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Full Length Research Paper

Relationship of tree ring width of *Cinnamomum camphora* with climate factors in Southern China

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Response of tree ring width to climate factor change is an important part of tree ring ecological research. A tree ring chronology of *Cinnamomum camphora* (*C. camphora*) was developed in Dagangshan forest area of Jiangxi Province in southern China. Correlation analysis and response function analysis were used to compare tree ring response to climate. The results showed that the built tree chronology of *C. camphora* included abundant of environment climate informations, and which could be used in dendrochronological research. Tree ring width of *C. camphora* was positively correlated to mean monthly temperature in the growing season. The correlation between tree ring width and precipitation was significantly negative in May of the current growing season and December of the previous growing season and was significantly positive with mean monthly precipitation of current June and August. Response function analysis mirrored the results of correlation analysis. There had been a quite significant response of tree ring growth of *C. camphora* to humidity index in May, June, August and September of the current year. Temperature and precipitation had obvious integrative influences on tree ring width of *C. camphora.* The results can not only provide scientific basis for studying effect of climate factor change on tree growth in sub-tropical regions, but also for the research in the interaction of structure and composition of forest communities with climate factor change under the conditions of warm and humid climate.

Key words: *Cinnamomum camphora*, tree ring width, climate factor, response.

INTRODUCTION

With frequent occurrence of abnormal weather in recent years, response of tree ring width to climate factor change has become an important part of tree ring ecological research (Liang et al., 2000; Filipe et al., 2010). Formation and variation of tree ring is one of the main features of radial growth of trees, and which is not only constrained by genetic factors of tree's own, but also influenced by environmental factors (Yu et al., 2003; Qin et al., 2010). Moreover, tree ring width can reflect tree growth situation under the external environments (Chen et al., 2003; Liang et al., 2010). So far, the studies on response of tree ring width to climate factor mostly concentrate in the impact of temperature and precipitation on tree ring width in arid and semi-arid regions (Briffa et al., 1990; Rigozo et al., 2002; Huang et al., 2006; Liu et al., 2010). Because tree ring changes are relatively insensitive to moisture and temperature under warm and humid climate in the tropical and subtropical regions, few studies on tree rings have been performed, and current studies in these areas mostly focus on the interaction of tree ring and the El Nino event in southeast coastal areas of China, and response of isotope in tree ring to macroclimate and environment (Sun et al., 2003; Ma et al., 2003; Shao et al., 2010). However, studies on response of tree ring width to climate factors have been rarely reviewed (Xing et al., 2004; Shi et al., 2010). So Dagangshan forest area in Jiangxi Province was chosen as the typical study area,

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Figure 1. Study areas shown in the map of China (the dot in the map is the area of the study).

which is located in the sub-tropical area, and evergreen broad-leaved species of *Cinnamomum camphora* as the research object.

A systematic study on response of tree ring width of *C. camphora* to climate factor change was conducted by correlation analysis and response analysis between tree chronology with mean monthly temperature and mean monthly precipitation. It aimed at studying the effect of climate factor change on tree growth in sub-tropical regions, and providing scientific basis for the research in the interaction of structure and composition of forest communities with climate factor change under the conditions of warm and humid climate.

MATERIALS AND METHODS

Study area and environmental conditions

The study was conducted at Dagangshan State Forest Ecosystem Research Station (27° 30' to 27° 50' N, 114° 30' to 114° 45' E) of Jiangxi Province in southern China (Figure 1), which is a first-class tributary of the Yangtze River, with hilly red soil as the zonal/regional soil. The experimental area has a subtropical humid monsoon climate with a mean annual precipitation of 1590.9 mm, which mainly collected from April to June and accounts for 44.6% of annual total precipitation, mean annual evaporation is 1503.8 mm, while mean annual temperature is 18.2℃ (Figure 2). Annual extreme minimum temperature is -8.3℃, annual extreme maximum temperature is 39.9℃, above 10℃ accumulated temperature is 5355℃, frost-free period is about 269 days. Vegetation types belong to subtropical evergreen broad-leaved forest, and the forest canopy is 76.4% (Wang et al., 2007a).

Sampling and data collection

There was lots of natural *C. camphora* species in Dagangshan forest area of Jiangxi Province. But the older ones always had the sign of rotten heart, so we selected 32 trees of *C. camphora* aging from 40 to 60 years as sample trees from June to August, 2009. Basing on the international tree rings database (ITRDB) standard, we got the cores through drilling holes into the tree in the contour line direction, or vertical direction with the slope (namely, the sampling core directions were along two directions of the level and slope), and breast height is usually in 1.3 m, every sample tree contributes 2 to 3 cores, and 66 sampling cores were collected (Table 1). After a serious treatment of the sample tree, tree ring width were measured by the Lintab5 Ring Analyzer (Frank Rinn, made in Germany) with 0.01 mm accuracy, and then checked the validity of the data series through COFECHA software (Homes, 1983) further. Meteorological data such as mean monthly temperature and precipitation from 1960 to 2008 comes from weather station which is located in Fenyi County near Dagangshan forest area. Considering the trend of annual climate change, we collected meteorological data of the different hydrothermal periods, and 32 meteorological factors had been selected from September of the previous year to December of the current year (a total of 16 months).

Moreover, to reflect the comprehensive influence of temperature and precipitation on tree growth, humidity index was used to measure climate factor change (Gou et al., 2002; Fang et al., 2009). Humidity index can be expressed as the following:

$$HI = \frac{P}{T}$$

Where: *HI* is humidity index; *T* and *P* are the mean monthly temperature and mean monthly precipitation in the same period.

Statistical analyses

Tree ring width index chronology of *C. camphora* was developed based on the ARSTAN software. Firstly, the age-related growth trend of trees was wiped away by spline function with step length of 30a (namely, detrend), and then transformed into standard

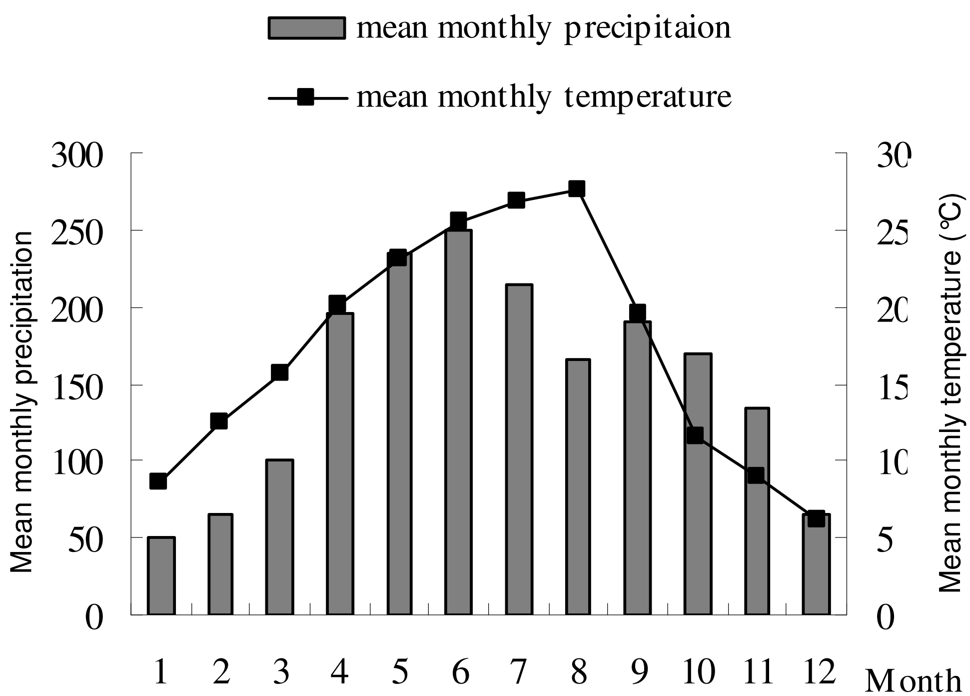

Figure 2. Mean monthly precipitation and temperature in the study area (1960 ~ 2008a).

chronology (STD) with double averaging method. In view of the majority of sampling points distributed in dense forest, and competition among trees might lead to the low-frequent changes of tree ring width. So, the regressive model of time series was used to simulate the growth trend of trees, namely, standardization again, and then was composed to residual chronology (RES). The interval analysis of series in residual chronology was carried out, and correlation analysis and response function analysis were used to compare tree ring growth response to climate factors.

RESULTS AND ANALYSIS

Basic statistical characteristics of tree chronology of *C. camphora*

Table 2 showed that mean sensitivity (MS) which measured tree ring series of *C. camphora* was 0.161 ~ 0.211, and all of them reached the acceptable level of 0.10, and the express population signal (EPS) of chronology was greater than the acceptable level of 0.85. Normally, if a tree chronology has high standard error and mean sensitivity, but first order autocorrelation coefficient is low, then this tree ring chronology contains higher ecological information (Shao and Wu, 1994). The results indicated that tree growth of *C. camphora* was more sensitive to climate change, and correlation function method could be used to study the relationship between tree growth and climate factors. Moreover, signal-to-noise ratio (SNR), EPS and variance of the principal component were all relatively higher, so it was further definite that *C. camphora* was suitable for analysis of tree ring ecology in Dagangshan forest area.

Relativity between tree ring width of *C. camphora* with climate factors

Figure 3 showed that there was a positive correlation between tree ring width of *C. camphora* and mean monthly temperature in the growing seasons. Furthermore, tree ring width had a significant positive correlation with mean monthly temperature in April ($P<0.05$) and a highly significant positive correlation of that in May ($P<0.01$). In April and May, as temperature increased, as trees grow much faster, and that will be propitious to formation of tree ring for early wood, but if temperature continues to rise in June, excessive high temperature will make trees speed up metabolism and strengthen transpiration, thus trees growth will be limited. In serious cases, it might result in summer dormancy. Consequently, there was a negative correlation between tree ring width and mean monthly temperature in June, despite it was not significant, it also indicated that this phenomenon existed in June in Dagangshan forest area of Jiangxi Province. Figure 4 showed that tree ring width of *C. camphora* had a significant negative correlation with mean monthly precipitation in May ($P<0.01$) of the current growing season and December ($P<0.05$) of the previous growing season, but a significant positive correlation of that in June ($P<0.05$) and August ($P<0.05$) of the current growing season.

Generally, with the increase of precipitation in April,

Table 1. Status of the sampling site in the study area.

Species	Longitude and latitude	Altitude (m)	No. of trees	Cores	Slope (°)	Direction	Position	Breast height* (cm)
C. camphora	27° 30' - 50' N, 114° 30' - 45' E	270 - 370	32	66	5 -2 5	Southwest	Mid-down slope	50 - 96

* indicated the breast height diameter of tree in 1.3 m.

Table 2. Statistics of the tree ring width and standard chronology of *C. camphora* in the study area.

Basic statistics	Measured value	Residual chronology (RES)
Total sample/tree	66/32	43/26
Standard deviation	0.804	0.183
Mean sensitivity (MS)	0.161	0.211
First order autocorrelation coefficient	—	0.146
Mean correlation coefficient within trees* (MC)	—	0.634
Express population signal* (EPS)	—	0.882
Signal to noise ratio* (SNR)	—	21.035
Variance of the principal component*	—	38.69%

* indicated the result of common time series analysis.

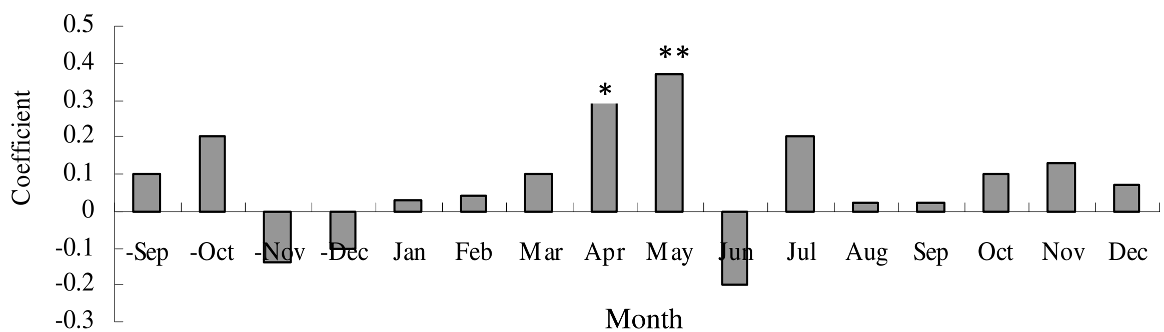

Figure 3. Correlation coefficients between tree ring width of *C. camphora* and mean monthly temperature in the study area. **P<0.01; *P<0.05. –Sep means month of the previous year; Jan means month of the current year.

when it gradually came into the rainy season in May, and continuous wet weather would make woodland soil water had been in saturated state, but actual available water for trees was inadequate. So it might produce narrow early-wood, and would result in the correlation between tree ring width and mean monthly precipitation was significantly negative in May of the current growing season. In June, with the increase of

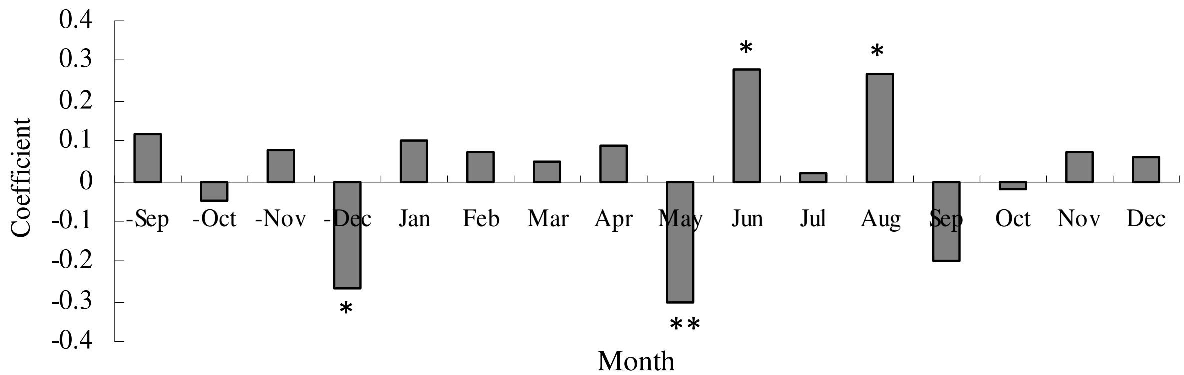

Figure 4. Correlation coefficients between tree ring width of *C. camphora* and mean monthly precipitation in the study area. ***P*<0.01; **P*<0.05. –Sep means month of the previous year; Jan means month of the current year.

temperature and evaporation enhanced, the utilization rate of soil moisture for trees had been improved, and which would result in rapid growth of tree ring, so the correlation of tree ring width and mean monthly precipitation was significantly positive in June. Although, further raise of temperature in July, soil moisture and groundwater could satisfy the needs of trees in a certain period as the rainy season just ended, therefore, it would be much weaker that precipitation limited the growth process of trees in July than that in the previous period. In August, due to continuous high temperatures, monthly precipitation was significantly reduced (Figure 2), that is to say, climate fell into the typical dry season in Dagangshan forest area at this time of the year. For this reason, actual available water for trees was decreased, and precipitation become a major limiting factor for tree growth, and resulted in the growth of narrow rings, so the correlation of tree ring width and mean monthly precipitation was significantly positive in August.

Response of tree ring width of *C. camphora* to climate factors

In the tropical and subtropical regions, the relevance of temperature and precipitation is significant, so comprehensive influence of temperature and precipitation on tree growth should be fully taken into account. Therefore, with the regression analysis method, we analysed chronology (W_z) and mean monthly temperature (T_1 ~ T_{14}) and mean monthly precipitation (P_1 ~ P_{14}) from September of the previous year to October of the current year, and then established the response function equation. Each selected factor was carried out correlation test gradually, and was made confidence interval test of 95%. The regression equation between tree ring width and monthly climate factors (mean monthly temperature and precipitation) is:

$$W_z = 0.07187T_2 + 0.08029T_8 - 0.00212P_4 - 0.00078P_9 + 0.00067P_{10} + 0.00143P_{12} - 2.0770 \quad (R = 0.675;\ R^2 = 45.6\%)$$

Where: T_2, T_8 are mean monthly temperature in October of the previous year and April of the current year; P_4, P_9, $P10$, $P12$ are mean monthly precipitation in December of the previous year and May, June, August of the current year. R is multiple correlation coefficients. R^2 is analysis of variance, namely, climate factor change can explain 45.6% of tree radial growth for *C. camphora* in the study area.

Precipitation and temperature changes have different impacts on tree ring width. When precipitation falls below a certain value, there will be a negative correlation between temperature and tree growth; when precipitation is in an appropriate value, the impact of temperature on tree growth will also not be obvious. It may be too limited if we only analyse the impact of individual climate factor on tree ring width. Therefore, humidity index was used to measure climate factor change. Figure 5 showed that the response of tree ring width to humidity index was relatively clear, and tree ring width had a significant correlation with humidity index in May (P<0.01), June (P<0.05), August (P<0.01) and September (P<0.05) of the current year in Dagangshan forest area.

DISCUSSION

Analysis of basic statistical characteristics of chronology of *C. camphora*

Table 2 showed that mean correlation coefficient (MC) for tree ring series of *C. camphora* was 0.634 in the study area, it indicated that tree ring radial growth among individuals was quite consistent, which was subject to influence of similar environmental factors, and this conclusion was similar to the studies of Wu et al. (1999) and Wang et al. (2007b). Mean sensitivity mainly reflected short-term and high-frequency changes of climate (Wei

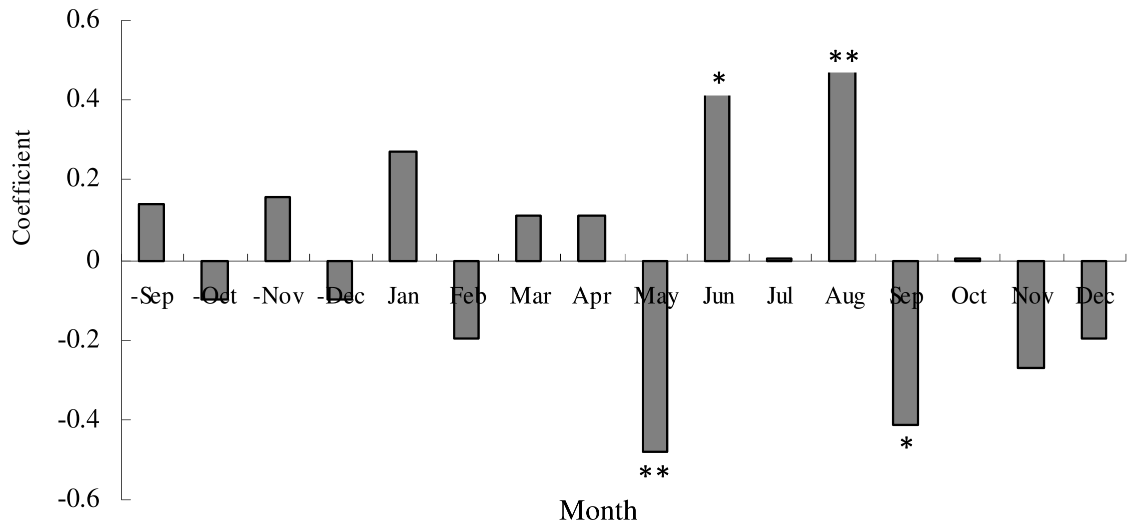

Figure 5. Correlation coefficients between tree ring width of *C. camphora* and humidity index in the study area. ***P*<0.01; **P*<0.05. –Sep means month of the previous year; Jan means month of the current year.

and Fang, 2008). In this study, mean sensitivity for chronology of *C. camphora* reached 0.211, which showed that *C. camphora* was quite sensitive to climate changes in this region, so correlation function method could be used to study relationships between tree growth and climate factors. Meanwhile, SNR of chronology was 21.035, EPS was higher than the acceptable level (0.85), variance of the principal component accounted for 38.69%, all of these basic statistical characteristic values were relatively higher, which indicated that chronology of *C. camphora* contained rich climate information and it was suitable for ecological analysis of tree ring ecology. Because various statistic in the chronology of tree ring could not directly explain the response of chronology to climate factors, such response relationship should be determined by the study of correlation between chronology and climate factors.

Correlation of tree ring width of *C. camphora* with climate factors was significant

In the study area, correlation of tree ring width and temperature as well as precipitation in the growing season was relatively higher; as it could be seen from Figures 3 and 4 that confidence interval was up to the significant level of 95%. Tree ring width of *C. camphora* was positively correlated to mean monthly temperature in the growing season, especially to that in April and May, and the result was similar to the findings of Xing et al. (2004). Correlation of tree ring width with mean monthly precipitation was more complicated, which was significantly negative in May of the current growing season and December of the previous growing season, but a significant positive correlation of that in June and August of the current growing season, and the conclusion was consistent with the findings of Zhang et al. (2007). This conclusion indicated that requirements of evergreen broad-leaved trees for precipitation were comparatively complex, and moisture changes during the growing season had a relatively great impact on tree ring width.

So, we could conclude that it is probably due to the instability of monsoon climate which caused spring and summer drought, and that directly affected normal growth of trees, therefore, correlation between tree ring width and climate factors in a single month was rather complicated.

Response of tree ring width of *C. camphora* to climate factors was sensitive

Response function can express how trees depend on the climate factors, and which can be used to analyse response of tree growth to many climate factors (Hou et al., 1999). By studying response of tree ring width of *C. camphora* to monthly climate factors, we could easily find that it was basically consistent between response function of tree ring width to mean monthly temperature and precipitation and the results of relevance. It specifically manifested that tree ring width had a positive response relationship with mean monthly temperatures in October of the previous year and April of the current year; meanwhile, it also had a relatively sensitive response to mean monthly precipitation in December of the previous year and May, June, August of the current year.

Response of tree ring width *C. camphora* to humidity index

Trees growth is generally effected by two or more factors together, among them, temperature and humidity are the main factors. Hou et al. (2003) had shown that the interaction between tree ring width of *Pinus massoniana* with temperature and precipitation had a relatively significant correlation in Hudingshan area of China, meanwhile, combinations of different temperature and humidity significantly influenced on radial growth of *P. massoniana*. In the study, we could conclude that there had been a quite significant response of tree ring growth of *C. camphora* to humidity index in May, June, August and September of the current year (Figure 5). Relativity, between tree ring width and humidity index of different month was higher than that with the temperature or precipitation.

By comparison with separate action of various climate factors, it was much more important that the comprehensive influence of temperature and precipitation on tree ring width of *C. camphora* in Dagangshan forest area of jiangxi Province in southern China.

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