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Original article

Altitudinal trends in climate change result in radial growth variation of *Pinus yunnanensis* at an arid-hot valley of southwest China

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ABSTRACT

Climate change has already had observable impact on the biophysical environment, and lead to the different sensitivity of vegetation to climate factors on spatio-temporal scale. Therefore, understanding how the radial growth respond to climate at different spatio-temporal scales is crucial to recognize forest growth dynamic and make scientific management decisions under the background of climatic change. In the present study, the tree ring of Pinus yunnanensis at six altitudes gradients between 1300 m and 2500 m from a typical arid-hot valley in Jinsha River, were collected. We analyzed the relationship between radial growth and climate at different altitudes, and the sensitivity of growth to climatic factors over time. The results showed that the mean width of tree rings decreased as the altitude increasing. The relationship between climatic factors and radial growth at low or high altitudes was different with that at mid altitudes. Radial growth was negatively correlated to the temperatures from February to July at both low altitudes (1300–1500 m) and at high altitudes (2200–2500 m), but positively correlated to the temperatures in October of the previous year to April at mid altitudes (1700–1900 m). Precipitation in October of the previous year, May, and June in growing year had a positive effect on radial growth at all altitudes. Temperature and precipitation in the previous year showed a time-lag effect on radial growth. A moving correlation analysis of the tree ring index and climate variables showed that the limiting factors for tree growth at different altitudes varied over time. The influence of drought on the tree growth increased gradually as the climate warming. In future research, evaluating the dynamic relationship between vegetation growth and climate warming at spatio–temporal scale will be particularly important to guide forest management.

1. Introduction

The mountain forest offers a global carbon sink and serves to mitigate the adverse effects of climate change (Bousquet et al., 2000; Peters et al., 2019). Also, the ecological function of mountain forests is susceptible to climate change (Trivedi et al., 2008; Lffler et al., 2011; Gottfried et al., 2012), especially in the case of subalpine forests. Recent studies have documented that high altitude regions experienced more rapid climate change than do the regions at lower altitude (Efe et al., 2015; Pepin et al., 2015). This could alter the tree growth and forest productivity across climate change at different elevational gradients (Vicente-Serrano et al., 2013; Bauwe et al., 2015). Therefore, further studies are needed to explore how tree growth respond to climate change at different altitudes, then comprehending the effects of global warming on mountain ecosystem in spatio-temporal scales (Tei et al., 2017; Klesse et al., 2018).

Tree rings offer the reliable ecological memory which could assess the biophysical environment and climate conditions (Peterson and Peterson, 2001; Rathgeber, 2017). As trees grow, climatic signals leave their mark in the form of the width of tree rings, or the gap between successive rings (Lo et al., 2010; Tei et al., 2017), which thus reflects variations in tree growth over time due to the differences in local topography and climate (Bunn et al., 2005; Bai et al., 2019). Massive researches and their subsequent analysis documents are on the response of growth-climate relationship at different specific sites (Gou et al., 2005; Panthi et al., 2018). For instance, the tree growth at lower altitudes is strongly affected by the availability of water in summer, whereas at high altitudes temperature has a greater impact on tree

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growth (Babst et al., 2013; Matías et al., 2017). Admittedly, external factors lead the tree growth has different response, like tree at alpine timberline could be limited by hot and dry climate because the large tropical volcanic eruptions (Liang et al., 2019). At temporal scale, the key drivers and the direction of potential climate change effects on tree growth are still controversial and might differ across biomes and forest communities (divergence problem) (Wu, 1990; D'Arrigo et al., 2008; Cai et al., 2020). Some researchers attributed the reasons to different tree ages or adaptability of trees growth respond to climate change (Rozas, 2005; Esper et al., 2008; Vieira et al., 2009). Previously reported that differential sensitivity to climate with age for different tree species and locations. Molina et al. (2019) found that adult trees showed higher intrinsic water-use efficiency values than young trees. Also, climate change leads to changes in the adaptability of trees growth to induce divergence problem (D'Arrigo et al., 2008; Cai et al., 2019; Du et al., 2020). Tree growth in cold environments will benefit from warming, whereas growth in moisture-limited regions will be restricted by drought stress caused by warming. Climate change in distinct locations has altered the response of trees to climate (Buechling et al., 2017; Conlisk et al., 2017). Therefore, lucubrating the tree growth respond to climate change at spatial and temporal scales could understand how the forest evolve dynamically and then proposing forest management measures under climate change (Palombo et al., 2014; Körner et al., 2016).

The Hengduan Mountains have huge differences along altitude gradient results in significant differences in climate, and thus offer an ideal area to explore the effects of altitudinal trends in climate change on vegetation (Duan et al., 2016). Earlier studies focused on high-altitude regions (above 3000 m) in Hengduan mountains (Fan et al., 2009; Yin et al., 2018). Fan et al. (2009) found that at higher elevations, current-season radial growth of conifers was favored by normal or high summer temperatures (in June and July), and Yin et al. (2018) found that radial growth in *Abies georgei* was affected positively by the temperature but negatively by the precipitation. Large regional and spatial studies on the climate-growth response usually minimized or even ignored the effects of potentially confounding factors, such as geographic location and local site conditions (Tei et al., 2017; Klesse et al., 2018). Our study focused on the local topographic element led to climate difference to explore how the tree growth respond to climate factors.

In the present research, *Pinus yunnanensis*, the dominant tree species occupied in the study area, was used for studying the effect of climate change on radial growth at different altitudes. The main objectives of the research were to (1) find the similarities and differences in radial growth of *P. yunnanensis* at different altitudes; (2) analyze the relationship between radial growth and climate change as affected by the altitude; (3) explore the differences in radial growth as affected by climate change over time. The findings of the present study could provide a theoretical basis for explaining the characteristics of tree growth in arid-hot valleys and for devising appropriate forest management strategies at different altitudes.

2. Materials and methods

2.1. Study area

The study area is a part of the Hengduan Mountains in north-western China (Fig. 1). The Hengduan Mountains arose as the consequence of a series of geological events in the Qinghai-Tibet Plateau, and the landscape spans a wide topographic gradient from deeply incised parallel

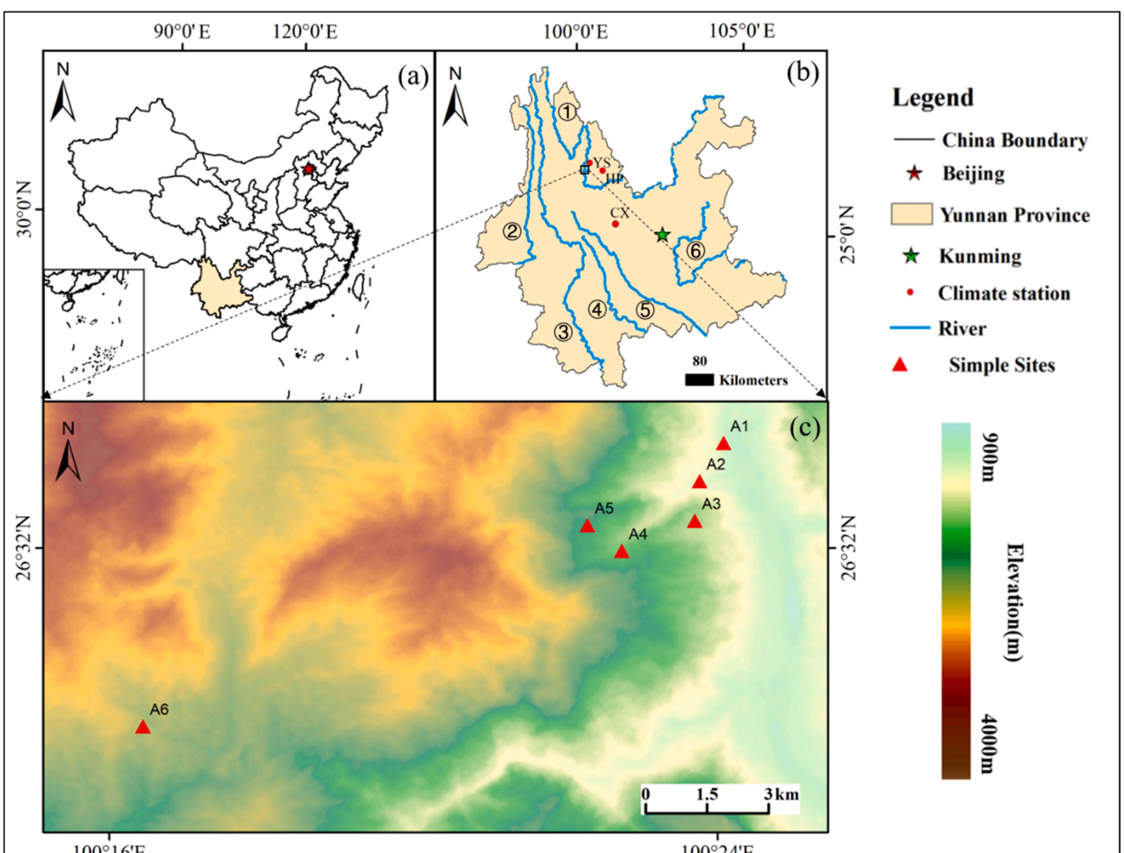

Fig. 1. Map of the sampling sites in the central Hengduan Mountains, north-western Yunnan: (a) China, (b) Yunnan province, (c) research area, elevations, and sample sites. Rivers in (b): ① Jinsha, ② Nu, ③ Mekong, ④ Lixian, ⑤ Yuan, and ⑥ Nanpan river. YS: Yongsheng meteorological station, HP: Huaping meteorological station.

valleys at about 1000 m above the sea level to glacial peaks rising beyond 6000 m. The difference in altitude between the valleys and ridges is mostly 1000–2000 m. Such uneven terrain and climatic conditions result in an extremely unbalanced distribution of water and heat, which is the main cause of the formation of the arid-hot valleys. In subalpine forests, the arid-hot valley is composed of typical alpine forests at higher altitudes and scrub or scattered trees at lower altitudes, similar to the savanna landscape (He et al., 2000). The main species in the arid-hot valleys are *Pinus yunnanensis*, *Picea asperata, Quercus semecarpifolia*, and other drought-tolerant species (Dong et al., 2014). *P. yunnanensis* is a heliophilous species with strong tolerance to drought and is mainly distributed at elevations from 1000 m to 3000 m in drought-affected parts of south-western China. The *P. yunnanensis* forms well-defined growth rings every year, which makes it ideal for studying dendrochronology (Shen et al., 2020).

2.2. Sampling and measurements

The sampling sites were distributed at different altitudes in the arid-hot valley of Jinsha river basin, near Longkaikou reservoir (26°31′50″ N, 100°24′51″ E), Heqing county, Yunnan province (Fig. 1c). At every sampling site, at least 20 well-grown trees were selected. To eliminate the impact of non-climatic factors, intact trees or those with only minor damage were selected as samples. From each selected tree, two increment cores per tree were taken from the trunk at a height of 130 cm by using incremental borers (Table 1). A6 sample site was located at the top of *P. yunnanensis* sample in the near region.

2.3. Sources of climate data

In mountain ecosystems, climatic conditions often vary with elevation. Based on the altitude, the climate background was divided into three groups, namely Huaping (HP) (1230 m), Chuxiong (CX) (1800 m), and Yongsheng (YS) (2130 m) meteorological stations, representing, respectively, the low altitudes (1300–1500 m), mid altitudes (1700–1900 m), and high altitudes (2200–2500 m) in the arid-hot valley. Data on the following climate variables were obtained from the three meteorological stations for the period 1957–2016: monthly precipitation, monthly mean temperature (T_{mean}), monthly mean maximum temperature (T_{max}), and monthly mean minimum temperature (T_{min}). For the third station the data were obtained from the China Meteorological Data Service Center (http://data.cma.cn/).

Monthly and yearly changes in precipitation and temperature at the three weather stations are presented in Fig. 2. The time period was from 1958 to 2015. The maximum precipitation was in July, and most of the precipitation occurred from mid-May to mid-October, accounting for over 85% of the annual precipitation, with scant precipitation in other months (Fig. 2). At YS and CX stations, T_{mean}, T_{max}, and T_{min} increased over time; at HP, the T_{mean}, T_{max}, and T_{min} increased gradually after 1980. The temperature peaked in June at YS and in May at HP and CX. The precipitation also showed a general increase in volatility.

2.4. Data analysis

We measured the tree rings using a LINTAB 6 Professional ring analyzer, combined with a high-resolution stereomicroscope. The measurements were accurate to the hundredth of a millimeter (10 μm). The samples were cross-dated using COFECHA, a computer program to test the quality of cross-dating and the accuracy of tree-ring measurements. Subsequent analyses were based on the standard version of the master chronology produced by ARSTAN, a program that produces chronologies based on tree rings. Before establishing the chronology, the data were de-trended and standardized. After a comprehensive comparison of commonly used functions such as age-dependent spline and Hugershoff, we decided to use a negative exponential/linear function. This residual method was used in conjunction with initial power transformation to avoid ratio bias problems (Cook and Peters, 1997; Sun et al., 2020). This was done to remove age-related biological growth trends and the incongruent fluctuation from inhibition and release of interference competition among trees while preserving growth variations that are likely to be related to climate variability (Fritts, 1976). Finally, we built the standard chronologies (STD). The standard tree ring width index (TRWI) was used for analyzing the relationship between radial growth and climate. Typically, the expressed population signal (EPS) was used for assessing the quality of the chronologies, and an EPS threshold of 0.85 was considered the confidence coefficient for the chronology. A correlation analysis was conducted using meteorological variables (i.e., P, T_{mean}, T_{max}, and T_{min} and SPEI) from previous May to current October, labeled as P10 … M10.

In arid-hot valleys, drought has a profound impact on plant growth. Global warming is also probably increasing the severity of droughts (Vicente-Serrano et al., 2014). Evaluating the influence of drought on tree growth is therefore a priority under the current climatic conditions. To explain the effects of drought on trees in detail, the standardized precipitation evapotranspiration index (SPEI; Vicente-Serrano et al., 2010) was used for exploring the relationship between TRWI and drought. Based on meteorological data, the SPEI was calculated using R Project for Statistical Computing, SPEI is a common indicator for measuring climatic drought by multi-timescale which is important because drought in a month is the cumulative result of soil water deficit in previous months. The potential evapotranspiration in SPEI was calculated by the Penman-Monteith equation in R program (Sun et al., 2020). and the index on a 6-month scale was used for analysis because the wet and the dry seasons were distinguishable in the arid-hot valley.

3. Results

3.1. Characteristics of tree rings at different altitudes

Tree-ring widths of *P. yunnanensis* at different altitudes were shown in Fig. 3. The average tree ring width reached the highest value of 3.26 mm per year at the lowest elevation of 1300 m and the lowest value of 1.92 mm per year at the highest elevation of 2500 m. The first-order correlation coefficient with chronology master was approximately 0.5. The autocorrelation value was 0.62 (Table 1), showing a time-lag effect, which became more apparent at higher altitudes. The sensitivity ranges from 0.368 to 0.458, indicating that the tree growth was sensitive to the climate variation. Six detrended chronologies of tree ring width were developed (Fig. 4). The reliable time (EPS > 0.85) spans from 1960 to 2017. The inter-correlations of TRWI are between 0.3 and 0.83,

Table 1
Six sampling sites chosen for study.

Sample site	Altitude (m)	Time sequence	Mean sensitivity (MS)	Correlation with master	First-order autocorrelation (AC1)
A1	1300	1958–2016	0.424	0.506	0.573
A2	1500	1940–2016	0.368	0.496	0.517
A3	1700	1945–2016	0.458	0.483	0.695
A4	1900	1941–2016	0.395	0.368	0.649
A5	2200	1944–2016	0.386	0.482	0.66
A6	2500	1949–2016	0.43	0.514	0.687

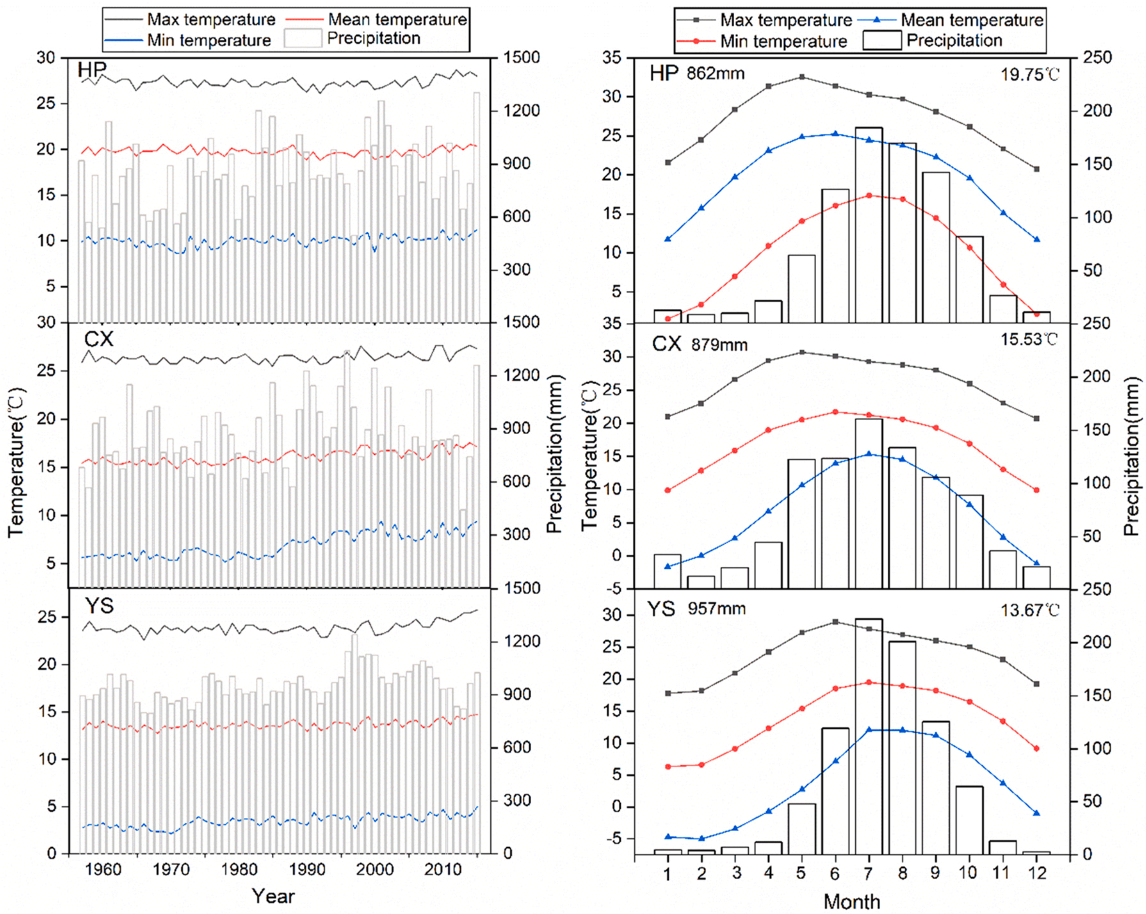

Fig. 2. Monthly and yearly temperatures and precipitation at three meteorological stations, namely Huaping (HP; 1230 m), Chuxiong (CX; 1800 m), and Yongsheng (YS; 2130 m).

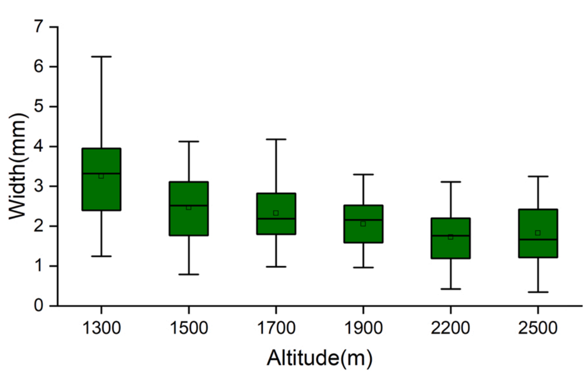

Fig. 3. Tree-ring widths at different altitudes.

implying strong common signals in the samples. Fig. 4 shows the results of six standardized chronologies. The width of rings at 2500 m fluctuated less than that at sites at other altitudes.

3.2. Relationship between radial growth of Pinus yunnanensis and climatic factors

The correlation between individual TRWI and climatic factors changed with the altitudes (Fig. 5). The correlation of five climatic variables, namely T_{mean}, T_{max}, T_{min}, precipitation, and SPEI, with the chronologies was analyzed at different altitudes. T_{mean} of February - August affected tree growth negatively at altitudes of 1300–1500 m (mean R=−0.28, $p < 0.05$) and 2200–2500 m(mean R=−0.25, $p < 0.1$), whereas at 1700–1900 m, T_{mean} of October-April affected tree growth positively (mean R=0.21). May-June temperatures had significant negative effects on tree growth at all altitudes (mean R =−0.31, $p < 0.05$). Whereas the impact of October temperature in the previous year on tree growth was negative at low altitudes but positive at high altitudes. From July to October, the correlation coefficient decreased progressively, indicating a matching decrease in the influence of temperature during the growing season. Both T_{max} and T_{mean} had the same effect on tree growth, whereas T_{min} and the T_{mean} at 1700–2200 m had the opposite effect. Precipitation showed a time-lag effect on tree growth: it showed a significant positive effect on that tree growth in May, as did of a given year was significantly affected by the amount of precipitation in October of the previous year. The chronologies and SPEI were also significantly and positively correlated, especially during the growing season from May to August. In addition, the correlation coefficients of the chronologies with SPEI were higher than those of the single variable of precipitation and temperature. SPEI was an integrated indicator influenced by both precipitation and temperature. These results provided further evidence that the radial growth of *P. yunnanensis* was severely affected by moisture availability, especially in May and the dry season.

3.3. Stability of radial growth to climate factors over time

To explore changes in the correlations between the growth of *P. yunnanensis* and climate factors over time, we used the TRWI to make a 30-year moving correlation with April-July monthly climate variables, which were crucial for tree growth over the entire period from 1957 to

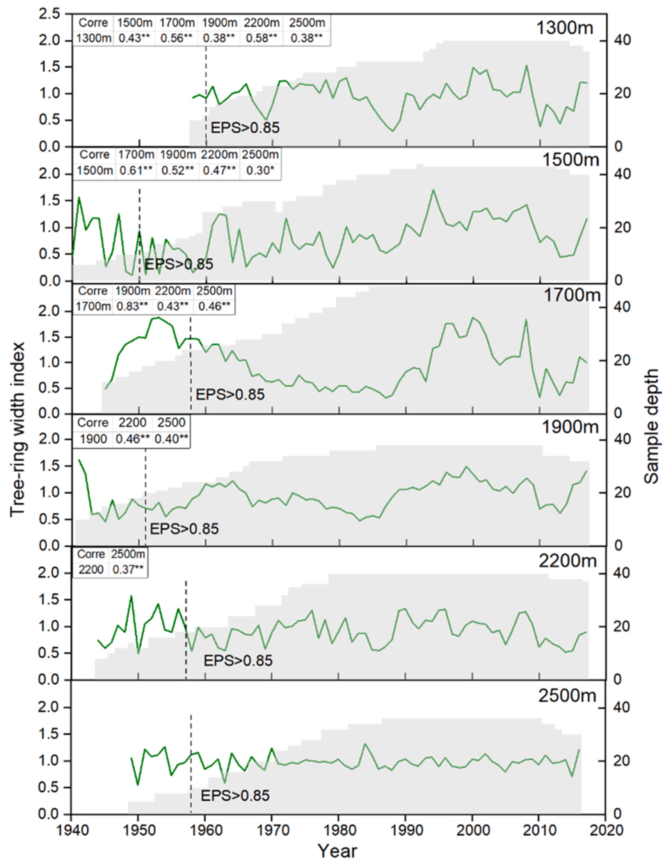

Fig. 4. Standard chronologies along the altitudinal gradient. The green curves and gray areas correspond to the tree ring width index and the sample depth, respectively. EPS is express population signal.

2016 (Fig. 6). The results showed that the influence of temperature on the growth of trees was increasing gradually at low (1300–1500 m) and high altitudes (2200–2500 m), and the effect of temperature on growth at middle altitudes (1700–1900 m) was adverse over time. The impact of precipitation was relatively stable at low altitudes (1300–1500 m), whereas at mid altitudes (1700–1900 m), the impact of precipitation on tree growth increased over time. At high altitudes (2200–2500 m), the relationship of chronologies with June-July temperatures became stronger, whereas precipitation gradually showed a negative impact on tree growth. Temperature and precipitation in May and June produced significant transient responses, which varied markedly within the 60-years. The relationship between SPEI and chronologies showed that the impact of drought on tree growth was gradually increasing. The increasing trend at low and mid altitudes was more obvious, whereas at high altitudes, the relationship between drought and chronology became relatively stable. In arid-hot valley, moisture played a decisive role in the growth of *P. yunnanensis* in the arid-hot valley.

4. Discussion

4.1. Characteristics of tree ring radial growth at different altitudes

Tree growth is closely related to some variables of their ecological environment such as temperature and moisture (Fan et al., 2009; Li et al., 2012). Topography is the crucial factor that determines the spatial water and heat variability in regional scale (Adams et al., 2014; Wason and Dovciak, 2017). The tree growth trend has different response on climate at different altitude sites. The decline in annual average temperature at higher altitudes (the adiabatic lapse rate) was 0.67 ℃ for every 100 m increase in altitude, and the rate of decline in the width of tree rings tree was 0.18 mm for every 1 °C decrease in temperature. These factors may result in narrower tree rings as the altitude increases and could also reduce the diversity of plants and other communities by affecting their metabolic processes and ecosystem dynamics (Mayor et al., 2017). The main peaks and troughs from standard chronologies (Fig. 4) were consistent at the altitudes of 1300–1900 m, indicating that those trees had been subjected to the same climate events. For example, during 2009–2010, a severe drought in Yunnan province (Yang et al., 2012) led to a marked decline in growth in 2009–2010, the magnitude of the decline decreasing as the altitude increased. The width of the tree rings is narrower at higher altitudes than at lower altitudes, this is because lower temperatures at high altitudes limit the physiological metabolic processes of trees (Gou et al., 2004; Kharal et al., 2014). This characteristic variation reflects the influence of the vertical zonation of climate on the radial growth of trees. At the same time, the amplitude of the chronologies is smaller at higher elevations than at lower elevations, which means that the climate at higher altitudes was more stable (Liu et al., 2007). To explain the fluctuation in the chronologies decreased along altitude, Qiang et al. (2003) analyzed the stomatal density and dry weight of *Picea crassifolia* needles and found that values of both the variables increased as the altitude increased, indicating that *P. crassifolia* could maintain a lower level of metabolism at higher altitudes. This might be an adaptive mechanism to minimize the impact of environmental changes. The observations demonstrated that changes in the environment could alter the ecological adaptation strategies of plants. The first-order autocorrelation coefficient values were all high and showed a gradual increase with elevation, indicating that the annual stand growth in this study area was strongly influenced by climate change in the previous year, especially in the high elevation areas (Peng et al., 2015). This means that growth is becoming more sensitive to variations in photosynthetic production as altitudes increasing.

4.2. Key factors influencing radial growth

Large-scale studies have shown that the sensitivity of forests to ambient environmental conditions was different depending on the altitude (Babst et al., 2013; Yang et al., 2017). Although the same species spanned large altitude gradient, the *P. yunnanensis* grew in different climate types. Low altitude areas are typical dry and hot areas, while high altitude areas are typical humid alpine areas. The mean temperature of M1-M8 affected tree growth at high and low altitudes negatively, whereas the mean temperature of P10-M4 affected tree growth at medium altitudes positively. Bai et al. (2019) also found that temperature in the winter season (October to February) was positively correlated with larch growth in low- and high-altitude stands, but negatively correlated with growth at medium altitude. The mid altitudes were the region of transition in which the adaptation mechanism of trees to temperature changed with the altitude (Chapman et al., 2013). The temperature difference between high altitude and low altitude can be seen from the weather station data (Fig. 2). The average annual temperature in the valley is about 20 ℃, while the average annual temperature in high-altitude areas is 13 ℃ or even lower. Tree growth was limited by the higher temperatures at lower altitudes and by the lower temperatures at higher altitudes whereas growth was favored by the optimal temperatures at mid altitudes. At all altitudes, precipitation during the early growth period (May to June) was the most important period for tree growth, this effect also showed a significant time lag (Fan et al., 2008; Wang et al., 2013), especially in showing the impact of precipitation in October of the previous year. With the increase in altitude, the months of restricted growth gradually moved forward. At 2500 m, the temperature in June and July became the key factor. This result was consistent with the earlier research (Fan et al., 2009), which reported that radial growth of fir was enhanced by normal or warm summer temperatures (June and July) during the current growing season. After July, the relationship between tree growth and climate weakened slightly because earlywood represents the onset of cambium

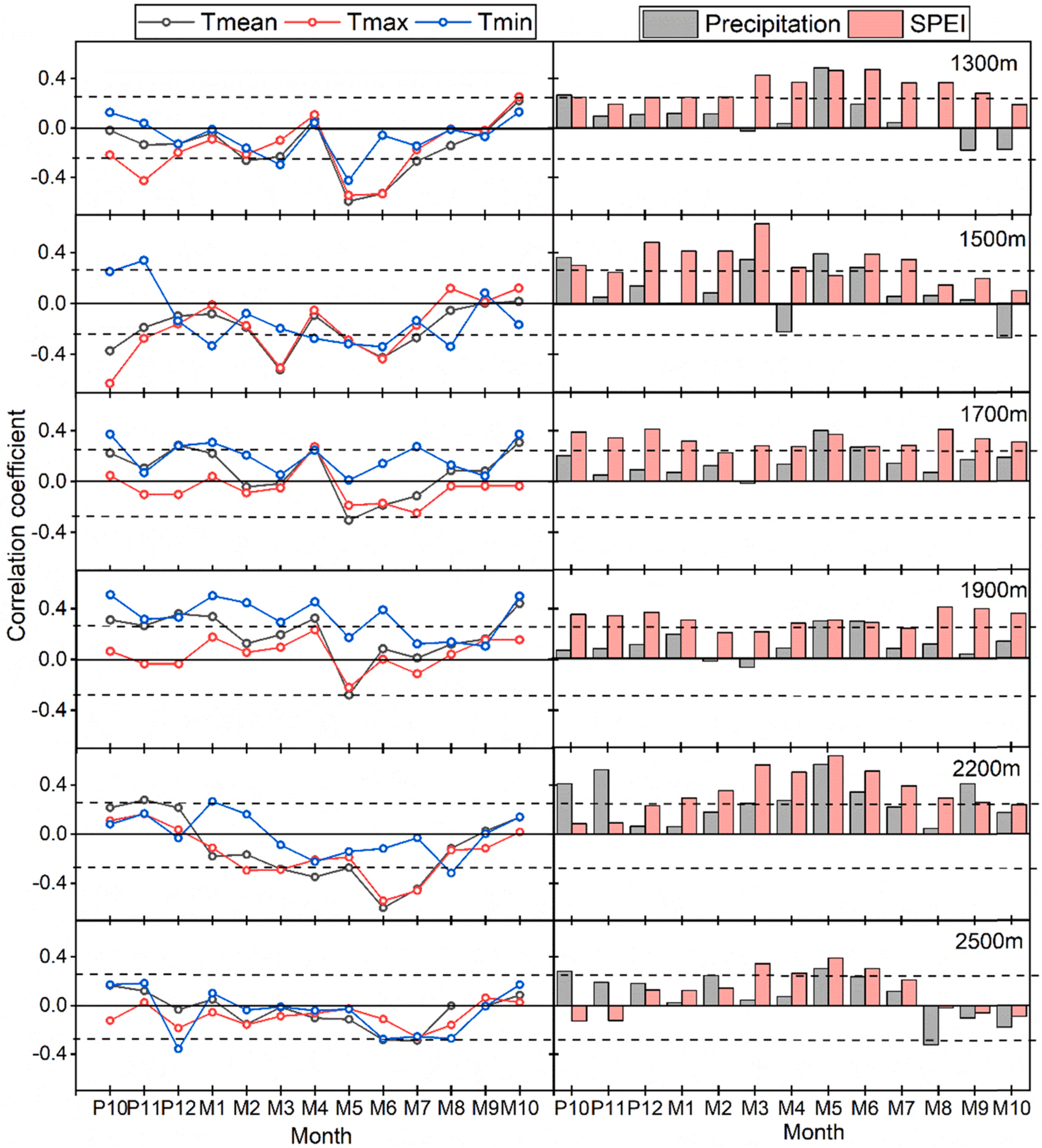

Fig. 5. Correlation between six chronologies at different altitudes and monthly climate factors from the previous October to current October for the period 1957–2016. The dashed lines represent 95% confidence intervals.

activity in spring, and earlywood accounts for 60%– 85% of the width of the entire tree ring (Fan et al., 2009; Zhao et al., 2012). Therefore, the correlation between growth and climate elements in May and June was high but gradually weakened as the growth continued (Zhang et al., 2012). The correlation between TRWI and SPEI in the growing season was positive, indicating that precipitation in this area had a greater impact on vegetation (Bauwe et al., 2015; Shekhar et al., 2018). Generally speaking, altitudinal trends resulted in different limiting factors on radial growth of *P. yunnanensis* in arid-hot valley.

4.3. Effect of climate change on the response stability at different altitudes

Tree rings are the most valuable materials and widely applied to reflect the history climate information at the millennium scale (Carrer and Urbinati, 2006). The 'uniformitarian principle' states briefly that the relationship between tree growth and limiting climate factors is stable over time (Fritts, 1976). However, the temporal stability of radial growth in response to climate change has been contradictory (Zhang et al., 2003; Wilmking et al., 2004; Wang et al., 2017). The results of our study showed that the stability of limiting factors varied with climate warming, which was also supported by the monthly moving correlation variables in growing seasons. Similar phenomena have been revealed widely in the mid-to-high latitudes of the Northern Hemisphere since the mid-20th century (D'Arrigo et al., 2008; Kurz-Besson et al., 2016; Jiao et al., 2019). The warming effect in different climate zones would lead to different level changes of climate factors and further influence the sensitivity of tree growth (Peterson and Peterson, 1994; Guo et al., 2016). A warming trend might trigger a shift in response to climate factors via a type of threshold mechanism (D'Arrigo et al., 2008; Gai et al., 2017). The radial growth sensitivity in our study in growing season showed a step-wise increase at different altitudes, because higher temperatures led to greater evaporation of soil moisture and thus to increased moisture deficit in arid regions (Suarez et al., 2015) and also increased the rate of transpiration, exceeding the critical point of water deficit (Zscheischler and Seneviratne, 2017). Thus, the limiting effect of temperature on the tree growth has gradually increased. As

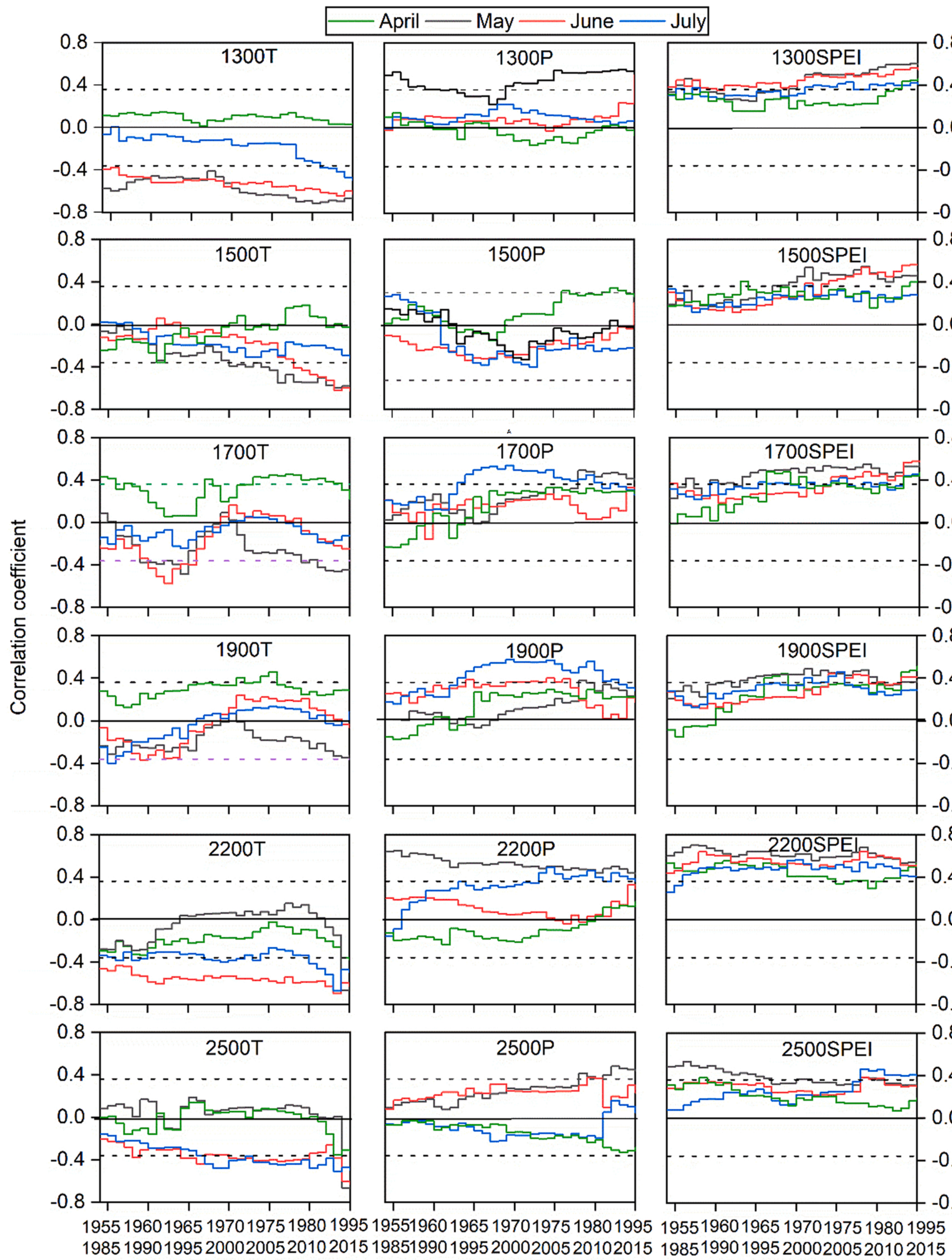

Fig. 6. Moving correlations over 30 years of tree ring width index and monthly climate variables for the most important months (April-July) during 1957–2016. The dashed lines represent 95% confidence intervals.

temperatures rising, trees need more water to maintain their growth, the increase in rainfall caused by climate change increased the correlation between the chronology and rainfall (Yu et al., 2005; Li et al., 2011; Zhang et al., 2016). Equilibrium was reached between the adaptation of trees to water deficit and higher temperatures, and the rising temperatures made the role of precipitation in tree growth increasingly critical (Stahle et al., 2016; Wang and Yang, 2020). The increasing correlation between SPEI and TRWI also emphasized the increasing effect of drought on tree growth. At present, the mechanism of such divergence is not clearly understood (Driscoll et al., 2005; Primicia et al., 2015). Some studies have demonstrated that sensitivity to climatic factors varies with tree species or the age of trees (Yu et al., 2008; Hart, Laroque, 2013). The average age of *P. yunnanensis* was about 40–50 years after 2000, and they were markedly more sensitive to temperature and precipitation. Yu et al. (2008) found that older (and larger) trees were more sensitive than younger (and smaller) trees to temperature because of the larger canopies of the older trees, which meant greater exposure to weather elements. Rozas et al. (2009) showed that sensitivity to weather elements decreased with age in *Juniperus thurifera*, 50- to 100-year-old trees being the most sensitive. By all accounts, this divergence phenomenon was mainly because of the difference between climate warming and the ability of plants to adapt to the changing environment. And the other factors impact on this divergence phenomenon like air pollution, local hydrological conditions should also be considered in the future (Wilson and Elling, 2004; McLaughlin et al., 2007).

5. Conclusions

Based on *Pinus yunnanensis* growth trends and current growth-climate response patterns, we identified contrasting growth-climate responses of forests along the altitudinal gradient in the Hengduan Mountains. As the elevation increased, tree rings and the amplitude of changes in their width became gradually narrower. In the arid-hot valley, precipitation and temperature in May and June (initial stages of growth) played a decisive role in growth. After June, radial growth became marginally less sensitive to climate. The effect of temperature on the radial growth of *P. yunnanensis* varied with the altitude: growth was limited at both low and high altitudes from February to August, whereas radial growth was positive with the temperature from October to April at mid altitudes region. Besides, we also proved that precipitation had a distinct time-lag effect on tree growth. The impact of climate change on the radial growth of *P. yunnanensis*, ascertained from time series data, indicated that growth became increasingly sensitive to climate as the trees aged. At low or high altitudes, the negative impact of temperature on tree growth increases gradually whereas at mid altitudes, the influence of precipitation increases gradually. The relationship between TRWI and SPEI indicated that growth of *P. yunnanensis* became more sensitive to moisture and is increasingly temperature restricted. The change in the growth-climate relationships was the result of plants adapting to climate change. A future study on the response of vegetation growth to climate change at different elevations is necessary because the montane ecosystem needs ongoing attention, and the study will be of great significance in enlightening the pattern of vegetation succession in mountainous areas and global carbon storage.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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