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Article

The Response of the Annual Rotation Width of Tea Trees to Climate Change in the Brown Mountains of Yunnan Province

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Abstract: Yunnan is located in the southwestern part of China, with rich tea tree germplasm resources and diversified geomorphological and climatic features, which help us to carry out research related to tea tree chronology and provide scientific and effective support information for enriching the database of tree rings in western Yunnan. This study took the Brown Mountain tea tree in Xishuangbanna as the research object, collected tea tree sample cores through tree growth cone sampling, measured the width of the annual rings, cross-dated them, and established a chronology of the width of the annual rings of the tea tree. The R language was used to analyze the response function of the tea tree's annual ring chronology with the climatic factors of the study site, discussed the relationship between the radial growth of the tea tree in subtropical regions and climatic factors, and determined the main factors that affected the radial growth of the tea tree. The results of the study showed that the chronology of the tea tree's whorl width spanned 70 years (1954–2023), with an average annual growth rate of 1.283 mm/year; the average sensitivity was 0.514, which indicated that the chronology contained richer climatic information. The representativeness of the sample group of the whorl width index (EPS) was 0.716, indicating that the consistency of the growth inter-annual variations was better among the different trees. The radial growth was correlated with climatic factors such as temperature and moisture; the radial growth of the tea tree was usually more sensitive to moisture availability, limited by hydrological and climatic factors throughout the rainy season of the year, and positively correlated with the temperature in summer and autumn. In terms of the stability of the radial growth of the tea tree in relation to the climatic response, the growth of the tea tree in the study area may have benefited from future warming of the climate and reduction in precipitation.

Keywords: tea tree; annual ring width; financial year; climate change; responsiveness

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1. Introduction

Tree annual rings not only record the age of the tree itself but also the process of climatic and environmental changes experienced by the tree as it grows. Changes in global mean surface temperature, as well as in other climate factors, have increased rapidly and are projected to continue increasing [1]. The (sub)tropics have experienced the most rapid warming in recent decades, which may have negatively affected tree growth and increased mortality risk [2]. It is evident that tree growth in tropical forests in Asia shows high sensitivity to climate change [3,4]. According to the survey, the southwest region has had a significant upward trend in temperature and a decreasing trend in precipitation over the last 50 years, but the intensity of precipitation is increasing [5,6]. The ranges of most woody plant species in Southwest China are projected to decrease by more than 30% by 2080 [7]. In this regard, tree annual rings provide high-resolution data on a wide range of interacting factors that affect tree growth [8], and in China, dendrochronological studies focus mainly on high-altitude regions and coniferous species that are more amenable to reconstructing past climate change [9]. Therefore, in order to better understand the growth response of tropical forests in Asia to climate change, it is particularly important to study the key scientific issue of the response pattern of tea tree annual cycle characteristics to changes in precipitation. At this time, cultural construction based on archeology from early to late periods in Yunnan Province, China, has not yet been conducted, so the study of tree chronology of tea trees is a very important topic.

The tea tree in China is distributed from eastern to southwestern regions [10], and although it is widely distributed from subtropical to tropical climates, the relationship between its growth and climate has not been reported in research. Since the tea tree is one of the important economic tree species in the subtropical region of southwestern China, in order to understand the main climatic variables limiting the inter-annual radial growth of the tea tree in southwestern Yunnan, a chronology of the tea tree's annual ring width was established based on comparing the tectonic characteristics and chemical composition differences in the tea tree in different regions. The study investigated the relationship between the response of its annual ring width and climate change. It aims to explore the following: what are the main climatic factors limiting the radial growth of tea trees in the study area?

2. Materials and Methods

2.1. Research Materials

The material was selected from the tea tree (Camellia sinensis) in Xishuangbanna, Yunnan Province, at low and middle altitudes (1100 m–1200 m), from the old forest of Brown Mountain in southwestern Yunnan. This species is temperature-loving, humidity-loving, and shade-tolerant, and it is distributed from 880 m to 2200 m above sea level [11,12].

2.2. Research Methodology

2.2.1. Sample Collection

Tree annual rings and tree core sampling aimed to study the relationship between tea tree growth and climate using the annual ring width characteristics of trees in the subtropical climate of Yunnan, southwestern China. Therefore, in this study, 20 tea tree growth cone samples were collected from the Brown Mountain study area to investigate the relationship between tree growth and climate. To obtain high-quality data on tree annual rings, tea tree individuals without obvious diseases and with upright trunks were selected. Tree cores were obtained for each sample at a distance of approximately 40 cm above the base [13].

During October 2023, one or two cores were collected from each tree using growth cones (5.15 mm inner diameter). Damage from growth cone sampling was treated with tree repair cream to the wound to allow for rapid healing; the diameter at breast height (DBH) of all sampled trees was measured using a tree measuring tape, and the latitude, longitude, and elevation of each tree were recorded using GPS. To ensure that estimates of common growth trends were not confounded by potentially low-frequency climatic or environmental forcing in the chronology, all live trees with a diameter at breast height (DBH) greater than 5 cm were sampled [14–16]. Samples were collected in plastic pipettes and taken back to the laboratory for subsequent experiments.

2.2.2. Measurement and Cross-Dating of Tree Annual Ring Widths

The method of determining the width of the annual rings of the tea tree was carried out in accordance with traditional dendrochronological studies. The tea tree core samples were fixed on a flat plate with adhesive tape to air dry (to prevent bending) for a fortnight, and to increase the visibility of the annual ring boundaries, the cores were fixed on a wooden frame with grooves and polished and sanded with sandpaper of grit sizes 200 mesh, 400 mesh, 600 mesh, 800 mesh, 1000 mesh, 1500 mesh, 2000 mesh, and 3000 mesh in that order. To enhance the visibility of the annual ring boundaries, the surface of the cores was chalked to increase the contrast of the annual ring boundaries. The width of the annual rings was measured under a stereomicroscope (Leica M50, Carl Zeiss AG, Jena, Germany) with the help of a cold light source using a tree annual ring meter, LINTABTM (RINNTECH, Heidelberg, Germany) 6 (Rinntech, accuracy: 0.001 mm), and the samples in TSAP-Win were cross-dated by visual curve matching and statistical tests (sign test, *t*-test, and cross-dating indices) during the measurement process. When performing cross-dating, cores that were severely broken at the time of sampling, decayed, and had low cross-dating index (CDI) values in relation to the main chronological sequence were discarded.

2.2.3. Establishment of Brown Mountain Tea Tree Chronology

In order to minimize the influence of non-climatic factors and to eliminate the 'young age effect' in the final tree chronology, the original tree-rotor width series were normalized using a two-step detrending process [17,18]. This detrending method maximized the common signals among tree-rotor sequences. It also removed low-frequency trends caused by stand dynamics and tree aging. The final mean annual wheel width was calculated from a double-weighted robust mean of the individual tree wheel width sequences to eliminate the effect of outliers. Several descriptive statistics, such as the average radial growth rate (AGR), mean sensitivity (MS), signal-to-noise ratio (SNR), and first-order autocorrelation (AC1), were then calculated for the tree chronology. Finally, a standard chronology of tree annual ring widths was created for related statistical analyses.

2.2.4. Statistical Analyses

The relationship between tea tree growth and climate was analyzed by calculating the Pearson correlation coefficients between the tree ring characteristics from August of the previous year to October of the current year—a total of 15 months—and the monthly climate dataset. Since the climate of the previous year's growing season might have influenced the growth of trees in the current year, it was essential to consider the climate variables from the previous growing season in the analysis. Using the bootstrap [19] package in R, the relationship between tree growth and climate factors was calculated through bootstrapping correlation. In addition to the monthly climate data, seasonal averages of climate parameters were also analyzed. This study examined tree chronology and climate variables—including monthly mean temperature (Tmean), minimum temperature (Tmin), maximum temperature (Tmax), precipitation (Pre), and relative humidity (RH)—from 1961 to 2022, employing a moving correlation analysis with a 20-year moving window and a 2-year offset, to assess the temporal stability of the climate–growth relationship. Finally, the dcc function in the R package treeclim was used for a moving correlation analysis to evaluate the temporal stability of the relationship between tree growth and climate.

2.3. Overview of Study Area

2.3.1. Climatic Profile of Study Area

The Yunnan region had a distinct seasonal climate, with the summer rainy season (May to October) influenced by the Asian and tropical southwestern monsoon, and the winter dry season (November to April) influenced by the northern continental cold air mass and temperate westerly winds [20,21]. In this study, the Brown Mountain tea tree in Xishuangbanna was selected as the research object to carry out the dendrochronological study. The study area was located in Xishuangbanna Nature Reserve, which has a subtropical monsoon climate.

2.3.2. Climate Data Acquisition in the Study Area

Monthly climatic data were obtained from the Menglun Meteorological Station (21.54° N –101.46° E, 580 m) at the Xishuangbanna Tropical Rainforest Ecosystem Research Station (XTRES), in a study area approximately 130 km away from the meteorological station. It was demonstrated that the correlation between the annual ring widths of the trees sampled within a range of 150 km around the meteorological station and the climatic factors did not significantly decrease [22]. Similarly, the distance between the meteorological station and the sampling site of tree core samples did not have to be very close in order to observe the link between tree core samples and regional large-scale changes [23]. Climatic data obtained from weather stations in this study included monthly mean temperature (Tmean), minimum temperature (Tmin), maximum temperature (Tmax), precipitation (Prec), and relative humidity (RH).

According to the data from the Menglun Meteorological Station (Figure 1), the average annual precipitation was 1447 mm (1959–2022), with more than 85 percent of the precipitation occurring during the rainy season (May–October); the average annual temperature was 24 °C (1959–2022).

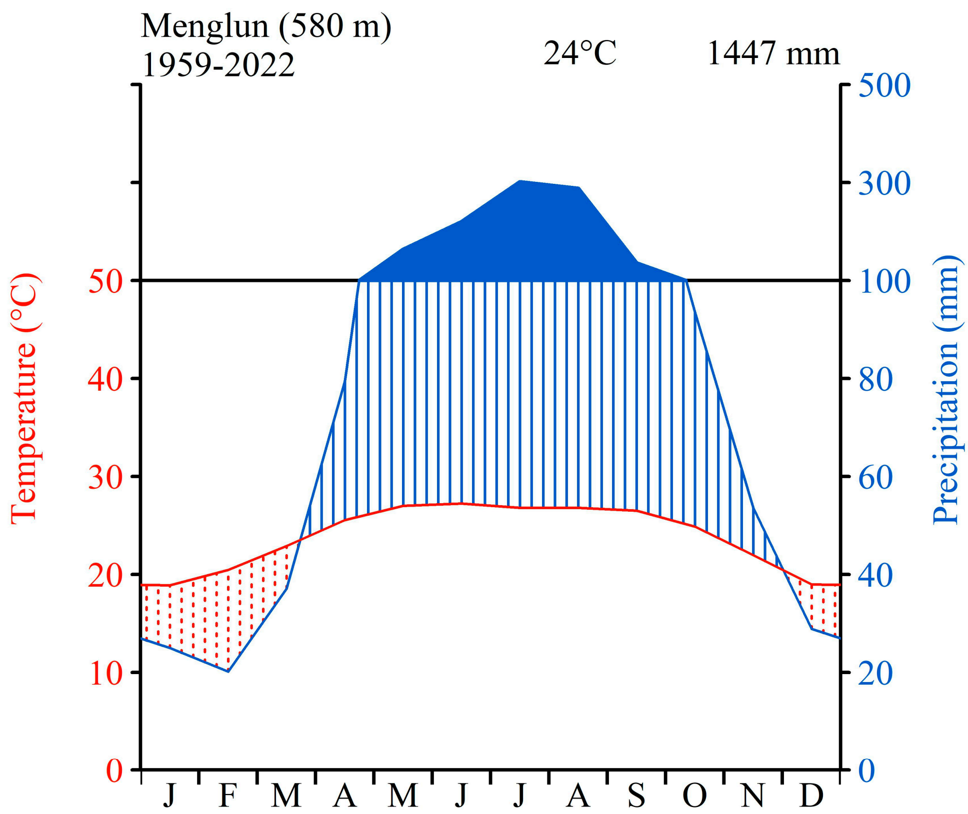

Figure 1. The Walter–Lieth climate diagram of the Menglun climate station for the period 1959–2022. (The red and blue lines indicate monthly mean temperature and precipitation, respectively; the red dotted area indicates periods of drought; the area labeled with blue vertical lines indicates wet months/seasons; and the blue shaded area indicates periods when monthly precipitation exceeds 100 mm, and the station name, altitude, time span, annual mean temperature, and annual mean precipitation are also shown).

The climate trend analysis was carried out on the data from the Menglun Meteorological Station (1959–2022) by using the lm function in the stats package of the R language. As shown in Figure 2, this indicated an increasing trend in mean temperature (Tmean), minimum temperature (Tmin), and maximum temperature (Tmax), and a slight decreasing trend in precipitation (mm) and relative humidity (Rh).

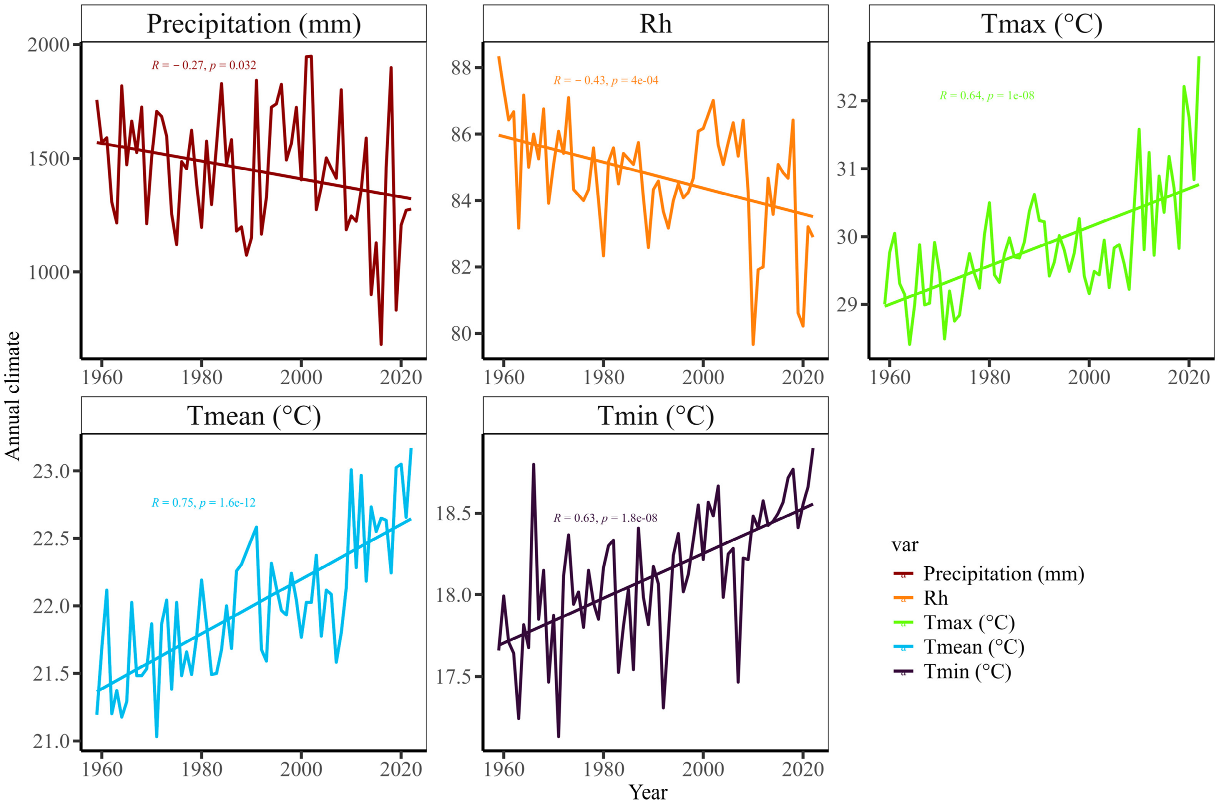

Figure 2. Long-term changes in mean annual temperature, maximum temperature, minimum temperature, precipitation, and relative humidity in the study area, 1959–2022 (Menglun Meteorological Station).

3. Results

3.1. The Chronological Characterization of the Width of the Annual Rings

In this study, a total of 36 cores were collected from 20 tea trees to establish a chronology of tea tree wheel widths, and the descriptive statistical characteristics of the standard tea tree chronology are shown in Table 1: the tea tree wheel width chronology spanned 70 years (1954–2023), and the average annual growth rate of the tea trees was 1.283 mm/year. The first-order autocorrelation coefficient (ACI) was 0.269, which indicated that the growth of the tea trees in the current year was less significantly affected by the previous year. The average sensitivity was 0.514, which indicated that the chronology contains richer climatic information. The correlation coefficient between core sequences was 0.112, and the sample population representativeness (EPS) of the wheel width index was 0.514. The first-order autocorrelation coefficient (ACI) was 0.269, indicating that the growth of the tea tree in the current year was influenced by the growth of the previous year. The average sensitivity was 0.514, indicating that the chronology contains rich climate information. The correlation coefficient of the tree core series (Rbar) was 0.112, and the expressed population signal (EPS) of the tree wheel width index was 0.716; the signal-to-noise ratio was 2.526. This indicated that the inter-annual variation in growth among different trees was more consistent, and the quality of the chronology was better, which could represent the overall characteristics of tea tree growth in the study area and contain more climate information. In the standard chronology of tree wheel width, it could be seen that the inter-annual growth of the tea tree fluctuated a lot, and there were more extreme narrow years (Figure 3), so the tea tree grew slowly in this region (Table 1).

Table 1. Statistics of tree ring width standard chronologies of *Camellia sinensis*.

Statistical Characteristics	
Time span	1954–2023
Average annual growth rate (mm/year)	1.283
First-order autocorrelation coefficient (ACI)	0.269
Average sensitivity (MS)	0.514
Signal-to-noise ratio (SNR)	2.526
Sequence correlation (Rbar)	0.112
Expressed population signal (EPS)	0.716

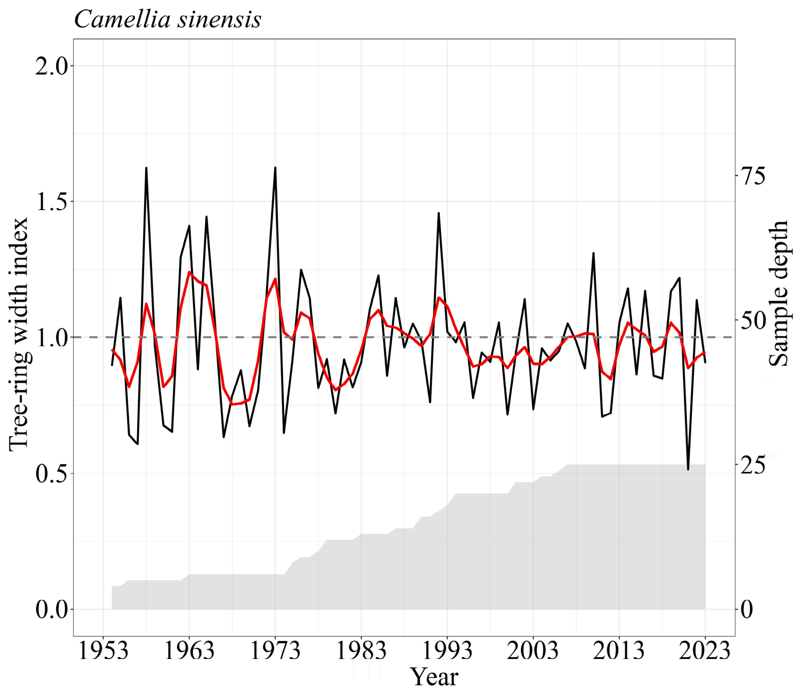

Figure 3. Camellia sinensis standard chronology (black line: tree ring width index; red line: 10-year low-pass filter; shaded area: sample depth).

3.2. Relationship Between Radial Growth and Climate

According to the Walter Lees climatological map of Menglun Meteorological Station, from 1959 to 2022, the average annual precipitation in Menglun Township was 1447 mm, with more than 85% of the precipitation occurring during the rainy season (May–October), and the average annual temperature was 24 °C.

The correlation analysis between the tea tree's tree ring standard chronology and climate factors is shown in Figure 4. The width of the tea tree's tree rings was positively correlated with temperature in most months and negatively correlated with precipitation and relative humidity. In the study area, the radial growth of tea trees showed a consistent response to mean temperature (Tmean), minimum temperature (Tmin), and maximum temperature (Tmax), with significant positive correlations with the average temperature in May (Tmean) and the maximum temperature in April (Tmax) of the same year. There was a non-significant positive correlation with the average temperature from February to April (Tmean) of the same year. It showed a significant positive correlation with December precipitation (Prec) of the previous year and a significant negative correlation with September of the current year; there was a non-significant positive correlation with relative humidity (RH) from October of the previous year to March of the current year.

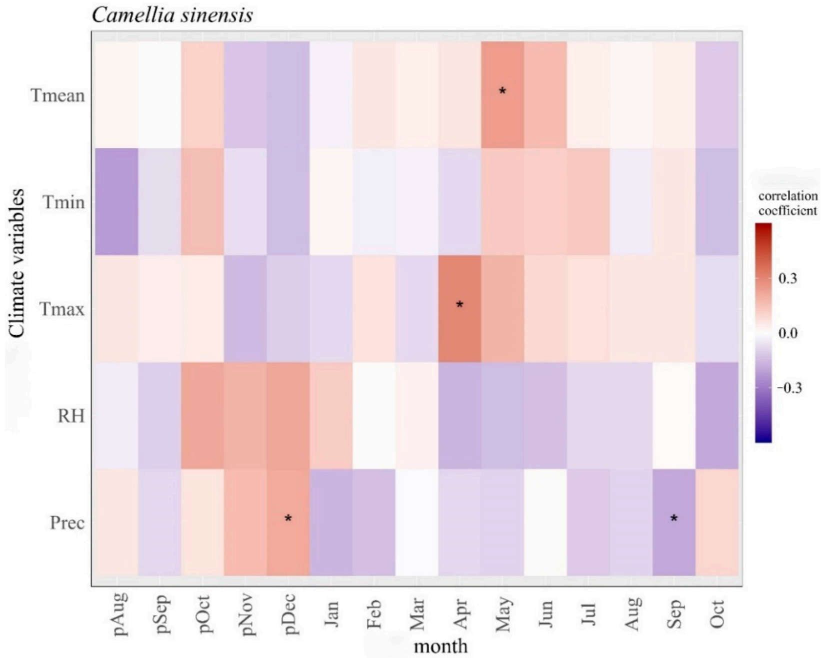

Figure 4. Correlation coefficients between ring-width standard chronology of Camellia sinensis and monthly climatic parameters (the bootstrapped correlation analysis was performed for the months from the previous August to the current October during the period 1982–2019). (Colors represent correlation coefficients ranging from negative (blue) to positive (red). * indicates a significant correlation coefficient. TMN, minimum temperature; TMP, mean temperature; TMX, maximum temperature; PRE, total precipitation; RH, relative humidity).

Based on the response of tea trees to climate parameters at different time scales, it was found that during the current growing season, the growth of tea trees was mainly influenced by temperature. The temperatures in spring and early summer were limiting factors, with radial growth positively correlated with temperatures from February to July [24]. In the previous growing season, the radial growth of tea trees was positively influenced by water supply, but in the current growing season, it was negatively affected, indicating that excessive rainfall during the growth period may inhibit the expansion of tree diameter [25]. The findings of this study align with observations in other humid forests in China, where researchers have found that relative humidity and precipitation are negatively correlated with the growth of *Tetracentron sinensis Oliv*, while being positively correlated with the duration of sunshine during the growing season [26]. Similarly, in the eastern part of China, the growth of *Schima superban. et Champ* in Gutian Mountain shows a significant negative correlation with summer precipitation and a positive correlation with sunshine duration [27]. It was evident that the year-round growth of evergreen species is significantly affected by climate conditions during the dry season [28], while there was generally a lack of climate records for trees in regions with relatively high humidity and low temperature amplitude [29].

Based on a study of red pine wood formation in eastern China, the dry season showed better tree growth compared to periods of abundant precipitation, and autumn was observed to play an important role in the overall growth of trees throughout the year [30]. In this regard, the present study observed that tea tree growth was negatively correlated with both relative humidity and precipitation in summer and autumn, but positively correlated with the temperature of the year. This may be attributed to the fact that in the lower layers of subtropical montane humid forests, smaller tea tree canopies did not dominate over the surrounding taller species, whose canopies blocked light and limited photosynthesis. This discrepancy was related to the distribution pattern of the tea tree in the sample plots. The study area is located at low to medium altitude and has a mild climate, which, during the summer months, is characterized by cloudiness and mist. This, together with high humidity and adequate precipitation, has a significant impact on sunlight hours and photosynthesis, ultimately limiting tree growth.

3.3. Stability of Radial Growth and Climate Response

A 20-year sliding correlation analysis of the tea tree wheel width chronology with climate factors from August of the previous year to December of the current year showed (Figure 5) that the *p*-value was below 0.05, indicating a significant correlation between tree growth and climate change, and that the radial growth of the tea tree varied in its stability in response to climate factors. The mean June temperature (Tmean) with the previous year shifted from a non-significant positive correlation (1961–1984) to a significant positive correlation (1985–2010) and then to a non-significant positive correlation (2010–2022). The maximum temperature (Tmax) in November of the previous year shifted from a significant negative correlation (1981–2012) to a non-significant positive correlation. The minimum temperature (Tmin) in June of the previous year shifted from a non-significant negative correlation (1973–2010) to a significant positive correlation. In terms of the moisture effect, the positive correlation with precipitation (Prec) from August to November of the previous year shifted from non-significantly positive to negative, and the positive correlation with precipitation (Prec) from December of the previous year basically reached significance. Relative humidity (RH) from October of the previous year to March of the current year was either significantly positively correlated or not significantly positively correlated. Overall, tea trees showed strong correlations in the mid- to late 20th century, but the response pattern has gradually weakened in the last two decades.

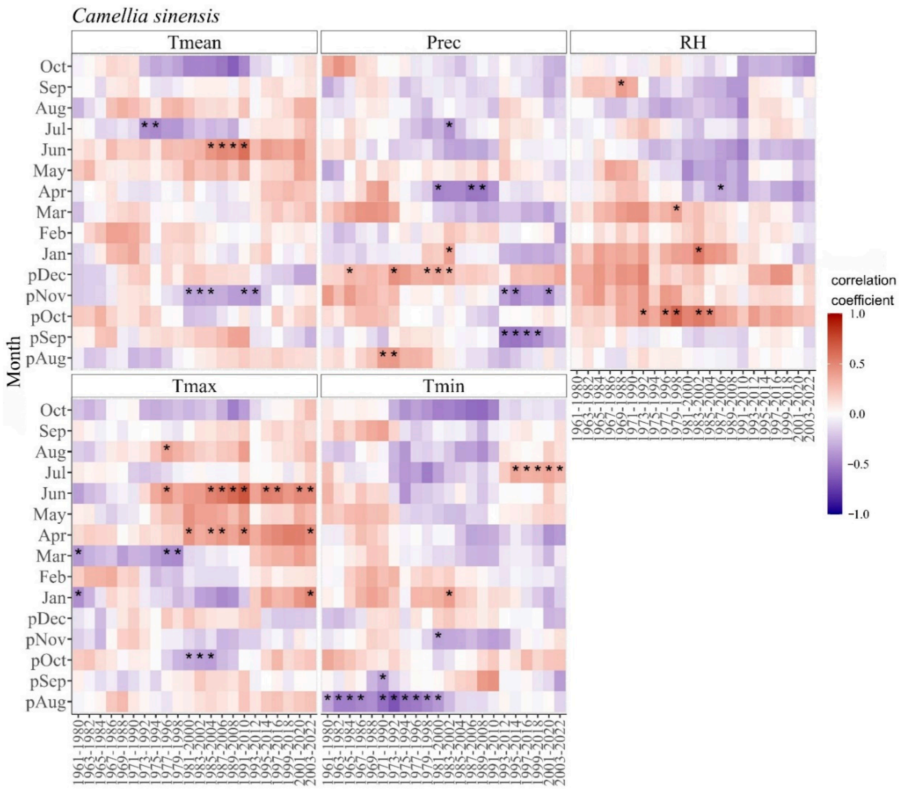

Figure 5. Moving correlation coefficients' ring-width standard chronology of Camellia sinensis and climatic parameters. (Correlations were computed for a 20-year moving window with a 2-year offset during the period 1961–2022. * indicates a significant correlation coefficient. TMN, minimum temperature; TMP, mean temperature; TMX, maximum temperature; PRE, total precipitation; RH, relative humidity).

Sliding correlation analyses revealed unstable relationships between tea tree growth and climate parameters over time. Overall, all correlations showed a weakening trend in recent decades. Tea plants as a whole exhibited persistent negative hydroclimatic impacts and positive maximum temperature (Tmax) during the season of abundant precipitation (May to October), while there were no limiting impacts during the dry season (November of the previous year to April of the current year). Although the strength of the correlations weakened over time, the results were consistent with and mutually validated by monthly growth climate correlations. However, the correlations between climate and tree growth were erratic for all tree species, suggesting that temperature may no longer be the main limiting factor for tree growth in the future.

4. Discussion

Tree annual rings are not only a record-of-time scale, but also a treasure trove of scientific information, containing in each whorl a chain of information influenced by the natural environment and anthropogenic activities [31]. In this study, the relationship between radial growth of the tea tree and climatic factors was investigated based on the annual ring width chronology of the tea tree, and the results revealed the sensitivity of tea tree growth to changes in temperature and moisture. The annual average growth rate of the tea tree annual ring width chronology was 1.283 mm/year, and the average sensitivity of the annual ring width sequence was 0.514, indicating that tea tree growth was significantly affected by climatic conditions. The sensitivity index of annual ring width reflected the responsiveness of tea tree annual rings to climate change, and this result suggested that tea tree growth had a high sensitivity to climate fluctuations, especially when temperature and moisture conditions changed. Compared with many other tree species, the sensitivity of the annual rings of tea trees to climate response was moderate, which was not too sensitive to cause data interference, but also reflected the trend of climate change better. The width index of tea tree rings (EPS) in this study was 0.716, indicating that the interannual variability of growth was more consistent among different tea trees, which was more representative and comparable. This implied that the measured sample population of tea trees could effectively represent the growth dynamics of tea trees in the region, which in turn provided a reliable basis for analyzing the climate–growth relationship. The relatively high value of the EPS also supports the validity and robustness of the chronology in long-term climate change studies.

In terms of climatic response, the radial growth of trees in different locations showed different responses to climatic factors [32], and the relationship between the radial growth of the tea tree and temperature and moisture was more pronounced. From the response relationship between the standard chronology of the tea tree and monthly climate, the growth of the tea tree showed a significant correlation with temperature (moisture), especially in the warm season, where the increase in temperature helped the growth of the tea tree, particularly in the season of abundant precipitation (May to October). However, during the dry season (November of the previous year to April of the current year), tea tree growth showed a strong negative hydroclimatic effect; i.e., the scarcity of precipitation inhibited its radial growth. This result also suggested that tea tree growth was not only dependent on adequate water supply, but the suitability of temperature was also a key factor in promoting its growth [33].

In particular, the tea tree showed stronger negative hydroclimatic effects and positive temperature (Tmax) effects during the season of abundant precipitation, possibly due to higher temperatures contributing to efficient water utilization and enhanced photosynthesis. In contrast, during the dry season, the lack of precipitation in conjunction with lower temperatures may have inhibited tea tree growth. The finding that the mechanisms by which climatic factors affected tea tree growth showed different patterns in different seasons further deepened the understanding of the complex relationship between tea tree growth and climate response. Thus, tree growth in the study area may have benefited from future warming and reduced precipitation, as predicted by recent global climate scenarios [34].

In later studies, stable oxygen isotopes [35] were used to analyze the moisture information and temperature signals of tea tree growth. Through the determination of stable oxygen isotopes, both the intra-annual variability characteristics of tree radial growth were explored, and the response of annual growth to climate was interpreted. The key climatic factors influencing the radial growth of trees were also explored by tapping into the more climatic information recorded in the tree whorls. In turn, this helped to formulate appropriate policies for the development and protection of ancient tea trees and to construct a tree-rotor database in western Yunnan.

In summary, this study showed that the radial growth of the tea tree is sensitive to climate change, especially the changes in water and temperature, which have important effects on its growth. The results not only provide a quantitative analysis of the relationship between tea tree growth and climate change, but also offer theoretical support for the study of tea tree cultivation and climate adaptation. Future research could further explore the growth pattern of tea trees under different climatic conditions, and combine the prediction results of climate models to provide a more scientific basis for tea tree cultivation management and climate adaptation strategies. Meanwhile, as the growth of tea trees is greatly influenced by climatic factors, the research results have some implications for the potential impacts of climate change on agricultural production.

5. Conclusions

This study established a tree ring width chronology by measuring the annual ring widths of tea trees and cross-dating them. The tea tree ring width chronology spanned 70 years (1954–2023), with an average annual growth rate of 1.283 mm/year; the average sensitivity of the ring width series was 0.514, indicating that the chronology contains rich climatic information. The expressed population signal (EPS) of the tree ring width index was 0.716, suggesting good consistency in inter-annual growth variations among different tea trees.

From the response relationship between the standard tea tree chronology and monthly climate, there was a correlation between the radial growth of tea trees and temperature and moisture. In terms of the stability of the climate response of tea tree radial growth, during the rainy season (May to October), tea trees generally showed continuous hydroclimatic negative impacts and positive impacts from maximum temperatures (Tmax). During the dry season (November of the previous year to April of the following year), unrestricted effects were observed, which were consistent with the correlations between monthly growth and climate.

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Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. *Climate Change 2013—The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 1st ed; Intergovernmental Panel On Climate Change, Ed.; Cambridge University Press: Cambridge, UK, 2014; ISBN 978-1-107-05799-9.

2. Phillips, O.L.; Aragão, L.E.O.C.; Lewis, S.L.; Fisher, J.B.; Lloyd, J.; López-González, G.; Malhi, Y.; Monteagudo, A.; Peacock, J.; Quesada, C.A.; et al. Drought Sensitivity of the Amazon Rainforest. *Science* **2009**, *323*, 1344–1347. [CrossRef] [PubMed]
3. Zaw, Z.; Fan, Z.-X.; Bräuning, A.; Liu, W.; Gaire, N.P.; Than, K.Z.; Panthi, S. Monsoon Precipitation Variations in Myanmar since AD 1770: Linkage to Tropical Ocean-atmospheric Circulations. *Clim. Dyn.* **2021**, *56*, 3337–3352. [CrossRef]
4. Vlam, M.; Baker, P.J.; Bunyavejchewin, S.; Mohren, G.M.J.; Zuidema, P.A. Understanding Recruitment Failure in Tropical Tree Species: Insights from a Tree-Ring Study. *For. Ecol. Manag.* **2014**, *312*, 108–116. [CrossRef]
5. Li, P.; Zhan, X.; Que, Q.; Qu, W.; Liu, M.; Ouyang, K.; Li, J.; Deng, X.; Zhang, J.; Liao, B.; et al. Genetic Diversity and Population Structure of Toona Ciliata Roem. Based on Sequence-Related Amplified Polymorphism (SRAP) Markers. *Forests* **2015**, *6*, 1094–1106. [CrossRef]
6. Zuidema, P.A.; Heinrich, I.; Rahman, M.; Vlam, M.; Zwartsenberg, S.A.; van der Sleen, P. Recent CO_2 Rise Has Modified the Sensitivity of Tropical Tree Growth to Rainfall and Temperature. *Glob. Change Biol.* **2020**, *26*, 4028–4041. [CrossRef]
7. Zhang, M.G.; Zhou, Z.K.; Chen, W.Y.; Cannon, C.H.; Raes, N.; Slik, J.W.F. Major Declines of Woody Plant Species Ranges under Climate Change in Yunnan, China. *Divers. Distrib.* **2014**, *20*, 405–415. [CrossRef]
8. Zuidema, P.A.; Brienen, R.J.W.; Schöngart, J. Tropical Forest Warming: Looking Backwards for More Insights. *Trends Ecol. Evol.* **2012**, *27*, 193–194. [CrossRef]
9. He, M.; Yang, B.; Bräuning, A.; Rossi, S.; Ljungqvist, F.C.; Shishov, V.; Grießinger, J.; Wang, J.; Liu, J.; Qin, C. Recent Advances in Dendroclimatology in China. *Earth-Sci. Rev.* **2019**, *194*, 521–535. [CrossRef]
10. Tang, J.X.; Wang, P.J.; E, Y.H.; Ma, Y.P.; Wu, D.R.; Hu, Z.G. Climatic Suitability Zoning of Tea Planting in Mainland China. *J. Appl. Meteor. Sci.* **2021**, *32*, 397–407. [CrossRef]
11. Luo, X.Q.; Li, S.Y.; Wang, J.J.; Chen, X.Y.; Liang, M.Z.; Zhou, Y.Z.; Jiang, H.B. Survey of Ancient Tea Tree Resources in Xishuangbanna. *Southwest J. Agric.* **2013**, *26*, 46–51. [CrossRef]
12. Dong, X.; Zhu, J.S. Globally Important Centre of Tea Tree Origins Yunnan Pu'er Jingmai Mountain Ancient Tea Forest Successful in Heritage Bidding. *China Business News (Newspaper)*, 19 September 2023; A12.
13. Bi, Y.; Xu, J.; Yang, J.; Li, Z.; Gebrekirstos, A.; Liang, E.; Zhang, S.; Yang, Y.; Yang, Y.; Yang, X. Ring-Widths of the above Tree-Line Shrub Rhododendron Reveal the Change of Minimum Winter Temperature over the Past 211 Years in Southwestern China. *Clim. Dyn.* **2017**, *48*, 3919–3933. [CrossRef]
14. Brienen, R.; Gloor, M.; Zuidema, P. Can We Detect Evidence for CO_2 Fertilization from Tree Rings? *Glob. Biogeochem. Cycles Int. J. Glob. Change* **2012**. [CrossRef]
15. Dietrich, R.; Anand, M. Trees Do Not Always Act Their Age: Size-Deterministic Tree Ring Standardization for Long-Term Trend Estimation in Shade-Tolerant Trees. *Biogeosciences* **2019**, *16*, 4815–4827. [CrossRef]
16. Herrera-Ramirez, D.; Andreu-Hayles, L.; del Valle, J.I.; Santos, G.M.; Gonzalez, P.L.M. Nonannual Tree Rings in a Climate-Sensitive Prioria Copaifera Chronology in the Atrato River, Colombia. *Ecol. Evol.* **2017**, *7*, 6334–6345. [CrossRef] [PubMed]
17. Cook, E.R. A Time Series Analysis Approach to Tree Ring Standardization (Dendrochronology, Forestry, Dendroclimatology, Autoregressive Process). Ph.D. Thesis, University of Arizona, Tucson, AZ, USA, 1985.
18. Bunn, A.G. A Dendrochronology Program Library in R (dplR). *Dendrochronologia* **2008**, *26*, 115–124. [CrossRef]
19. Zang, C.; Biondi, F. Dendroclimatic Calibration in R: The bootRes Package for Response and Correlation Function Analysis. *Dendrochronologia* **2013**, *31*, 68–74. [CrossRef]
20. Thomas, A. The Onset of the Rainy Season in Yunnan Province, PR China and Its Significance for Agricultural Operations. *Int. J. Biometeorol.* **1993**, *37*, 170–176. [CrossRef]
21. Li, Y.; He, D.; Hu, J.; Cao, J. Variability of Extreme Precipitation over Yunnan Province, China 1960–2012. *Int. J. Climatol.* **2015**, *35*, 245–258. [CrossRef]
22. Julian, P.; Fritts, H. *On the Possibility of Quantitatively Extending Precipitation Records by Means of Dendroclimatological Analysis*; National Center for Atmospheric Research: Boulder, Colorado, 1968.
23. Zhang, Z. Tree-Rings, a Key Ecological Indicator of Environment and Climate Change. *Ecol. Indic.* **2015**, *51*, 107–116. [CrossRef]
24. Liu, X.; Nie, Y.; Wen, F. Seasonal Dynamics of Stem Radial Increment of Pinus Taiwanensis Hayata and Its Response to Environmental Factors in the Lushan Mountains, Southeastern China. *Forests* **2018**, *9*, 387. [CrossRef]
25. Fontana, C.; Santini-Junior, L.; Olmedo, G.M.; Botosso, P.C.; Tomazello-Filho, M.; Oliveira, J.M. Assessment of the Dendrochronological Potential of Licaria Bahiana Kurz, an Endemic Laurel of Lowland Atlantic Forests in Brazil. *Acta Bot. Bras.* **2019**, *33*, 454–464. [CrossRef]
26. Bai, X.; Fan, Z.-X. Response of Tree Ring Width to Climate Change of Tetracentron Sinensis in Humid Evergreen Broad-Leaved Forest in the Middle Ailao Mountains. *Linye Kexue/Sci. Silvae Sin.* **2018**, *54*, 161–167. [CrossRef]
27. Su, H.; Axmacher, J.C.; Yang, B.; Sang, W. Differential Radial Growth Response of Three Coexisting Dominant Tree Species to Local and Large-Scale Climate Variability in a Subtropical Evergreen Broad-Leaved Forest of China. *Ecol. Res.* **2015**, *30*, 745–754. [CrossRef]
28. Zhou, B.; Fan, Z.X.; Qi, J.H. Intra-annual radial growth of evergreen and deciduous tree species and their response to climatic factors in a montane moist evergreen broad-leaved forest in the Ailao Mountains, Southwest China. *Ecol. Lett.* **2020**, *40*, 1699–1708.
29. Pavão, D.C.; Jevšenak, J.; Engblom, J.; Borges Silva, L.; Elias, R.B.; Silva, L. Tree Growth-Climate Relationship in the Azorean Holly in a Temperate Humid Forest with Low Thermal Amplitude. *Dendrochronologia* **2023**, *77*, 126050. [CrossRef]

30. Huang, J.-G.; Guo, X.; Rossi, S.; Zhai, L.; Yu, B.; Zhang, S.; Zhang, M. Intra-Annual Wood Formation of Subtropical Chinese Red Pine Shows Better Growth in Dry Season than Wet Season. *Tree Physiol.* **2018**, *38*, 1225–1236. [CrossRef]
31. Yu, J.; Chen, J.J.; Meng, S.W.; He, H.J.; Zhao, Y.S.; Zhang, P.; Yang, B.; Liu, Q.J. Reconstruction of April-July precipitation changes in northern Daxinganling over the past 242 years based on tree annual rings. *Quat. Stud.* **2024**, *44*, 895–907.
32. Zhou, P.; Huang, J.-G.; Liang, H.; Rossi, S.; Bergeron, Y.; Shishov, V.V.; Jiang, S.; Kang, J.; Zhu, H.; Dong, Z. Radial Growth of Larix Sibirica Was More Sensitive to Climate at Low than High Altitudes in the Altai Mountains, China. *Agric. For. Meteorol.* **2021**, *304–305*, 108392. [CrossRef]
33. Dang, H.; Jiang, M.; Zhang, Q.; Zhang, Y. Growth Responses of Subalpine Fir (Abies Fargesii) to Climate Variability in the Qinling Mountain, China. *For. Ecol. Manag.* **2007**, *240*, 143–150. [CrossRef]
34. Masson-Delmotte, V.P.; Zhai, P.; Pirani, S.L.; Connors, C.; Péan, S.; Berger, N.; Caud, Y.; Chen, L.; Goldfarb, M.I.; Scheel Monteiro, P.M. IPCC, 2021: Summary for Policymakers. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Intergovernmental Panel on Climate Change: Geneva, Switzerland, 2021.
35. Wang, L.; Liu, H.Y. Application of tree-wheel stable oxygen isotopes in soil moisture reconstruction and future challenges. *Quat. Stud.* **2021**, 1–10. [CrossRef]