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ORIGINAL PAPER

Variability in the climate-radial growth correlation of *Pinus massoniana* of different diameter classes

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Abstract The physiological characteristics of trees change with age, suggesting that growth-related climate signals vary over time. This study aimed to clarify the impacts of different diameter classes on the chronological characteristics of *Pinus massoniana* Lamb. and its response to climatic factors. Chronologies of *Pinus massoniana* were established in small diameter (14.1 cm), middle diameter (27.3 cm), and large diameter (34.6 cm) trees according to dendrochronology. The results show that: (1) radial growth of different diameter classes had varied characteristics and climate sensitivities; (2) radial growth of small diameter trees was affected by climatic factors of the previous and the current year, while large diameter trees were mainly affected by climatic factors of the current year; and (3) precipitation and temperature were key factors that restricted the radial growth of small and large diameter trees, respectively.

Keywords Radial growth · Climatic factors · *Pinus massoniana* · Diameter class

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Introduction

Observations and several important climate system indicators suggest that climate will continue to warm (Arnell et al. 2019). Climate affects the growth of trees by acting on physiological processes (Landsberg 1986), as demonstrated in terms of ring width changes (Fritts 1976). Tree rings are widely used in global climate change studies because of their accuracy and continuity, their seasonal or annual resolution, and their sensitivity to environmental changes (Fritts 1976; Cook et al. 2004; Babst et al. 2018; He et al. 2019).

Radial growth changes because of the combined effects of environmental factors, such as climate change, and by physiological mechanisms, such as tree size (Wilson et al. 2007; Rozas et al. 2009; Vieira et al. 2009). In dendroecological studies, dominant or average sized trees with large diameters at breast height (DBH), and are located in the upper canopy, are selected as samples to reduce the rate of tree-ring deficiencies and the impact of competition of surrounding individuals (Chhin et al. 2008). A series of detrending methods is used to eliminate growth trends related to physiological factors such as age, and to retain external information such as climate reflected in tree rings (Fritts 1976; Cook 1990). With growth trends removed, the correlation between tree-ring width and climate is no longer affected by age and diameter class. Trees of different ages and diameter classes should respond consistently to the climate over a given time series (Cook 1990; Melvin and Briffa 2008). However, some physiological studies have shown that age and diameter classes have significant effects on several physiological processes (Vieira et al. 2009; Wang et al. 2009). Climatic factors control radial growth by affecting these processes (Fritts 1971; Offermann et al. 2011; He et al. 2017), suggesting that the correlation between radial growth and climate may be related to tree age and diameter class.

Only a few studies have investigated the influence of age and diameter on the correlation between radial growth and climate, and no clear conclusion has been reported (Zhao et al. 2016; Babst et al. 2018; He et al. 2019). It has been reported that the sensitivity of *Pinus pinaster* Ait., *Pinus sylvestris* L. ≤ 40 years, and *Picea glauca* (Moench) Voss to climate change is positively related to age and DBH (Szeicz and Macdonald 1994; Linderholm and Linderholm 2004; Vieira et al. 2009), while the sensitivity of *Larix decidua* Mill., *P. sylvestris* > 250 years, and *Pinus cembra* L. is negatively correlated with age and DBH (Carrer and Urbinati 2004; Linderholm and Linderholm 2004). In addition, studies on *Pinus aristata* Engelm., *Picea abies* (L.) H. Karst., and *Larix lyallii* Parl. have shown that age is not correlated with climate (Fritts 1976; Pilcher et al. 1984; Colenutt and Luckman 1995; Wilson and Elling 2004). A limited number of studies have been conducted in China on the influence of age and diameter on chronology (Wang et al. 2011). A literature review only identified relevant studies on *Pinus tabuliformis* Carrière, *Picea schrenkiana* Fisch. & C.A.Mey., *Picea purpurea* Mast., *Larix gmelinii* (Rupr.) Kuzen., and *Pinus koraiensis* Siebold & Zucc., which are distributed in the eastern Qilian Mountains, on the Tianshan Mountains, in the subalpine area of western Sichuan, the northern Daxing'an Mountains, and the north slope of Changbai Mountain, respectively (Wang et al. 2009, 2011; Wu et al. 2013; Zhang et al. 2013; Zhao et al. 2016), but the results are inconsistent. Therefore, it is important to explore whether there is a rational and stable correlation between climate and the radial growth of trees of different diameters and ages (Liu et al. 2018; Zhang et al. 2018).

Pinus massoniana is an important coniferous species in the subtropical monsoon climate regions of China (Wang et al. 2010). A dendrochronological analysis of the radial growth of different diameter classes of *Pinus massoniana* was carried out to reveal differences in chronological characteristics and growth patterns and determine the main climatic factors limiting radial growth. The findings will provide a basis for managing *Pinus massoniana* stands and for the in-depth development of dendroecology.

Materials and methods

Study area

The study area was located on a state-owned forest farm in Jiangle County (26°26′–27°4′ N, 117°05′–117°40′ E) with a subtropical monsoon climate (Fig. 1). The mean annual temperature during the period of 1980–2017 was 19.3 °C, with a minimum temperature of –6.7 °C in January and a maximum of 41.7 °C in July. The mean annual precipitation was 1781 mm, mainly concentrated in March–September, accounting for 79.6% of the yearly precipitation. The average elevation in this area is 400–800 m and there is no obvious vertical distribution of vegetation. *Pinus massoniana*, *Cunninghamia lanceolata* (Lamb.) Hook., and *Phyllostachys edulis* (Carrière) J.Houz. are widely distributed as dominant tree species.

Sample collection and development of chronology

The sampling sites were set up at an altitude of 250 m in July 2018 in the main distribution area of *Pinus massoniana* free from human disturbance (Fig. 1). According to International Tree-Ring Data Bank (ITRDB) standards (Grissino-Mayer and Fritts 1997), samples of three different diameter classes were taken at breast height (1.3 m). One core was taken from each tree to reduce damage; more than 65 core samples were taken in each diameter class. There were 89, 85 and 121 cores in the large diameter (LD), middle diameter (MD), and small diameter (SD) classes, respectively (Table 1). The cores were packaged in special paper tubes and marked with the sampling site, sampling time, tree number, core number, DBH, tree height, and other information about the growth conditions (Cook 1990).

The collected samples were mounted and polished until the rings were easily distinguished. The tree rings were visually cross-dated under a binocular microscope (Cook 1990) measured using a LIN-TAB^{Tm} 6.0 with a precision of 0.01 mm. The ring-width series was examined with COFECHA software and errors were corrected following microscopic examination of the tree-ring characteristics (Holmes 1983). Poor quality samples that could not be cross-dated were excluded. A total of 36 cores in the SD class, 35 in the MD class, and 43 in the LD class were used to establish the tree-ring chronologies (Table 1). Using the ARSTAN program (Cook and Krusic 2005), the spline function method with a step length of 5 was selected to remove the interference of the growth trend and non-climatic factors. The standard chronologies (STD), residual chronologies (RES), and autoregressive chronologies (ARS) of the different diameter classes were established. The standard chronologies were used in the present study, considering the statistical characteristics and the quality of the chronologies (Fig. 2).

Meteorological data

Meteorological data were collected from the Jiangle Meteorological Station (26°44′ N, 117°28′ E, 173.9 m) (Fig. 1). Distances from the station to the three sampling sites were 5.6 km for A, 2.0 km for B, and 2.0 km for C. The data included mean monthly temperatures, extreme maximum and minimum temperatures, monthly precipitation, and relative humidity from 1980 to 2017 (Fig. 3). The standardized precipitation-evapotranspiration index (SPEI) was

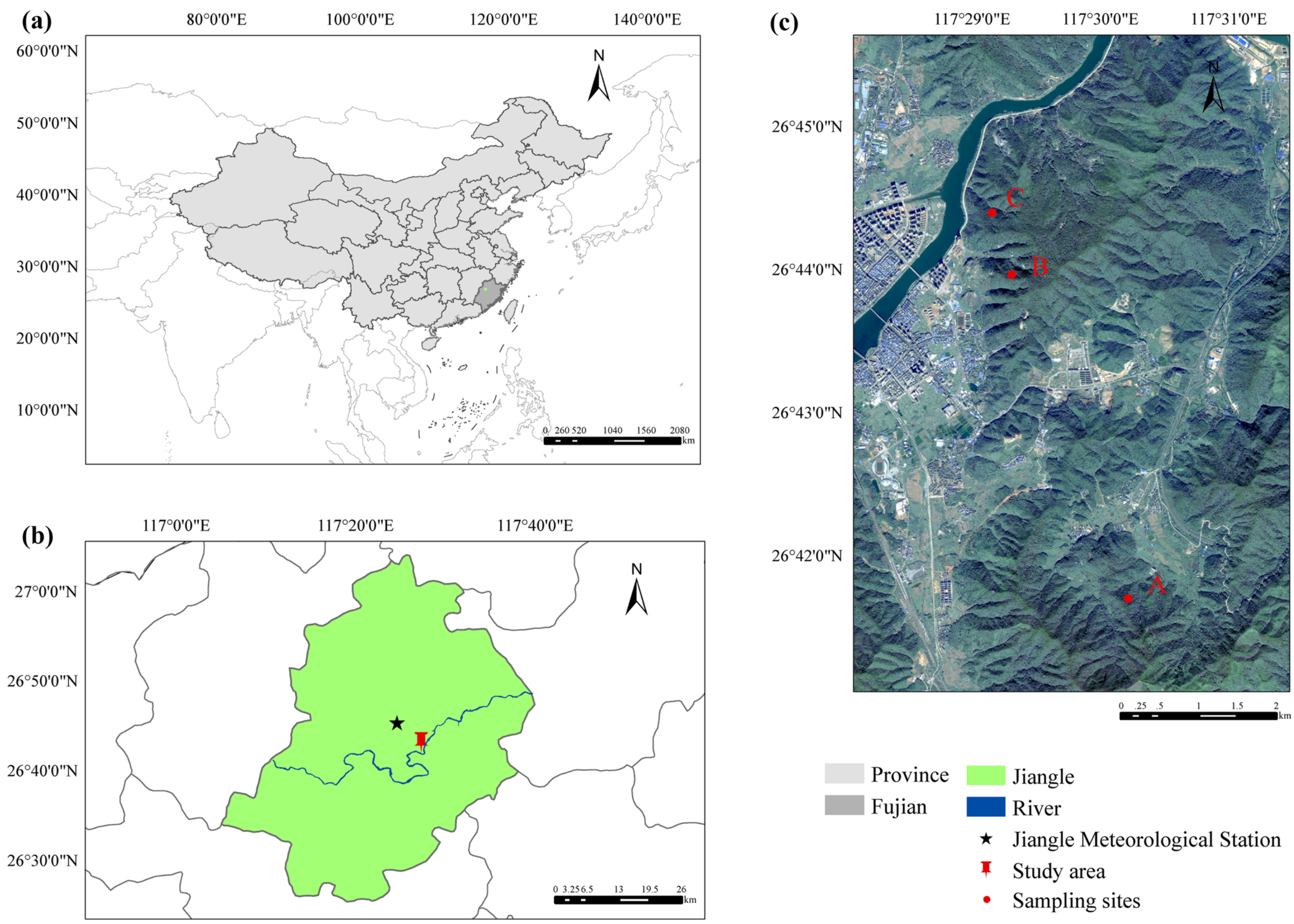


Fig. 1 **a** Location of the study area; **b** the nearest meteorological station; **c** distribution of the sampling sites; Description of sampling sites: A (26°41′42″ N, 117°30′12″ E, 260 m), B (26°44′15″ N, 117°29′10″ E, 270 m), C (26°44′24″ N, 117°29′09″ E, 265 m)

Table 1 Characteristics of tree-ring samples

Category	Range of DBH (cm)	Total samples		Samples for chronology	
		Average DBH (cm)	Sample number	Average DBH (cm)	Sample number
Small diameter	5 – 20.9	14.1 ± 0.3	121	15.3 ± 0.6	36
Middle diameter	21 – 30.9	27.3 ± 0.4	85	26.9 ± 0.5	35
Large diameter	≥ 31	34.6 ± 0.3	89	34.8 ± 0.5	43

Average DBH (cm) are expressed as mean ± SE

calculated using the spei.exe program based on the temperature and precipitation data (Vicente-Serrano et al. 2010). The Mann–Kendall test (Kendall 1990) and the double-mass method (Kohler 1949) were used to check data homogeneity. The results showed that the data were sufficiently uniform to represent the basic characteristics of the climate.

Considering the growth characteristics of *Pinus massoniana* in the study area and the lag effect of climatic factors on growth (Bao et al. 2007), data from January of the previous year to December of the current year were selected for analysis. Annual climate data were divided into four seasonal stages based on the cumulative and long-term effects of climatic factors (Churakova et al. 2016), the growth rhythm of *Pinus massoniana* (Zhang et al. 2017), and the mean monthly and extreme minimum temperatures in this region. The seasonal stages were the dormant period (DP, January to February), the beginning of the growing season (BG, March to April), the growing season (GS, May to October), and the

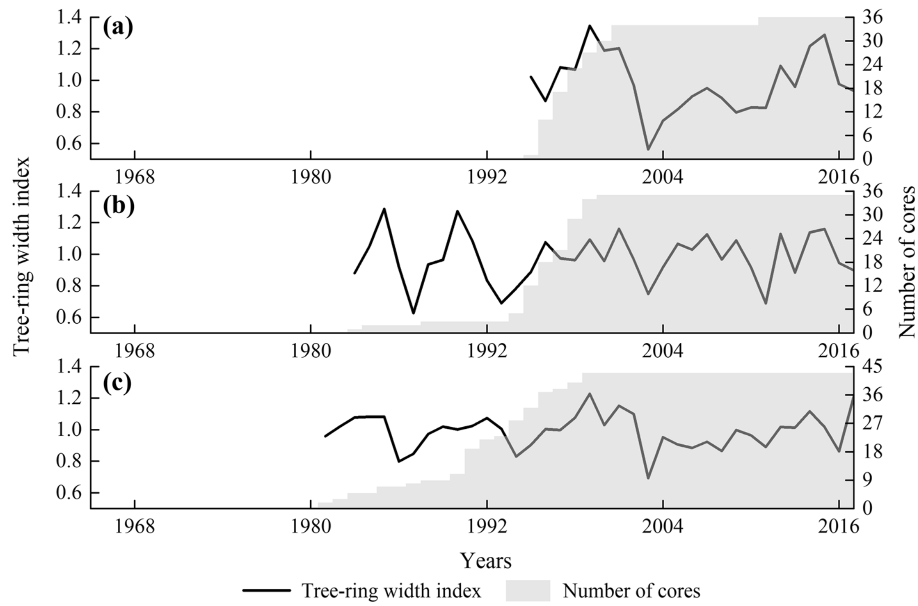


Fig. 2 Standard chronologies of *P. massoniana* at different diameter classes. **a** Small diameter; **b** middle diameter; **c** large diameter

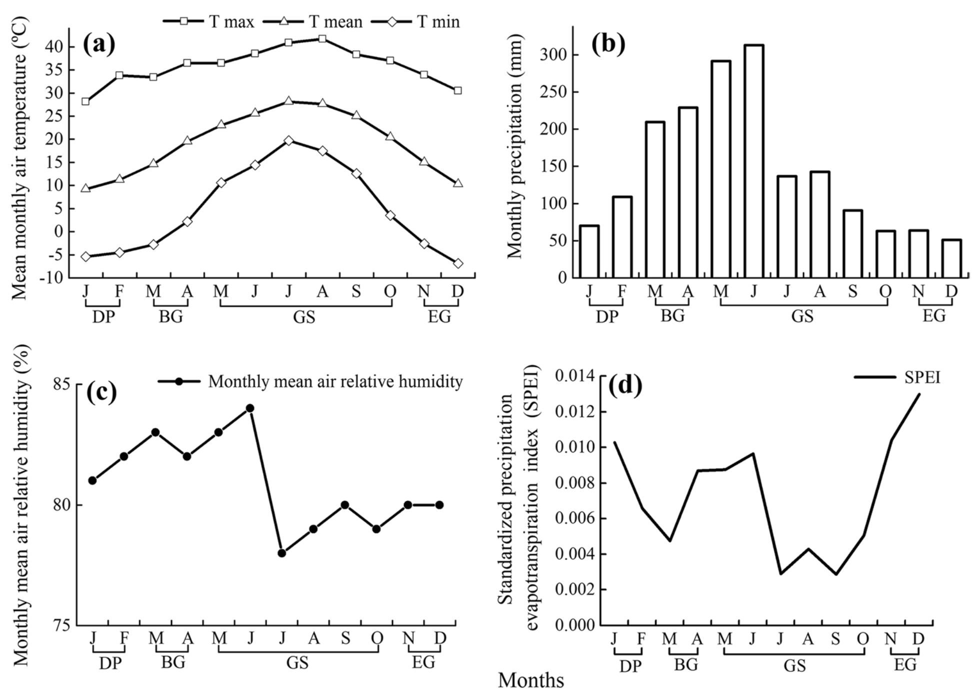


Fig. 3 Meteorological data of the research area from 1980 to 2017. **a** mean, minimum and maximum temperature; **b** monthly precipitation; **c** air relative humidity; **d** SPEI; DP: dormant period; BG: beginning of the growing season; GS: growing season; EG: end of the growing season. Abbreviation of four seasonal stages, the same below

end of the growing season (EG, November to December). The climate data for each stage were calculated from the monthly climate data (Fig. 3).

Statistical analysis

Correlations between the chronologies were analyzed with Pearson's correlation coefficient analysis in SPSS 20.0 software (SPSS Inc., Chicago, IL, USA). The trend and mutation characteristics of radial growth were analyzed with the Mann–Kendall test. The periodic changes in radial growth were described on multiple time scales by wavelet analysis (Addison 2002). The response and correlation analyses between the standard chronologies and the seasonal climatic factors were carried out using DENDROCLIM 2002 (Biondi and Waikul 2004). The correlation between the radial growth of *P. massoniana* and the climatic factors was further examined through redundancy analysis using CANOCO 5.0 software (Ter Braak and Smilauer 2012). A multiple linear regression analyses was carried out in R software (The R Foundation for Statistical Computing, Vienna, Austria) to establish the optimal multiple regression models for growth and climatic factors of the different diameter classes.

Results

Chronological statistical characteristics

The correlation coefficients between the chronologies of the SDs and the MDs, the MDs and the LDs, and the SDs and the LDs were 0.579 ($p<0.01$), 0.460 ($p<0.05$), and 0.689 ($p<0.01$), respectively. The chronology lengths of the LDs, MDs and SDs were 37, 35 and 23 years, respectively. There was no significant difference in the mean growth rate of the different diameter classes, with a mean growth rate of 0.981 $mm \cdot a^{-1}$. The mean sensitivity, standard deviation, and correlation between trees of different diameter classes were 0.1050–0.1860, 0.1120–0.1882, and 0.2050–0.3520, respectively. The first-order autocorrelation was 0.1522–0.5417 and the variation in the first eigenvector was 28.22–42.24%. The signal-to-noise rate of the SD chronology was 9.2410, while it was 4.8280 and 5.1650 for the MDs and LDs, respectively. The expressed population signals of the established chronologies ranged from 0.917 to 0.950, all of which reached an acceptable level of 0.85 (Table 2). These statistical characteristics show that the standard chronologies of the different diameter classes of *P. massoniana* established in this study were of good quality and sensitive to the climate.

Periodic variations in the tree-ring width index

The results of the nonparametric Mann–Kendall test for the tree-ring width index of the different diameter classes showed that the index trended upward in the SDs and MDs, with a Z-value of 0.78132 in the MDs. A downward trend was observed in the LDs, with a Z-value of -0.20928.

Multiple intersections of the progressive (UF) and the retrograde series (UB) curves were observed during the entire time, but the UF curves were almost all within the confidence limits ($\alpha=0.05$) (Fig. 4), indicating frequent changes in the radial growth of the different diameter classes, particularly around 2000 and after 2010, despite no mutations. As shown in Fig. 5, the SDs and MDs had significant 9–12 and 11–15 year periodic variations, while the LDs fluctuated on scales of 11–16 and 19–23 years.

Growth-climate correlations

Various climatic factors at the beginning of the growing season of the past year (PBG), during the growing season of the past year (PGS), the beginning of and the growing season, had significant effects on radial growth, particularly in the small diameter classes than during the other seasons (Fig. 6).

Table 2 Statistics of ring-width chronologies and common interval analysis

Category	Chronology length (a)	Mean growth rate (mm a^{-1})	Common intervals	Mean sensitivity	Standard deviation	Correlation between trees	First order autocorrelation	Signal-to-noise rate	Expressed population signal	Variation in first eigenvector (%)
Small diameter	23	0.9790	1998–2014	0.1860	0.1882	0.3520	0.5417	9.2410	0.9210	40.27
Middle diameter	35	0.9750	1997–2017	0.1485	0.1567	0.2440	0.1522	4.8280	0.9500	42.24
Large diameter	37	0.9890	1993–2013	0.1050	0.1120	0.2050	0.1753	5.1650	0.9170	28.22

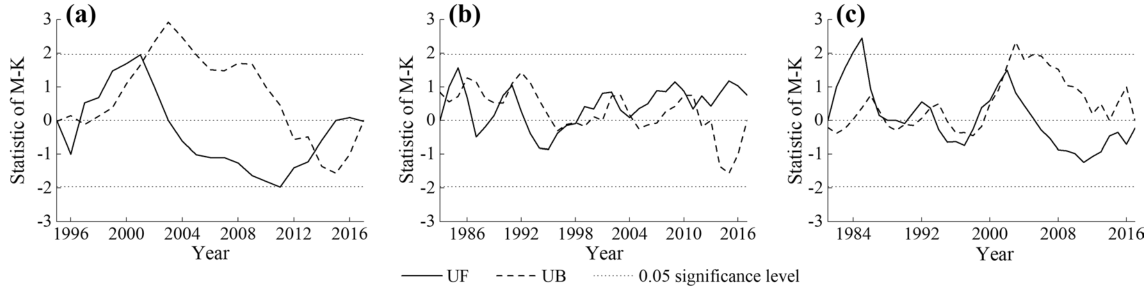


Fig. 4 Mann–Kendall mutation test curves for tree-ring width index; **a** small diameter; **b** middle diameter; **c** large diameter; the solid and short dashed lines represent the progressive series (UF) and the retrograde series (UB). Horizontal dotted lines are confidence limits (α = 0.05). The intersection of the UF and UB curves and between the confidence limits corresponds to the time the mutation began

Radial growth of the small diameter trees was significantly and positively correlated with the extreme minimum temperature in the PBG, the precipitation and the standardized precipitation-evaporation index (SPEI) in the beginning of the growing season, and the precipitation and relative humidity during the growing season. Moreover, the radial growth of the small diameter trees was significantly and negatively correlated with the extreme maximum temperature during the growing season, and significantly and positively correlated with the extreme minimum temperature at the beginning of the growing season and the SPEI during the growing season. Radial growth of middle-diameter trees was significantly and negatively correlated with the precipitation during the PBG, and significantly and positively correlated with the extreme minimum temperature in PGS. However, radial growth of large diameter trees was only significantly and positively correlated with the extreme minimum temperature at the beginning of the growing season.

Redundancy analysis of tree-ring width index and climatic factors

Redundancy analysis indicated that, among the 48 climatic variables in the eight growth stages, the climatic factors at the beginning and throughout the growing season of the previous and current year had the most significant effects on radial growth (Fig. 7a). The effects of precipitation in the previous growing season (PBG) were the strongest, followed by the SPEI at the beginning of the growing season (BG) and then the extreme maximum temperature during the growing season (GS). Specifically, precipitation during the PBG was positively correlated with the chronology of the small- and large-diameter trees but negatively correlated with the chronology of the middle diameter trees. SPEI during the BG, the extreme minimum temperatures in the PBG, BG, and PGS, and the relative humidity during the GS were all positively correlated with the three chronologies. SPEI at the beginning of the growing season (BG) and the extreme minimum temperature in PGS had stronger correlations with the chronology of middle diameter trees, while the other three climatic factors were more positively correlated with the chronologies of the other diameter classes. The extreme maximum temperature during the current growing season was negatively correlated with the chronology of each diameter class, with the chronology of the large diameter class being the strongest.

Among the 144 monthly climatic variables, nine had significant effects on the radial growth of the different diameter classes at different growth stages (Fig. 7b). The extreme maximum temperature in August of the current year had the most significant effect, followed by the mean temperature. Both were significantly and negatively correlated with the chronologies of the different diameter classes. The SPEI in August of the current year, the monthly precipitation in July of the current year, and the extreme maximum temperature in March of the current year all showed positive correlations with the three chronologies, with a decreased sequence of small, middle, and large diameter classes. The extreme maximum temperature during May of the current year was negatively correlated with the different diameter chronologies, and had the strongest negative correlation with the chronology of the middle diameter trees. The mean monthly temperature in October of the past year and the SPEI in April of the current year were positively correlated with the three chronologies. The extreme maximum temperature in July of the past year was negatively and positively correlated with the chronologies of the small and large diameter trees, respectively, but not with the middle diameter trees.

Simulation of the correlation between the growth of Pinus massoniana and climatic factors

The variance inflation factor of the coefficients for the established equations was > 0 and less than 10, indicating no multicollinearity among the explanatory variables in the models. The R-squared value and verification results of the equations were relatively high (Table 3). Without considering the effect of the climatic factors, the order

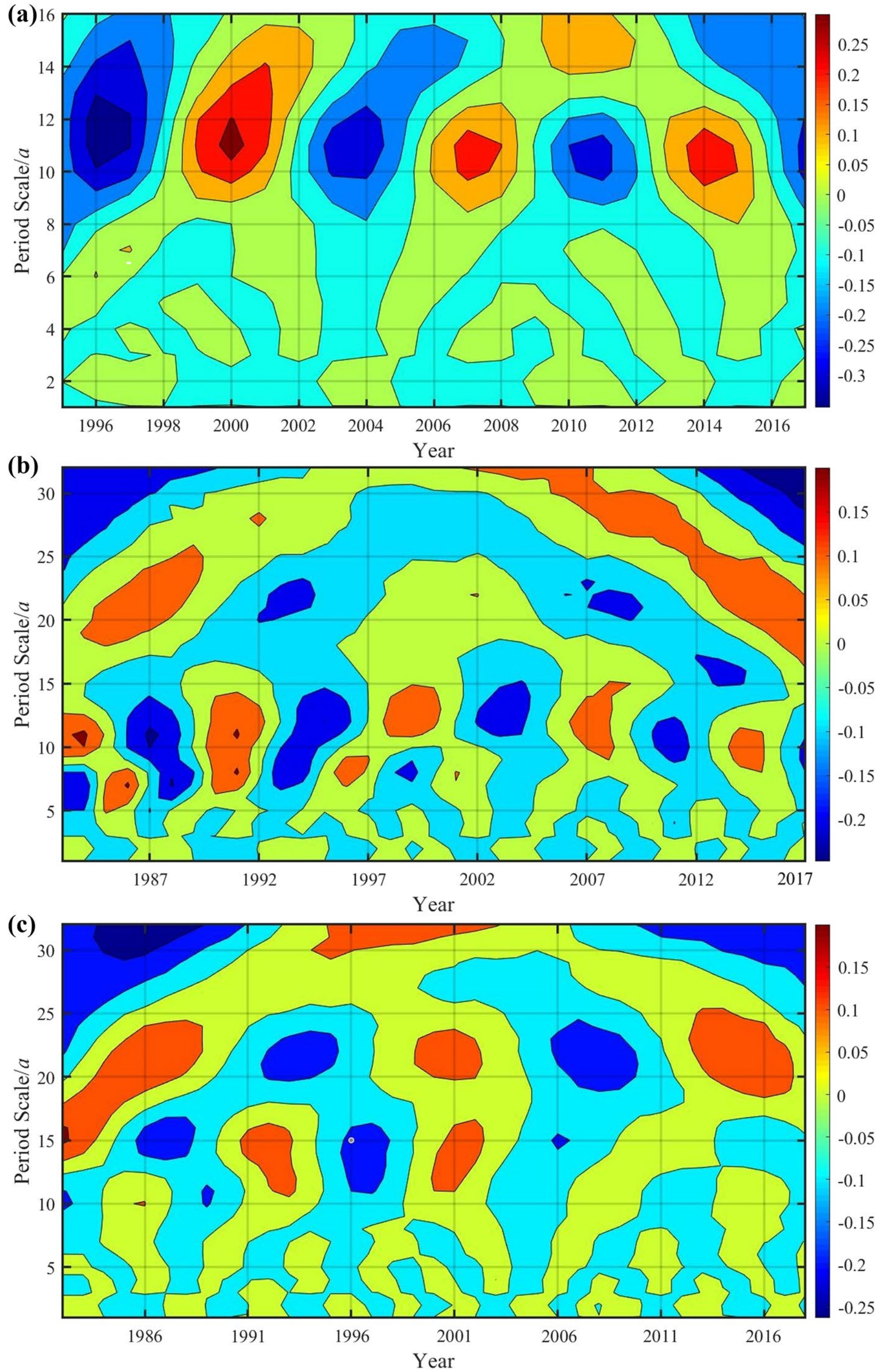
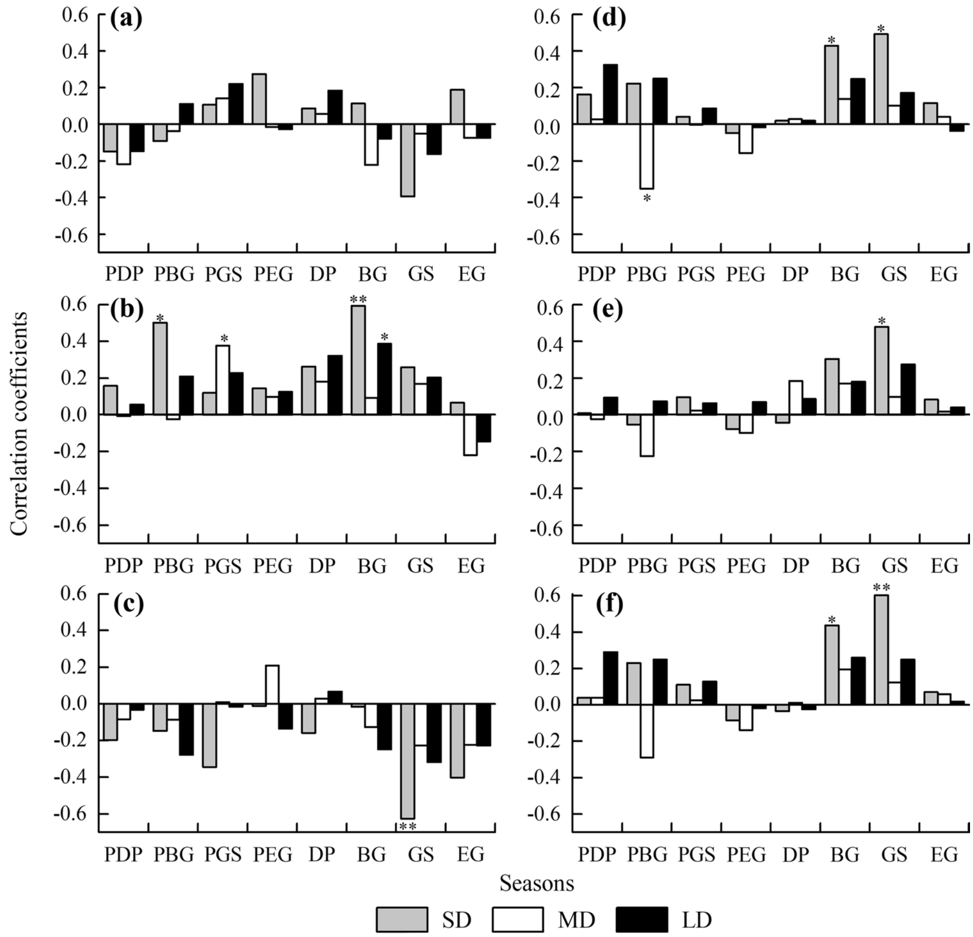


Fig. 5 Wavelet analysis of tree-ring width index of different diameter classes; **a** small diameter; **b** middle diameter; **c** large diameter

of the radial growth of the different diameter classes was middle, large and small, and tree-ring width index values were 0.976, 0.971 and 0.966, respectively. According to the Paris Agreement target to limit the global temperature rise within 2 °C in this century (IPCC 2019), only considering temperature change, global warming had the greatest impact on radial growth of the large diameter trees in this region, followed by the small and middle diameter trees, with increases of 28.0%, and decreases of 10.4 and 0.9%, respectively.

Fig. 6 Correlation coefficients between the standard chronologies of the different diameter classes of *P. massoniana* and seasonal meteorological factors; **a** mean temperature; **b** extreme minimum temperature; **c** extreme maximum temperature; **d** precipitation; **e** relative humidity; **f** SPEI; $*p < 0.05$; $**p < 0.01$



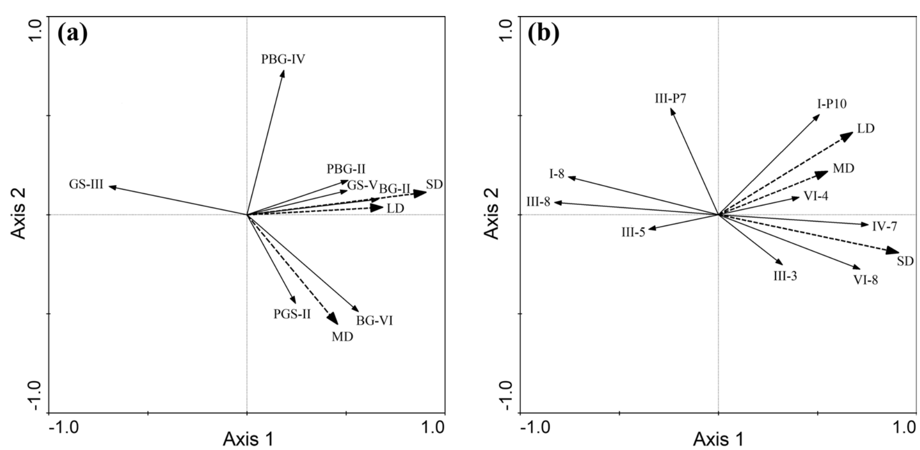


Fig. 7 Redundancy analysis for the standard chronologies of the different diameter classes (dashed vectors) and **a** seasonal & **b** monthly climatic factors (solid vectors) during 1980–2017. I: mean temperature; II: extreme minimum temperature; III: extreme maximum temperature; IV: precipitation; V: relative humidity; VI: SPEI. **a** The climatic factor for a specific seasonal stage was abbreviated "seasonal stage–seasonal climatic factor" (e.g. precipitation in PBG: PBG-IV). **b** P: past year. The climatic factor for a specific month was "monthly climatic factor-corresponding month" (e.g. mean monthly temperature in October of the past year: I-P10)

Table 3 Optimal multiple regression model for the growth of *Pinus massoniana* and climatic factors

Standard chronology	Optimal multiple regression equation	R^2	Verification results of regression equation	
			p	*r*
Small diameter	$Y = 0.96611 - 0.05011HL_8 - 0.20333P_8 + 0.31913S_8$	0.5771	0.000	0.797**
Middle diameter	$Y = 0.97664 - 0.07241A_4 + 0.06799L_6 - 0.06657SL_3 + 0.07396R_8$	0.6093	0.000	0.810**
Large diameter	$Y = 0.97100 + 0.04362AL_{10} + 0.05061L_3 + 0.05056L_5 + 0.03140PL_1$	0.4815	0.000	0.734**

*$p < 0.05$; **$p < 0.01$. HL_i: Extreme maximum temperature of the month *i* of the past year; P_i: Precipitation of the month *i* of the current year; S_i: SPEI of the month *i* of the current year; A_i: Mean temperature of the month *i* of the current year; L_i: Extreme minimum temperature of the month *i* of the current year; SL_i: SPEI of the month *i* of the past year; R_i: Relative air humidity of the month *i* of the current year; AL_i: Mean temperature of the month *i* of the past year; PL_i: Precipitation of the month *i* of the past year

Discussion

Effects of diameter on chronological characteristics

The climate sensitivity of trees varies over different diameter classes. This study confirmed that small diameter *Pinus massoniana* had higher chronological statistical parameters than that of large diameter trees and contained more climatic information. This suggests that small-diameter trees are highly climate sensitive and could be used to explore the impact of climate warming on this species. This is consistent with the results of similar studies on *Pinus koraiensis* at different latitudes (Liu et al. 2018), *Pinus tabuliformis* in Inner Mongolia and the Hunshandak sandy area (Jiang et al. 2012a, 2012b), and *Picea schrenkiana* in the Tianshan Mountains (Wang et al. 2016). All these studies show that small-diameter trees have complex climate-radial growth correlations. However, some studies have found a lack of correlation or a positive correlation between trees of different diameter classes and their sensitivity to climate (Fritts 1976; Szeicz and Macdonald 1994; Colenutt and Luckman 1995; Linderholm and Linderholm 2004; Wilson and Elling 2004; Vieira et al. 2009). This may be related to changes in environmental conditions, morphological structure, or physiological function of trees during growth (Wang et al. 2016).

Seasonal climate-growth response of the different diameter classes

The different diameter classes of *Pinus massoniana* showed various climate-growth response patterns during different seasons. The small- and middle-size trees were more susceptible to climatic factors of the previous year compared to large diameter trees, particularly at the beginning and during the growing season (Figs. 6, 7a). This is consistent with studies on the response of radial growth of different diameter classes of *Pinus koraiensis* to climate change carried out in Baishilazi, Shengshan, Liangshui, and Changbai Mountain Nature Reserves (Liu et al. 2018). The explanation may be that trees of different diameters are at different growth and development stages and their physiological functions and nutritional requirements are different (Wang et al. 2011). Most small diameter trees are in a period of rapid growth (Wu et al. 2011), and the accumulation of nutrients and energy the previous year has a strong effect on radial growth during the current year. Large diameter trees are often in a stagnated growth stage and are less affected by climatic factors of the previous year, as their physiological activities are slower (Cui et al. 2014). Variability in the seasonal climate-growth response emphasizes the necessity to consider the cumulative and long-term effects of climatic factors in tree-ring studies, particularly when studying the small and middle diameter classes.

Key monthly climatic factors affecting radial growth

The type and extent of the impact of monthly climatic factors on the radial growth in different diameter classes varied among months. Radial growth of small diameter trees was strongly and positively correlated with precipitation in July, and the standardized precipitation-evaporation index (SPEI) in April and August of the current year (Fig. 7b). This was attributed to the intense competition amongst trees caused by rising heat and moisture stresses (Fig. 3). Large diameter trees with deep roots are less restricted by rainfall than are small diameter trees with shallow root systems and rely on rain to obtain water (Kloeppel et al. 1993; Jiang et al. 2012b). This is similar to the results of studies on radial growth response to climate of small-diameter *Pinus tabuliformis* in Heilihe Nature Reserve and small-diameter *Picea schrenkiana* in the mountainous area of the Central Tianshan Mountains (Jiang et al. 2012b; Wang et al. 2016).

The different diameter classes of *Pinus massoniana* were distributed in different layers where micro-environmental conditions vary considerably spatially. Large diameter trees were located in the main story or upper canopy, where solar radiation is strongest, wind speed higher, and vapor pressure lower. In contrast, the small diameter trees grew in the understory where ambient temperatures were relatively stable and humidity high. The maximum temperature of the understory during the day was lower than that of the main story, and the minimum temperature was higher at night (Kimmins 1997; Wu et al. 2011). These differences made the radial growth of large diameter trees more sensitive to temperature changes, indicating a positive correlation with the extreme maximum temperature in March of the current year, and a significant negative correlation with the extreme maximum temperature in May and August of the current year (Fig. 7b). These results are consistent with research on the response of radial growth to climate change in large-diameter *Pinus koraiensis* at different latitudes (Liu et al. 2018). Nevertheless, the results of this study are different from those on the limiting factors of radial growth in large-diameter *Picea schrenkiana* (Wang et al. 2016) and *Pinus tabuliformis* (Jiang et al. 2012a) distributed in the mountainous area of the Central Tianshan Mountains and the Hunshandake sandy area, respectively. First, the study areas were located in different climatic regions and the corresponding climate types and hydrothermal conditions differed greatly (Jiang et al. 2012a; Wang et al. 2016). Secondly, the same meteorological data used at different sampling sites could lead to different climate-growth responses. Additionally, the sample trees of the same diameter class were different ages, as radial growth rates of *Pinus massoniana* varied at the different sampling sites. The radial growth of large diameter *Pinus massoniana* was mainly affected by temperature changes. However, it remains uncertain whether temperature is the key climatic factor for radial growth of other large diameter species. This study has tentatively explored the impact of climate on the radial growth of different diameter classes of *Pinus massoniana* in a subtropical monsoon climate region. Additional studies are required with more intense sampling and in a wider area.

Conclusion

Our results suggest that diameter affects tree growth patterns and the response to climatic factors. The radial growth of different diameter classes of *Pinus massoniana* exhibited distinct multiple-scale periodic variations. Small diameter trees had higher chronological characteristics and were more affected by climatic factors. Climatic factors of the previous year, particularly at the beginning and throughout the growing season, had more influence on radial growth of small and middle diameter trees. Precipitation was critical for radial growth of small diameter trees, while temperature was vital for large diameter individuals. These results suggest that diameter be considered in growth-climate response studies of *Pinus massoniana*.

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