Low Altitude (MLZ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude (N)</td>
<td>51.35</td>
<td>51.53</td>
</tr>
<tr>
<td>Longitude (E)</td>
<td>120.86</td>
<td>120.74</td>
</tr>
<tr>
<td>Average altitude (m)</td>
<td>1100 (±20)</td>
<td>650 (±20)</td>
</tr>
<tr>
<td>Slope direction</td>
<td>SE</td>
<td>N</td>
</tr>
<tr>
<td>Slope (°)</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Canopy density</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Tree/cores</td>
<td>24/53</td>
<td>23/48</td>
</tr>
</tbody>
</table>

![Figure 2](image-url)

Figure 2. (A) Climatic data of the Genhe Station from 1958 to 2020; (B) change in average annual temperature; (C) change in annual precipitation.
2.4. Research Methods

We used SPSS 2022 software to calculate the Pearson correlation effects between the time series of Mongolian tree-ring width index and monthly climate factors \((T, T_{\text{min}}, T_{\text{max}}, P)\) in the high and low altitude sites of Mordoga. In this study, standardized chronologies of better quality and higher correlation with climate variables were selected for analysis. According to the known growth rates of coniferous forest species in northern China and taking into account the “delayed impact” of the previous year’s climate on tree growth, climatic variables from October of the preceding year to September of the current year were chosen for the correlation analysis to identify the main climate factors limiting the radial growth of the two tree species. The Mann–Kendall \((M–K)\) method was used to test for a shift in the mean temperature of MP at high and low altitudes from 1958 to 2012 (Figure 3) [38]. To investigate the changes in tree growth–climate relationships after the warming shift (i.e., 1985), the relationships between major climate elements and radial growth of MP before and after the warming in 1985 were compared. The “zoo” package in R was used to conduct a sliding correlation analysis between the width of tree rings and climatic factors, starting in 1958, with 31 years sliding window size and a sliding step of 1a, to observe the dynamics of the correlation between the tree growth of trees and climatic factors over the past 63 years. The graphical portion of the article was plotted using Origin 2022 software.

Figure 3. Standardized chronologies of tree-ring width standard chronologies and sample depths of Mongolian pine \((\text{Pinus sylvestris var. mongholica})\) from (A) high MHZ and (B) low MLZ altitudes; the dashed lines indicate years with SSS values above 0.85.

3. Results

3.1. Chronological Characteristics

As can be seen from Figure 3, the length of the MHZ (MLZ) standard chronology sequence is 269 years (249 years) \((1754–2022; 1774–2022, \text{SSS} > 0.85)\), respectively. The standard deviation and mean within tree correlation of 0.216 (0.282) and 0.608 (0.676) can be seen in Table 2, indicating that the sample cores have a more consistent variation in wheel width, which can represent the average growth condition of MP in the region. The first-order autocorrelation was 0.683 (0.719), indicating that the growth condition of the trees in the previous year had some influence on their growth in the current year. The expressed population signal of the sample was 0.936 (0.953), which exceeded the critical threshold of 0.85, and the mean sensitivity was 0.144 (0.182), with a high signal-to-noise ratio of 14.574 (20.174), which indicated that the constructed chronology was of good quality and retained a richer climatic signal, which is suitable for tree-rotation climatology.
studies. Overall, all the parameter values of MLZ are higher than those of MHZ, suggesting that the chronology quality may be better in the lower altitude MLZ.

**Table 2.** Statistical characteristics analysis of MP’s standardized chronology.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MHZ</th>
<th>MLZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean sensitivity</td>
<td>0.144</td>
<td>0.182</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.216</td>
<td>0.282</td>
</tr>
<tr>
<td>First-order autocorrelation</td>
<td>0.683</td>
<td>0.719</td>
</tr>
<tr>
<td>Mean within tree correlation</td>
<td>0.608</td>
<td>0.676</td>
</tr>
<tr>
<td>Signal-to-noise ratio</td>
<td>14.574</td>
<td>20.174</td>
</tr>
<tr>
<td>Expressed population signal</td>
<td>0.936</td>
<td>0.953</td>
</tr>
<tr>
<td>The first year of subsample signal strength &gt; 0.85</td>
<td>1797</td>
<td>1826</td>
</tr>
<tr>
<td>Chronological length</td>
<td>1754–2022</td>
<td>1774–2022</td>
</tr>
</tbody>
</table>

**3.2. Correlation between Radial Growth of MP and Climatic Factors**

Figure 4 presents the outcomes of the Mann–Kendall test, demonstrating an abrupt shift in the mean annual temperature from lower to higher values in 1985. The mean annual temperature, annual precipitation, and tree-ring width index before and after the temperature shift point (1985) were divided into two time periods, 1958–1985 and 1985–2012 (Figure 5), for a comparative analysis. For both intervals, the mean figures of the parameters were computed (Table 3). There was a rise in temperature by 0.809 °C and a marginal alteration in rainfall, with a reduction of 18 mm. Figure 5 shows their corresponding trend lines. Evidently, annual precipitation did not change significantly before versus after the temperature shift, yet, as noted above, the annual mean temperature did increase significantly. Prior to 1985, at MLZ, tree growth did not change significantly, but it declined as MHZ declined (Table 3); however, at both elevations, the growth trend of MP increased after 1985. Taken together, these results indicated that the temperature shift of 1985 altered the growth trends of MHZ and MLZ, from a decreasing or flat trend before it to a significant upward trend afterwards. This suggested that temperature exerted a significant beneficial effect on the radial growth of MP trees.

![Figure 4](image-url)  
*Figure 4. Results of Mann–Kendall tests for the annual mean temperature (1958 – 2020). UF, sequence of statistics (upward trend); UB, sequence of statistics (downward trend).*
Figure 5. Annual climate data and trends for changes in the tree ring index of MP at two altitudes during the 1958–2012 period.

Table 3. Climatic data and chronological coefficients for MP at two altitudes before and after 1985.

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Mean Annual Temperature (°C)</th>
<th>Annual Precipitation (mm)</th>
<th>Tree Ring Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before abrupt change (1958–1985)</td>
<td>–5.15</td>
<td>449</td>
<td>0.94</td>
</tr>
<tr>
<td>After abrupt change (1985–2012)</td>
<td>–3.35</td>
<td>431</td>
<td>1.14</td>
</tr>
</tbody>
</table>

3.3. Correlation between Radial Growth of MP and Climatic Factors

We analyzed the response of standardized chronology to climatic elements at two altitudes of MP. As shown in Figure 6, tree growth at both altitudes was positively correlated with winter temperatures of the previous year. MHZ had a considerable positive effect with the growing season; in particular, the correlation coefficient with $T_{\text{min}}$ in May was the largest ($r = 0.48$, $p < 0.01$), and there was also a positive effect with $P$ in May at MHZ. In contrast, tree growth in the MLZ was negatively correlated with $T_{\text{max}}$ in April ($r = −0.25$, $p < 0.05$); there was a considerable positive effect with $P$ in April–July.

Figure 6. Correlation between MPs at different altitudes during 1958–2020 and monthly climate elements from the previous October to current September. (A) MHZ, (B) MLZ; $p$, previous year; $c$, current year; * represents $p < 0.05$ significance, ** represents $p < 0.01$ significance.
3.4. Response of Radial Growth to Climate before and after 1985

As seen in Figure 7, the correlation coefficients and considerable levels of MHZ and MLZ with various parameters changed to different degrees before and after 1985 temperature shift. Before 1985, the radial growth at MHZ and MLZ with various parameters changed to different degrees before and after the 1985 temperature shift. Before 1985, the radial growth of MHZ and MLZ was positively correlated with the temperature in December of the previous year, and both of them had a negative correlation response with the temperature from April to July; they had a considerably positive effect with P in April. However, after the 1985 shift, MHZ and MLZ both had a significant positive effect with P in May, and MHZ had a considerably positive effect with T\textsubscript{min} in May. However, after 1985, both MHZ and MLZ were considerably positively correlated with P in May, and MHZ had a considerably positive effect with T\textsubscript{min} in May.

Figure 7. Correlation analysis of annual table and monthly climate elements of MP at two altitudes before and after sudden warming; * represents p < 0.05 significance, ** represents p < 0.01 significance.

3.5. Temporal Stability of Climate–Growth Relationships

The sliding correlation analysis revealed pronounced differences in the stability of the correlation between climatic factors and MP’s growth at the two altitudes (Figure 8). Evidently, with global warming, the sensitivity of MP to climatic factors showed signs of generally increasing. In some periods, the correlation coefficients of the response to certain temperature factors switched from positive to negative, or vice versa.

For MHZ, the ring width chronology showed considerably positive correlations with T in the previous year’s October–December and the current year’s February. Considerably positive effects with T in April–July were also detected, which had switched from a prior considerably negative effect. Also found were unstable positive effects with T in August–September; considerably positive effects with P in the previous year’s October–November and March–July as well as September; and considerably positive effects with P in February, which had gradually switched from a prior significant negative effect.

For MLZ, the ring width chronology showed considerably positive correlations with T in the previous year’s October and the current year’s May, both having switched from previous considerably negative correlations; considerably negative correlations with T in the current year’s February–April; a considerably positive correlation with P in April–July; and a considerably positive correlation with P in February, this being a gradual reversal from a considerably negative effect before. Overall, then, with global warming, the positive responses of ring width chronologies at MHZ and MLZ to both T and P got stronger.
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Figure 8. Moving correlation analysis of mean temperature and precipitation and tree ring index of MP during the period 1958–2020. The * indicates a significant correlation.

4. Discussion

Considerably positive effects were found between MHZ and temperatures from October of the previous year to February of the current year and between MLZ and temperatures in November of the previous year. A warmer fall prolongs the growing season and increases the growth potential of trees in the coming year due to the accumulation of nutrients, leading to accelerated radial growth in the next growing season [39]. Winter temperature is indispensible for the growth of trees in the subsequent year [40], although cambial activity is paused at this time. A higher temperature in winter would have helped these pine trees synthesize organic matter, providing favorable conditions for their growth and development in the next year [10]. There was considerable spatial variation in the MHZ with May–September temperatures across the altitude gradient. At high altitudes, the temperature factor acts as a major limiting factor [41]. May–September, the early summer to fall of the growing season, is the period when trees grow most vigorously. Rising temperatures are favorable for photosynthesis, thus producing enough photosynthetic products for tree growth, while low temperatures limit their photosynthesis [42]. In MLZ, growth was considerably negatively correlated with the temperature in April, due to the high temperature in spring increasing transpiration and causing drought stress. This delayed the occurrence of xylem and the production of xylem cells, which ultimately governs the growth of forest trees [43]. For both MHZ and MLZ, we found a significant positive correlation of growth with the precipitation in summer, when MP was in a state of rapidly growing its branches and accelerating its dry matter and water consumption rates; yet the forest was still relatively dry, so as temperature rose, so did the water demand of trees. The later increase in precipitation would bolster soil moisture content, thus supplementing the water needed for internal physiological activities of trees, hastening cell division, and promoting tree growth [44]. Based on the above conclusions, we can think that the growth of trees in high-altitude areas is mainly limited by temperature, whereas in low-altitude areas, it is limited chiefly by water availability [16,45].

The annual average temperature in China is on an upward trend, with numerous climate indicators experiencing significant changes around the 1980s [46–48]. Climate change is altering the water distribution and temperature regimes at different altitudes, thereby modifying habitat conditions that will likely affect tree growth dynamics [49]. Before climate warming, it was found that radial growth in MHZ (high altitude) was
inversely related with temperatures from April to July, which may be due to increased temperatures accelerating evaporation and loss of soil moisture, increasing the water vapor pressure difference and resulting in drying out of the soil, limiting the physiological and metabolic activities of the trees, thus inhibiting tree growth [50]. Thus radial growth at high altitudes before 1985 showed a significant downward trend. However, since the climate warming in 1985, the MP ring width index at both altitude levels showed a significant upward trend. For altitude, the previous negative effect with April–July temperatures disappeared and was instead replaced with a positive effect with the minimum temperature ($T_{\min}$) in May. In the GKM, the temperature is generally low. Higher $T_{\min}$ may accelerate radial growth by enhancing photosynthesis in trees and promoting early xylem growth in this case, the promotional effect of $T_{\min}$ outweighs the inhibitory effect of $T_{\max}$ [51]. We believed that $T_{\min}$ in May was the main driver of the upward trend in MHZ growth. At low altitudes, $P$ in May was considerably and positively correlated with radial growth after the abrupt climate change, and sufficient precipitation may have alleviated the drought stress caused by high temperatures, thus promoting tree growth. Therefore, we believed that $P$ in May was the main reason for the accelerated growth trend of MLZ. Therefore, to a certain extent, climate warming could have a favorable outcome for the radial growth of MP in the GKM, allowing tree growth rates there to significantly increase.

By analyzing the stability of the relationship between MP’s growth at different altitudes and climatic factors over time, this study explored the impact of global warming on the tree-ring width changes in the GKM (Figure 8). The correlation coefficients between MHZ and MLZ tree-ring width chronology and climate factors in May switched from negative to positive, and the positive responses increased in magnitude. The rapid warming after 1985 may have positively influenced tree radial growth. From a physiological point of view, warmer spring temperature mean earlier snow melting, the early termination of dormancy, the extension of the growing season, and the facilitation of earlywood development, all of which are beneficial for the trees [44]. At the same time, in the beginning part of the growing season, warmer spring temperatures are arguably conducive to photosynthesis, promoting the buildup of organic matter and nutrient formation, stimulating cell division within the cambium, and facilitating the formation of wider earlywood rings [44,52]. MLZ tree-ring width chronology was positively correlated with precipitation and negatively correlated with temperature. The surface may be affected by water stress, when the increase in temperature accelerates soil water evaporation, reduces soil water content, and accelerates the lignification process of the plant root system, reducing its water uptake efficiency, so that it suffers from water stress [53]. In the GKM region, more annual precipitation, more humidity, and sudden warming changes in temperature may not exceed the critical temperature of the growth of MP. At this time, higher temperatures can enhance tree photosynthesis, prolong the tree growing season, and promote the radial growth of MP [54]. If the current warming trend continues, we can expect that forest growth and distribution will continue to be affected, which will require further research and monitoring.

5. Conclusions

We established a chronology of tree-ring widths of Mongolian pine at two altitude gradients in the GKM region of Northeastern China. The results showed that there were substantial variances in the response of Mongolian pine to climatic factors at different altitudes. The growth of MP at high altitudes was associated with temperature factors, and the growth of MP at low altitudes was mainly influenced by precipitation. With increasing altitude, the effect of temperature on tree growth changed from a negative to a positive correlation, and the positive response to precipitation weakened. Both MHZ and MLZ annual ring indices began to increase with temperature after the sudden change in temperature, and $T_{\min}$ in May of that year ($P$ in May of that year) was the key reason for the considerably upward trend in the tree-ring width index of MHZ (MLZ). The study in this paper provides valuable new information on vegetation changes in the Northeast and provides important information for predicting future changes in forest vegetation. This is


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