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DENDROCLIMATOLOGICAL STUDIES OF *PICEA LIKIANGENSIS* AND *TSUGA DUMOSA* IN LIJIANG, CHINA

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SUMMARY

Expansion of climate proxy records over space is needed for improving our knowledge of past climate variability. Here we report on a 112-year tree-ring chronology of *Picea likiangensis* (Franch.) E. Pritz. and a 165-year tree-ring chronology of *Tsuga dumosa* (D. Don) Eichler for the Lijiang area, northwestern Yunnan, China. Mean correlation coefficients of tree-ring width series among individual trees are 0.48 for *P. likiangensis* and 0.45 for *T. dumosa*, indicating a growth response to common environmental variability. Analysis of climate-growth relationships shows that the radial growth of *P. likiangensis* is mainly negatively correlated with temperature from December of the prior growth year to May of the growth year, and that of *T. dumosa* is mainly positively correlated with precipitation of January and May in the growth year. We further found that the chronology of *T. dumosa* can be used to reconstruct the May-June Palmer Drought Severity Index. The reconstruction shows that major wet periods occurred in the 1860s, 1910s and 1940s, and drought periods in 1892–1905, 1914–1924 and 1928–1938. The moisture condition of the late 20th century is characterized by a near-normal state from the 1950s to the 1970s and an increasing trend from 1982 to 2003.

Key words: Dendroclimatology, tree ring, drought, PDSI.

INTRODUCTION

Severe droughts and extremely cold periods may affect the dynamics of water resources, agricultural production, and socioeconomic development, particularly in areas having a high climate sensitivity and rich cultural and natural resources (Cook *et al*. 1999, 2004; deMenocal 2001; Hodell *et al*. 2001; Shao *et al*. 2005; Liu *et al*. 2006; Treydte *et al*. 2006). The Lijiang area in the northwestern Yunnan province of China is well known for its rich cultural heritage and unique natural sceneries. It attracts thousands of tourists every year (Ning *et al*. 2006). The Lijiang Old Town, built in the Song Dynasty more than 800 years ago, has been included in the United Nations World Heritage list since 1997. On the Yulong Mountain, in the vicinity of Lijiang city, there

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is the southernmost glacier in subtropical Eurasia (He *et al*. 2001; He & Gu 2003). These cultural heritage and natural sceneries are, however, facing challenges of the current global climate change (He & Gu 2003; Ning *et al*. 2006). For example, the glaciers on the Yulong Mountain are shrinking due to climate warming, and the sector of tourism is highly vulnerable to the occurrence of extreme weather (He & Gu 2003). Understanding climate variability, particularly the regional climate history, is of great significance for providing guidelines for sustainable management of the cultural and natural resources.

Studies of climate history rely on the availability and quality of instrumental climate data and proxy records. The instrumental data in the Lijiang area are only available since A.D. 1951 which is too short to cover a wide range of climate variability. Information about regional climate variation at longer time scales is usually obtained from climate proxies such as ice cores and tree rings. Previous studies of ice cores from the Yulong Mountain glaciers showed that the Lijiang area experienced two cold stages in the Little Ice Age during the last 400 years and the temperature increased in a fluctuating manner during the 20th century (He *et al*. 2001, 2002; He & Gu 2003). The rate of glacier retreat accelerated after the 1980s (He & Gu 2003; Ning *et al*. 2006). Tree rings, however, have not yet received much attention in the study of climate change in this area. Given that the Lijiang area is well forested and sensitive to climate change, studies of tree-ring characteristics are useful not only for understanding past climate variation but also for improving our knowledge of forest ecology and management. The purpose of this paper is 1) to develop tree-ring chronologies for the Lijiang area, 2) to identify the climate-growth relationships, and 3) examine past climate variations from tree-ring data.

MATERIAL AND METHODS

The tree-ring sampling site is at Maoniuping, Yulong Snow Mountain Natural Reserve in Lijiang (Fig. 1). Its geographical location is 27° 03'–27° 40' N and 100° 04'–100° 16' E. The elevation is 3060 m above sea level. The mean annual air temperature in Lijiang is 12.6 °C. The hottest month occurs in July and the mean highest temperature is 21.3 °C. The total annual precipitation is almost 1000 mm, and more than 80% of the rainfall occurs from June to September (Fig. 2).

The dominant tree species at Maoniuping are *Picea likiangensis* (Franch.) E. Pritz. and *Tsuga dumosa* (D. Don) Eichler. Increment cores, one core per tree and at breast height, were collected from 23 trees of *P. likiangensis* and 22 trees of *T. dumosa*. To maximize the length of the tree-ring chronologies, large-diameter trees growing on thin-layer soil were selected for sampling. Trees with an obvious injury or disease and on thick-layer soil were avoided in order to minimize non-climatic influences on tree-ring width. In the laboratory, the increment cores were dried, mounted on wooden core holders and then sanded with progressively finer grit sand papers. Tree-ring widths were measured to the nearest 0.001 mm with a TA Unislide Measurement System (Velmex Inc., Bloomfield, New York). The tree rings were cross-dated by examining the patterns of wide and narrow rings as well as other characteristics available such

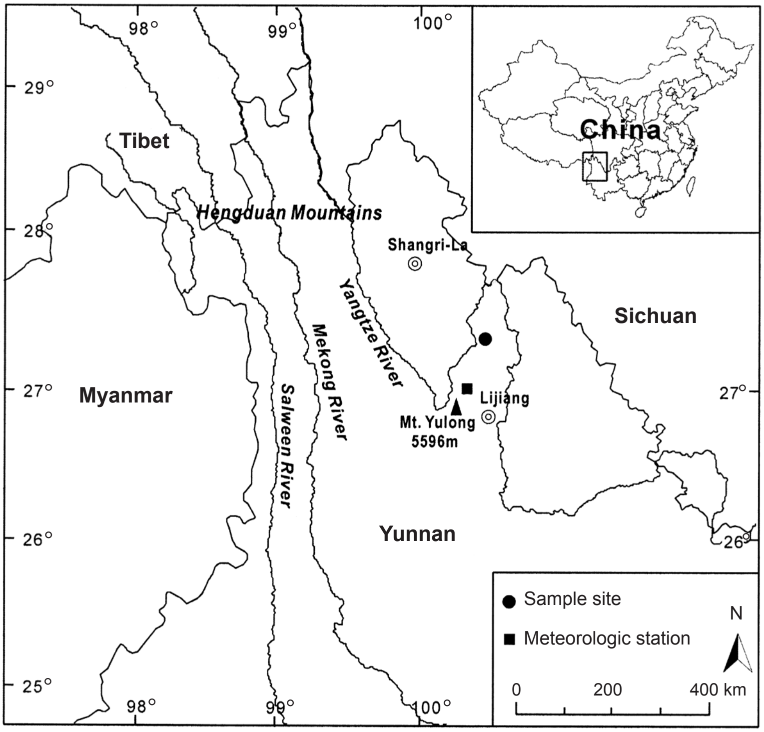

Figure 1. Tree-ring sampling site and meteorological station in Lijiang, northwestern Yunnan, China.

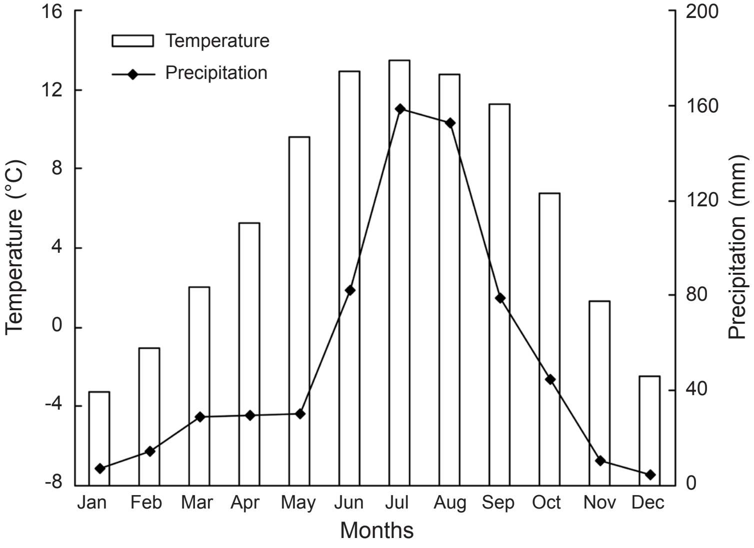

Figure 2. Mean monthly air temperature (°C) and sum of precipitation (mm) at the study site in Lijiang, northwestern Yunnan, China.

as light latewood. The computer program COFECHA was used to quality-check the cross-dated series (Holmes 1983). Cores that could not be cross-dated due to poor quality (such as having too many broken pieces or being too much locally influenced) were discarded.

A tree-ring chronology for each species was constructed using the program ARSTAN (Cook & Kairiukstis 1990) following standard methods (Fritts 1976; Schweingruber 1988). A conservative detrending method (negative exponential function or straight line) was chosen to retain the climate signals as much as possible (Fritts 1976). Standard chronologies with at least five sample replications for each year were used for further dendroclimatic studies. The climate-growth relationships were identified using correlation analysis. Climate variables included monthly mean temperature and total monthly precipitation from 1951 to 2002 at the Lijiang meteorological station (26° 52' N, 100° 13' E, 2393 m above sea level). Regression techniques were used for developing a transfer function in which the tree-ring chronology was the independent variable and the corresponding climatic factor (identified from the climate-growth relationship analysis) was the dependent variable.

RESULTS AND DISCUSSION

Following the standard procedure of cross-dating, 20 cores of *Picea likiangensis* and 20 cores of *Tsuga dumosa* were cross-dated successfully, and five cores that did not

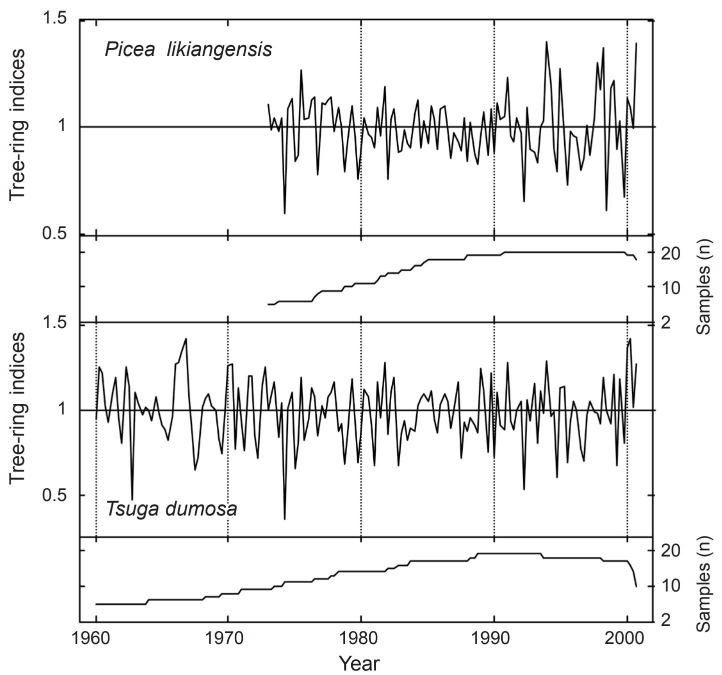

Figure 3. Standard tree-ring width chronologies of *Picea likiangensis* and *Tsuga dumosa*, with the number of samples included, in Lijiang, northwestern Yunnan, China.

cross-date were discarded. The standard chronologies developed for each species are shown in Figure 3. The mean interseries correlation coefficients were 0.48 and 0.45, respectively, indicating that radial growth of individual trees of each tree species was responding somewhat commonly to climate factors. The values of Expressed Population Signal (EPS) and Signal-to-Noise Ratio (SNR) indicated that the chronologies could be used to represent common climate signals. The Mean Sensitivities (MS) were 0.18 and 0.21, respectively, indicating that the two species were sensitive to environmental changes (Rolland 1993). These statistics suggested that the two tree species are useful for further dendroclimatic studies in this area.

The climate-growth relationships showed that the chronology of *P. likiangensis* was negatively correlated with temperature from December of the prior growth year to May of the growth year and positively correlated with precipitation of February of the current year (Fig. 4). The chronology of *T. dumosa* was positively correlated with precipitation of January and May in the current year and negatively correlated with temperature of May in the current year. For both species, May temperature was the most significant month that had negative correlation with tree-ring width. In general, monthly temperature and precipitation had opposite signs of correlation coefficients with tree-ring width of both species.

The climate-growth relationships suggested that both temperature and precipitation should be taken into consideration. Precipitation during the growing season directly increases the soil moisture available for tree growth, whereas high temperature during this period intensifies the evapotranspiration rate thus decreasing moisture content in soil. Temperature and precipitation in winter may play a role in preconditioning tree growth (such as through modulating soil moisture storage and tree's bud physiology) in the coming year.

Because the Palmer Drought Severity Index (PDSI) incorporates both temperature and precipitation in calculating moisture availability for tree growth (Palmer 1965), we examined the relationship between the tree-ring chronologies and the PDSI series. The PDSI data were obtained from the NOAA-CIRES ESRL/PSD website (http://www.cdc.noaa.giv/) from 1951–2002. Correlation analysis showed that radial growth of *T. dumosa* was positively correlated with May-June PDSI ($r = 0.477$, $p < 0.001$), but that *P. likiangensis* growth did not show any significant correlation with PDSI. This suggests that the sensitivity of the two species to PDSI is different. We therefore selected the PDSI-sensitive species, *T. dumosa*, to develop a regression model in which the tree-ring chronology was the independent variable and May-June PDSI was the dependent variable. The model obtained was

$$Y = 3.668\,X - 3.508$$

where Y is May-June PDSI and X is the tree-ring index.

The May-June PDSI produced by the model showed good agreement with the variation of actual PDSI (Fig. 5). Leave-one-out cross-validation and sign test statistics indicated that the model was useful for reconstruction of May-June PDSI in the past.

The reconstructed May-June PDSI for the period A.D. 1839–2003 in the Lijiang area showed that major wet periods occurred in the 1860s, 1910s and 1940s and drought periods in 1892–1905, 1914–1924 and 1928–1938 (Fig. 6). The moisture condition of the late 20th century is characterized by a near-normal state from the 1950s to 1970s and an increasing trend from 1982 to 2003 with the value of PDSI increasing from -1.14 in 1982 to 2.34 in 2003. This recent wet episode in Lijiang is very similar to that of the southeast Tibetan Plateau where the period since 1980 shows an increase in summer rainfall unprecedented in the past 350 years (Bräuning 2001; Bräuning & Mantwill 2004).

The PDSI series reconstructed from *T. dumosa* tree rings quantitatively extends the drought record back to A.D. 1839 for the Lijiang area. This record presents a historical background for evaluating drought occurrences in modern time. The tree-ring analysis of *P. likiangensis* provides information about its growth response to climatic factors and reveals that temperature from December of the prior growth year to May of the current year is a main factor influencing radial growth. The tree-ring data from both species contribute to the regional tree-ring network for large-scale climatological and ecological studies (Zhang & Shao 2007; Fang *et al*. 2009; Liang *et al*. 2009; Park & Lee 2009; Shao *et al*. 2009; Tian *et al*. 2009; Zhang *et al*. 2009). Our ongoing work will continue to expand the spatial coverage of tree-ring data and improve the paleoclimate reconstruction in the northwestern Yunnan, China.

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