
AI translation · View original & related papers at
chinaxiv.org/items/chinaxiv-202303.00121

Response of *Pinus tabuliformis* Tree-Ring Width to Climate Change and Its Mechanism in Maijishan, Tianshui: Postprint

Authors: Yao Daijun, Liu Kang, Yuxiang Hui, Wang Kaixin, Liu Kang

Date: 2023-03-13T00:00:00+00:00

Abstract

To investigate the changes and mechanisms in the response patterns of Chinese pine (*Pinus tabuliformis*) radial growth to climatic factors in the Maijishan Scenic Area of Tianshui from 1980 to 2019 against the backdrop of climate change, dendroclimatological methods and the Vaganov-Shashkin model were employed to examine the climatic response and growth processes of Chinese pine in Maijishan before and after the temperature abrupt change. The results indicate: (1) The temperature in Maijishan experienced an abrupt change in 1997, with post-change temperatures being significantly higher than pre-change temperatures. During 1980-1997 and 1998-2019, the response changes of Chinese pine to climatic factors exhibited three patterns: decreasing correlation (May temperature), increasing correlation (October temperature and precipitation, July precipitation, December temperature), and oscillation (June precipitation, July temperature). (2) Significant climate warming provided more abundant heat supply for Chinese pine growth in spring and autumn, substantially extending the growing season; summer growth of Chinese pine was affected by high temperature and water stress. (3) The changes in the response patterns of Chinese pine growth to climatic factors were primarily caused by climate warming and alterations in the growing season; if temperatures continue to rise, these response patterns may change further, and similar processes may also exist in other Chinese pine growing regions.

Full Text

Response and Mechanism of *Pinus tabulaeformis* Tree-Ring Width to Climate Change in Maijishan Mountain, Tianshui, China

YAO Daijun, LIU Kang, HUI Yuxiang, WANG Kaixin

College of Urban and Environmental Sciences, Northwest University, Xi' an 710127, Shaanxi, China

Abstract

This study investigates the changing response patterns and underlying mechanisms of radial growth in *Pinus tabulaeformis* to climatic factors in Maijishan Mountain, Tianshui, under the context of climate change. Using dendroclimatological methods and the Vaganov-Shashkin (VS) model, we examined the climate response and growth processes of *P. tabulaeformis* before and after an abrupt temperature shift. The results indicate that: (1) A temperature regime shift occurred in 1997, after which mean annual temperatures increased significantly. Three distinct response patterns emerged in the relationship between tree growth and climate factors: declining correlation (May temperature), increasing correlation (October temperature and precipitation, July precipitation, December temperature), and fluctuating correlation (June precipitation, July temperature). (2) Significant climatic warming enhanced heat availability for spring and autumn growth, substantially prolonging the growing season. Summer growth was constrained by high temperatures and water stress. (3) The altered response patterns were primarily driven by climate warming and growing season changes. If warming continues, these response patterns may further evolve, and similar processes likely occur in other *P. tabulaeformis* distribution areas.

Keywords: tree rings; climate change; Vaganov-Shashkin model; *Pinus tabulaeformis*; Maijishan Mountain

Introduction

Tree growth in the mid-to-high latitudes of the Northern Hemisphere is strongly influenced by climatic factors, with tree rings recording substantial climate information. These records offer accurate dating, high resolution, and easy replication, making tree rings widely applicable for studying tree growth-climate responses and regional climate reconstruction. Dendrochronological studies typically assume stable relationships between regional climate factors and tree growth. However, since the mid-20th century, an anomalous phenomenon termed the “divergence effect” —characterized by an unusual decline in temperature sensitivity of tree growth—has been identified in many tree-ring records from high-latitude regions of the Northern Hemisphere. This phenomenon demonstrates that tree growth-climate relationships are not necessarily stable. Stud-

ies on the Tibetan Plateau, Wolong in western Sichuan, and Niubeiliang in the Qinling Mountains have also documented the divergence effect, confirming its occurrence in mid-low latitude and high-altitude regions. A global study based on 54 tree-ring sites further indicated that temperature responses of tree growth in the Northern Hemisphere have significantly weakened, while water stress has intensified globally. Continued climate change may lead to a redistribution of climate drivers governing global tree growth. Therefore, understanding the mechanisms of tree growth-climate relationships under climate change is essential for predicting impacts on global ecosystem material cycles and energy flows.

This study selects Maijishan area, located on the northern slope of the western Qinling Mountains and influenced by the southeast, southwest, and plateau monsoons. The region features a unique and complex climate system that is exceptionally sensitive to climate change. Using *Pinus tabulaeformis*, a species commonly employed in dendrochronological research, we explore its growth response to climate change and investigate the underlying mechanisms using the VS model. This work aims to provide a basis for understanding the response mechanisms of *P. tabulaeformis* to climate in this region and for evaluating the reliability of climate reconstructions.

1.1 Study Area

Maijishan Scenic Area in Tianshui, Gansu Province (34°07'~34°28' N, 105°56'~106°10' E) is situated at the eastern end of the northern branch of the western Qinling Mountains [Figure 34: see original paper]. The region borders the Loess Plateau to the north, adjacent to the Wei River, and connects to Jialing in the east, serving as a watershed between the Yellow River and Yangtze River systems. The climate belongs to the warm temperate humid/semi-humid zone, with a mean annual temperature of 9-13°C, annual precipitation of 420-660 mm concentrated in June-September, and a frost-free period of 170-220 days. The soil is predominantly mountain brown soil, and the vegetation belongs to the warm temperate coniferous-broadleaf mixed forest type.

1.2 Sample Collection and Chronology Development

The sampling site was established at 34.34°N, 106.02°E, 1720 m a.s.l. on the north slope of Maijishan Mountain. In May 2019 and 2020, we collected tree cores from 30 *P. tabulaeformis* trees at breast height (1.3 m) using increment borers from different directions. In the laboratory, the cores were preprocessed following standard dendrochronological procedures. Ring widths were measured using a LinTAB measuring system with 0.01 mm precision, and COFFECHA software was used to check measurement accuracy and identify dating errors. Cores with large errors were excluded, leaving 30 cores for chronology construction. The ARSTAN program was used for detrending and standardization, employing an exponential function to remove growth trends. This yielded a residual chronology (RES) and an autoregressive chronology (ARS). The standardized

chronology (STD) primarily excludes interference from inherent growth trends while retaining most high- and low-frequency environmental signals, and was selected for this study [Figure 2: see original paper].

1.3 Meteorological Data

Meteorological data were obtained from the nearest Maiji meteorological station (34.57°N, 105.87°E, 1085.2 m), located 15 km from the sampling site. Daily observations from 1980-2019 were sourced from the Resource and Environment Science Data Center (<https://www.resdc.cn>). Based on these data, the station's mean annual precipitation is 92.94 mm and mean annual temperature is 11.45°C. Previous studies indicate a regional temperature shift in the western Qinling Mountains during the 1990s. We applied the Mann-Kendall test to mean annual temperatures in Maijishan, confirming an abrupt change in 1997 that aligns with existing research [Figure 4: see original paper]. As tree growth-climate response patterns are temperature-dependent, we used 1997 as the breakpoint to analyze relationships before (1980-1997) and after (1998-2019) the temperature shift.

1.4 VS Model

The VS model simulates seasonal cambial activity and cell formation processes based on daily temperature, precipitation, and solar irradiance, yielding important parameters such as daily growth rates, primary limiting factors, and growing season dates. The model can be validated against actual tree-ring samples, making it widely applicable for investigating tree growth processes and influencing factors. This study employs the oscilloscope version of the VS model, which differs from previous versions primarily through improved GrE calculation formulas. The model consists of four modules: data input, basic calculations, cambial simulation for estimating seasonal cell numbers and sizes, and data output.

The tree growth rate is calculated as:

$$Gr = k \times \min\{GrE, GrT, GrW\}$$

where Gr is the overall tree-ring growth rate, and GrE , GrT , and GrW are the daily growth rates triggered by light, temperature, and soil moisture, respectively.

2 Results

2.1 Chronology Statistics

The standardized chronology exhibits high statistical quality (Table 1). The high mean sensitivity indicates that *P. tabulaeformis* is sensitive to climatic variations. The low first-order autocorrelation suggests minimal “lag effect” from previous year's climate. The mean correlation coefficients among all cores,

between trees, and within trees are all significant ($P < 0.05$), with high signal-to-noise ratio. The first principal component explains 41.28% of variance, and the overall representativeness exceeds 0.85, exceeding the minimum threshold for reliable chronologies and indicating high credibility.

2.2 Variation Characteristics of Tree-Ring Index and Climate Elements

Using 1997 as the breakpoint, independent samples t-tests compared climatic factors and tree-ring indices between the two periods. Boxplots reveal that mean annual temperature was significantly higher in 1998-2019 than in 1980-1997 ($P < 0.05$), while precipitation and tree-ring index showed no significant differences [Figure 5: see original paper]. The most pronounced difference was the significant temperature increase. Trend analysis shows that mean monthly and annual temperatures increased significantly ($P < 0.05$) for all months except June, while precipitation increased significantly only in August and October [Figure 6: see original paper]. This significant warming-drying trend implies that tree growth may experience intensified water stress.

2.3 Response of Tree-Ring Index to Climate Elements

Given the low first-order autocorrelation, we analyzed correlations between the standardized chronology and monthly climate data for the current year. Correlation analysis for the two periods shows distinct patterns [Figure 7: see original paper]. During 1980-1997, tree growth exhibited significant negative correlation with May temperature ($P < 0.01$) and significant positive correlation with May precipitation ($P < 0.05$), suggesting that high temperatures in May caused drought that limited growth, while precipitation alleviated water stress. During 1998-2019, the relationship with May temperature remained significantly negative ($P < 0.05$), while correlations with October temperature ($P < 0.01$) and precipitation ($P < 0.05$), and December temperature ($P < 0.05$) became significant. The most notable changes were the declining correlation with May temperature, increasing correlations with October temperature/precipitation and July precipitation, and fluctuating correlations with June precipitation and July temperature.

Forward evolutionary interval correlation analysis [Figure 8: see original paper] reveals that the correlation between May temperature and tree-ring index declined continuously, while correlations with October temperature and precipitation increased. This indicates that the response patterns of *P. tabulaeformis* growth to climate in Maijishan exhibit three modes: correlation decline, correlation increase, and correlation fluctuation.

2.4 VS Model Simulation

The VS model requires daily temperature and precipitation data, sampling site latitude, and growth parameters. We adjusted parameters to optimize agree-

ment between simulated and measured data. The correlation between simulated and measured series is significant at $P < 0.05$ for both periods, indicating good fit and reliable representation of actual growth [Figure 9: see original paper].

2.5 Mechanistic Explanation of Response Changes

To analyze changes in growth processes, we examined simulated daily growth rates and their differences between periods [Figure 10: see original paper]. Compared to 1980–1997, soil moisture-induced growth rates (GrW) decreased throughout 1998–2019, reflecting stronger water stress. Temperature-induced growth rates (GrT) showed a bimodal pattern: decreased contribution during late winter-spring (days 30–150) and summer (days 150–250), but increased during late winter-early spring (days 150–270) and autumn (days 270–330). The growing season start and end dates changed significantly ($P < 0.05$), beginning earlier and ending later, thereby extending the growing season [Figure 11: see original paper].

The overall growth rate difference correlates more strongly with temperature-induced growth rate changes ($r = 0.85$) than with soil moisture-induced changes ($r = 0.73$), indicating that temperature-driven changes dominate overall growth variation. However, the overall growth rate also reflects the influence of reduced soil moisture-induced growth, particularly evident in the delayed transition from decreasing to increasing growth rates.

The declining negative correlation with May temperature likely reflects that warming has increased heat supply, raising temperature-induced growth rates and offsetting negative impacts of May high temperatures. The increasing positive correlation with October temperature occurs because autumn warming provides more sufficient heat for growth. The increasing negative correlation with October precipitation results from precipitation cooling effects that reduce temperature-induced growth rates. The increasing positive correlation with July precipitation reflects that warming-induced drought intensifies water stress, making precipitation more critical for relieving drought and promoting growth.

3 Discussion

The “divergence effect” –unstable tree growth-climate relationships–has important implications for predicting climate change impacts on ecosystem processes. Our study reveals significant changes in *P. tabulaeformis* growth-climate relationships in Maijishan after 1997, with three distinct response modes. These findings can be compared with climate reconstruction studies to validate the stability of historical tree growth-climate relationships and assess reconstruction reliability. Previous studies using *P. tabulaeformis* from Shimenshan in Tianshui found stable correlations with May temperature before reconstructing historical temperatures, suggesting our results support the reliability of those

reconstructions.

The VS model simulations indicate that climate warming and growing season changes are the primary drivers of altered response patterns. Warming extended the growing season by advancing the start date and delaying the end date, while intensifying summer heat and drought stress. These changes modified correlations between monthly climate factors and tree growth, particularly the declining May temperature correlation and increasing October temperature/precipitation correlations. If warming continues, these response patterns may further evolve. Given the widespread distribution of *P. tabulaeformis* and similar warming trends across China, analogous changes likely occur in other regions with comparable habitats.

While VS model applications are common, simulations cannot fully replace field observations or guarantee all physiological parameters are realistic. We adjusted root depth to 1600 mm based on literature showing *P. tabulaeformis* roots can reach this depth, enabling access to deeper soil moisture. This adjustment, along with modified soil moisture parameters, improved model performance. Future research should incorporate long-term monitoring and high-precision observations to further refine model parameters.

4 Conclusions

Using dendroclimatological methods, we examined the response of *P. tabulaeformis* tree rings to climate change in Maijishan, Tianshui, across two periods (1980–1997 and 1998–2019), and explored the mechanisms using the VS model. The main conclusions are:

- 1) Under significant warming-drying trends in Tianshui, the growth-climate relationship of *P. tabulaeformis* changed markedly, exhibiting three patterns: correlation decline, correlation increase, and correlation fluctuation, indicating that these relationships are not entirely stable.
- 2) The correlation between May temperature and tree-ring index declined notably after 1997, though it remained significant until after 2005, supporting the reliability of previous climate reconstructions in this region.
- 3) VS model simulations demonstrate that changes in growth-climate response patterns are primarily caused by climate warming and growing season alterations. Continued warming may induce further changes in these patterns, which likely occur in other *P. tabulaeformis* regions with similar environmental conditions.
- 4) The VS model effectively simulates the actual growth processes of Maijishan *P. tabulaeformis*, with simulated daily growth characteristics and factor influences successfully explaining the mechanisms underlying changing growth-climate relationships. The model shows promise for explaining similar relationships in other regions.

References

- [1] Shishov V V, Tychkov I I, Popkova M I, et al. VS-oscilloscope: A new tool to parameterize tree radial growth based on climate conditions[J]. *Dendrochronologia*, 2016, 39(34): 42-50.
- [2] Shao Xuemei. Advancements in dendrochronology[J]. *Quaternary Science*, 1997, 17(3): 265-271.
- [3] Gao Linlin, Gou Xiaohua, Deng Yang, et al. An overview of the divergence phenomenon in dendroclimatology[J]. *Journal of Glaciology and Geocryology*, 2011, 33(2): 453-460.
- [4] D'Arrigo R, Wilson R, Liepert B, et al. On the divergence problem in northern forests: A review of the tree-ring evidence and possible causes[J]. *Global and Planetary Change*, 2008, 60(3-4): 289-305.
- [5] Yu Jian, Xu Qianqian, He Xiu, et al. Response divergence of *Larix olgensis* ring widths to climate variation in eastern slope of Changbai Mountain, Northeast China[J]. *Journal of Central South University of Forestry & Technology*, 2013, 33(3): 89-97.
- [6] Gao Na, Li Shuheng, Bai Hongying, et al. Response divergence of *Abies fargesii* ring widths to climate variation in the Niubeiliang Nature Reserve of the Qinling Mountains[J]. *Chinese Journal of Ecology*, 2016, 35(8): 2056-2065.
- [7] Li Zongshan, Liu Guohua, Fu Bojie, et al. Evaluation of temporal stability in tree growth-climate response in Wolong National Natural Reserve, western Sichuan, China[J]. *Chinese Journal of Plant Ecology*, 2010, 34(9): 1045-1057.
- [8] Shi C M, Valerie M D, Valerie D, et al. An unstable tree growth response to climate in two 500-year chronologies, North-Eastern Qinghai-Tibetan Plateau[J]. *Dendrochronologia*, 2010, 28(4): 225-237.
- [9] Babst F, Bouriaud O, Poulter B, et al. Twentieth-century redistribution in climatic drivers of global tree growth[J]. *Science Advances*, 2019, 5(1): eaat4313.
- [10] Chen Lan, Li Shuheng, Hou Li, et al. Response of *Larix chinensis* radial growth to climatic factors based on the Vaganov-Shashkin model[J]. *Chinese Journal of Applied Ecology*, 2017, 28(8): 2470-2480.
- [11] Bao Guang, Liu Zhiye, Liu Na, et al. Simulation analysis of the radial growth characteristics of *Pinus sylvestris* var. *mongolica* in Hulunbuir sandy land by Vaganov-Shashkin Model[J]. *Chinese Journal of Applied Ecology*, 2021, 32(10): 3448-3458.
- [12] Chen L, Huang J G, Stadt K J, et al. Drought explains variation in the radial growth of white spruce in western Canada[J]. *Agricultural and Forest Meteorology*, 2017, 233(54): 133-142.
- [13] Song H M, Liu Y, Li Q, et al. Tree-ring based May-July temperature reconstruction since AD 1630 on the Western Loess Plateau, China[J]. *PLoS ONE*,

2014, 9(4): e93504.

[14] Ning Yingzhi, Wang Juan, Liu Na, et al. Species diversity of soil ciliates in scenic spots and historic sites of Maijishan, Tianshui, Gansu[J]. Zoological Research, 2007, 28(4): 367-373.

[15] Guo Jirong. Research on resources of wild medicinal plants in Maiji Mountain Scenic Spot of Tianshui, Gansu[J]. Forest Science and Technology, 2019, 553(1): 68-69.

[16] Compilation Committee of Gansu Provincial History Local Chronicles, Gansu Provincial Local Chronicles, Physical Geography Local Chronicles Compilation Committee. *Gansu Province Local Chronicles: Physical Geography*[M]. Lanzhou: Gansu Culture Publishing House, 2018: 528-529.

[17] Liu Xiaolin, Zheng Zilong, Lin Yanxiong, et al. Physical characteristics of the soil moisture in the main forest types in Xiaolong Mountain[J]. Journal of Northwest Forestry University, 2013, 28(1): 7-11.

[18] Liu Weimin, Pu Jinyong, Yao Xiaohong, et al. A study on variation law of soil moisture and relationship between soil moisture and output of wheat at Tianshui, Gansu in arid region[J]. Agricultural Research in the Arid Areas, 2008, 26(3): 29-32.

[19] Qin Jin. The Tree-Ring Based Study on Response of Typical Timberline Tree Species in the Qinling Mountains to Climate and Regional Temperature Reconstruction[D]. Xi' an: Northwest University, 2018.

[20] Chen F, Yuan Y J. May-June maximum temperature reconstruction from mean earlywood density in north central China and its linkages to the summer monsoon activities[J]. PLoS ONE, 2017, 9(9): e107501.

[21] Wu M L, Liu N, Bao G, et al. Climatic factors of radial growth of *Pinus tabulaeformis* in eastern Gansu, Northwest China based on Vaganov-Shashkin model[J]. Geografiska Annaler: Series A, Physical Geography, 2020, 102(3): 196-208.

[22] Yang Fengmei, Wang Nai' ang, Wang Shigong, et al. Spatial and temporal patterns of precipitation in the west Qinling over the past 60 years[J]. Arid Land Geography, 2015, 38(5): 867-879.

[23] Li Shuangshuang, Yan Junping, Wan Jia. The characteristics of temperature change in Qinling Mountains[J]. Scientia Geographica Sinica, 2012, 32(7): 853-858.

[24] Shi Jiangfeng, Liu Yu, Vaganov E, et al. A primary discussion on the climatic response of *Pinus tabulaeformis* in the Helan Mountain[J]. Quaternary Science, 2005, 25(2): 245-251.

[25] Tychkov I I, Sviderskaya I V, Babushkina E A, et al. How can the parameterization of a process-based model help us understand real ring growth?[J]. Trees, 2019, 33(2): 345-357.

- [26] Song Weifeng. Study on Physical Mechanism of Interface Between Root System and Loess Soils[D]. Beijing: Beijing Forestry University, 2006.
- [27] Shi Jiangfeng, Liu Yu, Cai Qiufang, et al. A case study of physiological characteristics of statistical correlation between *Pinus tabulaeformis* ring widths and climatic factors[J]. Acta Ecologica Sinica, 2006, 26(3): 697-705.
- [28] Wu Qin. Effect of Soil Moisture on Photosynthetic Physiological and Biochemical Characteristics of Three Afforestation Tree Species[D]. Tai' an: Shandong Agricultural University, 2013.
- [29] Yang Qi, Li Shuheng, Li Jiahao, et al. Phenology of forest vegetation and its response to climate change in the Qinling Mountains[J]. Arid Zone Research, 2021, 38(4): 1065-1074.
- [30] Yang Dong, Yang Xiuqin. Studies on biomass and productivity of *Pinus tabulaeformis* plantation in the Wufengshan of Wudu, Gansu Province[J]. Journal of Northwest Normal University (Natural Science), 2004, 40(1): 70-75.

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

Source: ChinaXiv –Machine translation. Verify with original.