Relationships of climate change and tree ring of *Betula ermanii* tree line forest in Changbai Mountain

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Abstract: Based on the tree-ring growth characteristics of Erman's birch (*Betula ermanii* charm.) and the relationships between it and climatic factors at elevation of 1950m, the sensitivity of tree lines in Changbai Mountain to climatic factors was assessed. The results indicated tree line forest in Changbai Mountain had an obvious sensitivity to climate factors. However, difference from other study sits is that the main climatic control factor on tree-ring growth was not current growth season temperatures, as might be expected, but previous winter and current March temperature. Although the precipitation in the region was quite abundant, the tree-ring growth was still significantly correlated with the precipitation during previous winter and current spring. Additionally, climatic factors which influenced the Erman's birch growth were not the yearly variables, but seasonal and monthly variables. Therefore, the reported increase in yearly mean temperature and total yearly precipitation since 1980s was not responded by sustained increase in ring widths in recent decades.

Keywords: Climatic change; dendrochronology; Erman's birch; Tree line in Changbai Mountain

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Introduction

During the past decades, considerable attention has been focused on global climate change. Climate models predicted that global warming will impact the whole world, especially the interior continental sites at mid- to high-latitudes in Northern Hemisphere (Chapman and Walsh 1993; Serreze *et al.* 2000; Forster and Spear 1990; IPCC 2001; Hu *et al.* 2002). The northeast area of China, with wider range of longitude and latitude, is suitable for performing the studies of climatic change. And previous studies also suggested that the climatic changes in this region are more obvious than those in any other place in China (Wang *et al.* 2002). Furthermore, the Northeast of China is a most important forest product area, thus the influence of the future climate variation on tree growth has become the common concerns of ecologists and government officials (Liu and Fu 2001).

The strongest relationships between climatic factors (especially temperature and rainfall) and tree radial growth are conformed at natural tree lines, where single climatic factors are believed to be most responsible for the annual variation in tree rings (Fritts 1976; Robertson and Jozsa 1988; Wu 1990). Consequently, tree growth at tree line is likely to be sensitive to climate fluctuation, and furthermore, climate fluctuation influences the advances and retreats of tree line. Up to now, many studies have been conducted the facts of the increased rates of tree growth at tree line and the invasion rate to tundra over the last 50 to 100 years, which coincide with warmer climate (Briffa *et al.* 1995; Cullen *et al.* 2001).

If trees growing at their altitudinal limit are the most sensitive to climate variation, then tree growth-temperature relationships should be strengthened with the increase of elevation and be strongest at tree line. A pattern has been confirmed by several studies (Buckley *et al.* 1997; Villalba *et al.* 1997; Cullen *et al.* 2001; Fritts 1976; Robertson and Jozsa 1988; Wu 1990). Nevertheless, Norton (1985) suggests that processes such as flowering and fruiting, competition, or the impacts of natural disturbance may be accentuated at tree line, thereby reducing the climate sensitivity of tree line forests. Given that disturbance impacts at tree line could disrupt growth-climate relationships, Erman's birch forests, located below tree line which shows less evidence of disturbance, may provide more climate information. If so, the optimal site for examining growth trends in response to climate variation may occur below tree line.

Although early observers realized radial growth of tree ring in this region was correlated with the climatic factors in Changbai Mountain (Shao and Wu 1997; Zhou *et al.* 2002), most of their studies were conducted at lower elevation, how about the tree line at higher elevation? Previous researches showed the radial growth of trees at latitudinal (D'Arrigo *et al.* 1992; Briffa *et al.* 1995) and altitudinal (Villalba *et al.* 1997) tree lines in both the Northern and Southern Hemisphere are strongly correlated with summer temperatures. However, more recent studies in other region indicated this was really an oversimplification (D'Arrigo and Jacoby 1993). One reason is that trees selected for developing chronologies grow in closed forest, in which natural disturbances, including windstorms and heavy snowfall that are known to substantially affect the population dynamics and short-term growth trends of trees at tree line, rarely appear. Another is that the trees used in early tree-ring studies are primarily evergreen conifers, for which photosynthesis can take place over a much longer season than the relatively short summer period of actual cambial-cell division. In temperate and subarctic regions, photo-

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synthesis continues down to temperature near freezing, and these photosynthates are stored and used in the radial growth season in summer (D'Arrigo and Jacoby 1993). However, few studies have been done on broad-leaved deciduous trees in this aspect. So far the relationship between the broad-leaved deciduous trees and climate variation is not clear. Studies on the relationships between tree growth and ambient CO_2 concentration implied that deciduous trees species are more sensitive to the double CO_2 concentration than coniferous trees species (Wisley *et al.* 1994; Wisley 1996), and the faster tree species grow, the more sensitive to external environmental variation (Loehle 1995). Thus, annual ring width of Erman's birch may provide a clear indication of tree radial growth responses to climate warming.

The objective of our study was to investigate whether Erman's birch growing near tree line in Changbai Mountain was sensitive to the climatic variation and showed the increased growth in response to recent and future climate warming. To achieve this objective, the Erman's birch chronologies were developed from a 20-m wide belt around the mountain about 50 m below tree line (1 950 m a.s.l.), the climate factors of influencing the radial growth were determined, the growth trends were examined in the chronology for evidence of the increased growth in response to recent climatic variation, and the relationship of radial growth with future climate warming were modeled.

Materials and methods

Study area

The study area is located in Changbai Mountain region (41°31′–42°28′N, 127°9′–128°55′E) of the Northeast China neighboring North Korea. There are four vegetation zones arranged with elevation varying from 700 m to 2 691 m a.s.l. (above sea level) in northern slope of Changbai Mountain. The Erman's birch forest extends from 1 700 m to 2 000 m a.s.l., which is the upper elevation limit of the forest distribution, called the Erman's birch forest line, namely tree line. The tree line is actually a zone of transition between Erman's birch forests and the alpine tundra, which is composed of fascicular Erman's birch trees and trees islands. A 20-m wide belt around the mountain following the contour line 50 m below the tree line (1 950 m a.s.l.) were selected, where forest consists of 95% Erman's birch and 5% Larch (*Larix olgensis* (A. Henry)). The study area was chosen for the following reasons: (1) the area is unlikely to be affected by anthropogenic activity, because Changbai Mountain is a nature reserve. (2) Changbai Mountain is the highest distribution area of Erman's birch forest in elevation. (3) Erman's birch tree lines around Changbai Mountain are typical Erman's birch tree lines in the Asia.

At the area of tree line, the climate characterized by cold and windy in winter, rainy and wet in summer. The annual mean temperature is from -2.3 °C to -3.8 °C. The periods of the highest and the lowest temperature are in July and January, respectively. Annual precipitation ranges from 1 000 mm to 1 100 mm. The duration of frost-free period is about 65–70 days. Few tree species can survive in such a long snow cover period except for Erman's birch.

Cores sampling

Six 20 m×90 m (with the longer side extended along contour line) plots were established at the elevation of about 1 950 m a.s.l., and, four to seven Erman's birch trees were selected for analysis at each plot. Paired increment cores were taken at breast height using increment borers at two radial opposite directions, only a few trees was taken one core due to the steep slope. A total of 88 cores from 47 trees were extracted.

Development of chronology

All cores were mounted, sanded, and visually cross-dated. Since the boundary of rings from Erman's birch was unclear and difficult to identify, before the cross dating, the cores were treated with a little water and white chalk. The ring widths were measured with a precision of the nearest 0.001 mm using a linear digitizing tablet coupled to a computer. Then the absolute dating was subsequently verified and calculated statistically using the COFECHA program (Homes 1983). This program can identify segments of a core or a group of cores where dating or measurement errors might occur. Finally, 18 cores of 10 stems that showed low correlation values with the chronology and 12 cores of 7 stems that could not identify the rings clearly were excluded from the site chronology (Table 1). The measurement series were individually detrended with a cubic smoothing spline (50-years frequency response) to eliminate specific growth trend of tree that resulted from the differences of age and size, and competition effects of tree growing in closed canopy conditions (Esper *et al.* 2002). Ring-width measurements of each core were divided by the fitted spline values to produce a standardized tree-ring series for each core. These individual dimensionless index series were then averaged together using a biweight robust mean to develop a mean standardized chronology (STD) (Wu 1990) using the program ARSTAN (Cook *et al.* 1985, 1990; Hughes and Brown 1991). During the standardization process we removed the autocorrelation (correlation between the growth of one year and that of the previous years) using autoregressive moving average (ARMA) time-series models (Box and Jenkins 1976) in ARSTAN to produce "residual" chronologies (RES). Previous research (e.g. Jacoby and D'Arrigo 1989; Shao and Wu 1997) has suggested that removing autocorrelation may remove real trends in ring width related to climate change (e.g. Increased growth in recent decades), therefore, in our study, RES was selected for determining the relationship between tree radial growth and climatic factors.

Climate data

The climate data were taken from the Tianchi Meteorological Station (TMS) at 2 600 m and the Opened Research Station of Changbai Mountain Forest Ecosystems (ORS) at 740 m in Changbai Mountain region. Seven months of the prior year (t-1) from June to December were used in addition to nine months of the current year (t) from January to September. Instrumental climate data were available from 1959, with some missing data after 1988 at the TMS and 1982-2000 at the ORS. The climate data were summarized into 105 variables, which were defined to reflect the tree growth patterns as follows:

(1) Monthly climate factors, 80 in total, include: Mean temperature (Tm), maximum temperature (Tmax) and minimum temperature (Tmin), total precipitation (Pm) and humid index (Pm/Tm) from July (t-1) to September(t) (16 months in total);

(2) Seasonal climate factors, 20 in total, include: Previous growth season (previous June, July, August, and September), Previous winter (previous October, November and December), Current spring (current January, February and March), Before growth season (current April and May), Current growth season (current June, July, August and September) mean temperature, maximum, minimum temperature and total precipitation;

(3) Yearly climate factors, 5 in total, include: Annual mean temperature (Atm), maximum temperature (Atmax) and minimum temperature (Atmin), annual total precipitation (AP); Annual humid index (AH (AP/Atm)).

Relationships between tree rings and meteorological data

Correlation function analysis was performed to characterize the relationships between ring width indices and climate variables. Correlation coefficients were calculated in a 30-year period (1959-1988) by the data of TMS. At the same time, the uniformity between the two stations was checked by Mann-Kendall (Kendall 1970) and Double-mass method (Kohler 1949). The result proved their relative uniformity could stand for the changes of natural climatic elements. According to the result of correlation function analysis, the ring width and climate factors were modeled by multi-regressive analysis (stepwise). And then the model was checked by the data of 20-year period (1982-2000) from the ORS.

Table 1. Characteristics of Erman's birch chronologies developed for the six tree line sites.

Samples	T1	T2	T3	T4	T5	T6
Number of cores/stems	8/4	11/6	8/4	10/5	9/5	12/6
Interval	1810-2002	1793-1996	1830-2002	1856-1998	1800-2002	1796-1999
Mean ring width (±SD*) (mm)	0.41±0.45	0.42±0.53	0.56±0.53	0.69±0.27	0.56±0.33	0.43±0.45
Mean sensitivity	0.405	0.293	0.175	0.175	0.223	0.396

*SD stands for standard deviation of the mean ring-index value.

Results and analysis

Chronology statistics

The six plots differed in stand age. Tree established in plots T2 and T6 date back to the 1790s while plots T3 and T4 date back to 1830s (Table 1). However, most trees sampled in the study were established around the turn of the 19th century. The average annual increment was the smallest in the T1, T2, T6 plots, and these three plots also had the highest mean sensitivity in ring widths, which is not expected for older Erman's birch trees (Table 1). The largest average annual increment occurred in the plot T4, the youngest stand.

The 188-year (25 trees in total reach to the age) standardized (STD) and residual (RES) chronology, ranged from 1815 to 2002, are shown in Fig. 1. The strength of cross-dating among these trees was high as reflected by an inter-series correlation of 0.371 and 0.356 (Table 2). Mean sensitivity was about 0.23 and 0.26 for the STD and RES chronology, respectively. Common interval analysis suggested SNR (7.652 and 7.185) and EPS (0.884 and 0.878) and variance according to loadings on the first component (42.5% and 41.2%) are high, which indicated that the trees distributed near the upper growth limit were more suitable and adaptive for dendroclimatic analysis. The difference from previous studies was that, at our study sites, the RES chronology did not show much more low frequency changes comparing with STD chronology (Table 1 and Table 2). However, the first-order autocorrelation of STD, as measures of the influence of the previous year's growth on the growth in the current year, was obviously larger than 0.05, while that of RES was very low. Furthermore, RES is considered to reflect more real information of climate (Fritts 1976; Shao and Wu 1997), and in this study its mean sensitivity is slight higher than that of STD. therefore, RES was still selected for the study. In addition, previous studies (D'Arrigo and Jacoby 1993) in tree line implied that there should be less missing rings, however, the opposite result occurred in this study.

Table 2. Summary statistics over the period common to the Erman's birch chronologies, 1815-2002.

Chronology type	Standard chronology	Residual chronology
Mean	1	1
Mean sensitivity	0.2345	0.2643
Standard deviation	0.2364	0.2233
First-order autocorrelation	0.3261	-0.0026
Correlation*	0.371	0.356
Signal-to-noise ratio (SNR)	7.652	7.185
EPS	0.884	0.878
Variance in first eigenvector (%)	42.5	41.2

Note: Mean sensitivity is the mean percentage change from each measured ring to the adjacent ring (Fritts 1976); and EPS, express population single are both measures of chronology confidence.

*Mean among-tree correlation for the common period. This is a measure of the common variance.

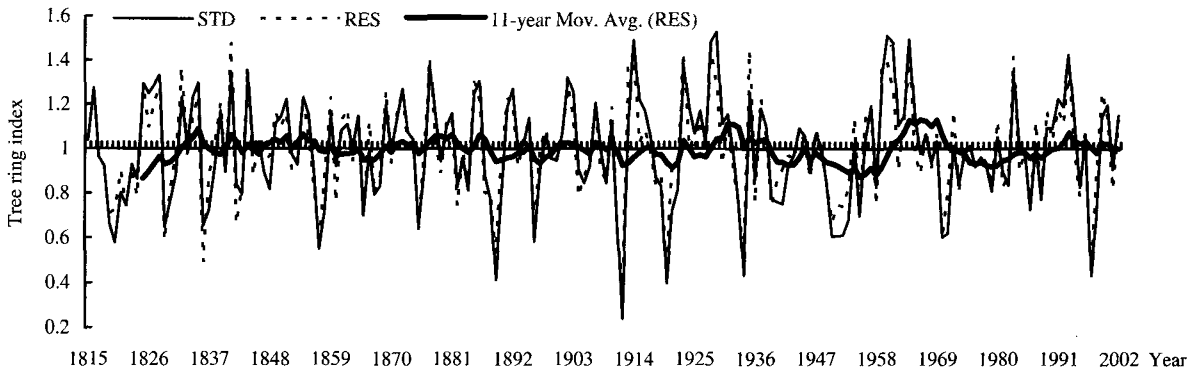

Fig.1 Tree-ring chronologies from each of the six sites standardized to remove long-term growth trends

Climate-growth relationships

Overall results indicated that the temperature showed significant correlation with tree growth (Table 3, Table 4, and Table 5). Significantly positive correlations were found between Tm, Tmax in March (t), Tmin in December (t-1) and RES (Table 3). Negative correlations were found in Tmin in June (t).

Table 3. Correlation coefficient between Erman's birch chronologies and climate data from Tianchi Meteorological station

	Month	Monthly mean temperature	Monthly mean maximum temperature	Monthly mean minimum temperature	Monthly total precipitation	Humid index (Pm/Tm)
	June	0.099	0.027	0.219	0.071	-0.017
	July	-0.025	-0.148	-0.026	0.294	0.261
	August	0.225	0.183	0.249	0.099	-0.009
Previous year	September	-0.197	-0.234	-0.102	0.353*	0.210
	October	0.146	0.125	0.094	0.129	-0.224
	November	0.148	0.068	0.226	0.439*	-0.430*
	December	0.255	0.222	0.368*	0.391*	-0.372*
	January	0.150	0.148	0.197	0.379*	-0.404*
	February	-0.025	-0.078	0.048	0.120	-0.102
	March	0.477**	0.489**	0.171	0.196	-0.228
	April	0.258	0.294	0.178	0.258	-0.428*
Current year	May	0.186	-0.082	0.106	-0.029	-0.347*
	June	-0.289	-0.292	-0.370*	0.280	0.430*
	July	-0.074	-0.058	-0.080	0.014	0.015
	August	0.076	-0.024	0.133	0.193	0.118
	September	0.252	0.187	0.271	0.167	-0.080

Note: ** indicates the correlation is significant at 0.01 level; * indicates the correlation is significant at 0.05 level.

The total monthly precipitation and Erman's birch growth index was highly related surprisingly. Significant correlations ($P<0.05$) between Pm and RES were found in September (t-1), November (t-1), December (t-1), and January (t). In this study, the humid indices (Pm/Tm) were calculated for discussing the common effects of temperature and precipitation on tree growth. The results showed that the humid index had a negative influence on tree radial growth during the November (t-1), December (t-1), January (t), April (t) and May (t), exclusive of positive effect during June (t). It may be proved the temperature had a more effect than precipitation.

The seasonal climate data analysis also showed that the previous winter climate factors had a strong influence on tree growth (Table 4). Furthermore, current spring precipitation and humid index also affected the tree-ring width growth. Non-correlation between the growing season climate and Erman's birch growth was found in this study, which was different from previous studies.

It was interesting to note that the Erman's birch growth was more closely correlated with the short-term climatic variables, such as monthly climatic variables and seasonal climatic variables, than that with the long-term (annually) climatic variables (Table 4, Table 5).

Table 4. Correlation coefficient between Erman's birch chronologies and seasonal climate factors

Items	Mean temperature	Mean maximum temperature	Mean minimum temperature	Total precipitation	Humid index (Pm/Tm)
Previous growth season	0.050	-0.082	0.163	0.319	0.098
Previous winter season	0.294	0.231	0.364*	0.405*	-0.443*
Current spring season	0.336	0.293	0.248	0.403*	-0.321
Before growth season	0.263	0.142	0.167	0.184	-0.329
Current growth season	0.016	-0.070	0.019	0.263	0.133

Table 5. Correlation coefficients between annual climate data and chronologies

Items	Correlation coefficient
Annual total precipitation	0.337
Annual mean temperature	0.303
Annual mean maximum temperature	0.256
Annual minimum temperature	0.364*
Annual humid index	-0.432*

Note: * indicates the correlation is significant at 0.05 level.

In order to verify the result of correlation function analysis, we applied the multi-linear regressive technique (stepwise, the stepping method criteria is based on the probability of F, when Sig≤0.05, the variable was introduced into regression equation) to simulate the tree ring-width variation (RES) by climate data from Tianchi Meteorological station, ranged from 1960 to 1988, and verify the simulation by the climate data from the ORS, ranged from 1983 to 2000. However, considering the high autocorrelation of monthly mean maximum, minimum temperature and mean temperature, and the linearity of the model, only monthly mean temperature and monthly total precipitation were used in regression (Fig. 2). The simulation equation can express as follow:

$RWI=0.995+0.062\times Tp8+0.059\times Tp12+0.074\times T3-0.040\times T6+0.065\times T9+0.031\times Pp7+0.026\times Pp9+0.029\times Pp11+0.038\times P1$ (Regression model: $R^2=0.667$, $N=29$, $P=0.003$; Checked model: $R^2=0.671$, $N=18$, $P=0.002$)

Where, RWI is ring-width index, Tp8, Tp12 are the monthly mean temperature in previous August, December; Pp7, Pp9, Pp11 are the total precipitation in previous July, September, November, respectively. T3, T6, T9 are the monthly mean temperature in current March, June, September, respectively; P1 is total precipitation in current January. The R^2 and P value of Regression and Checked model suggested the result of simulation is reliable.

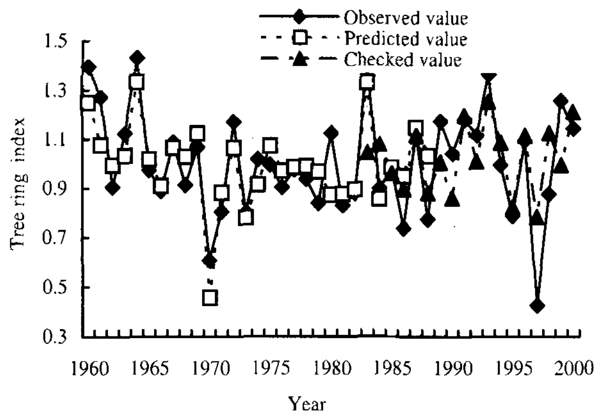

Fig. 2 Time series analysis of tree ring width in Erman's birch tree line. The RES chronology was taken to model with climatic data from TMS, ranged from 1960 to 1988 and the check with climatic data from ORS, ranged from 1983 to 2000.

Growth trends and climate warming

Recent growth trends are not completely consistent with the climate warming trend, as might be expected. Average temperature in Northeast China have been above the long-term mean since the 1920s–1940s and since 1980s–1990s (Delworth and Knutson 2000; Wang *et al.* 2002). In contrast, although growth increase in the two periods is in corresponding period of warming, the growth increases during 1980s was not sustained and during 1960s was not explained by annual mean temperature (Fig.1). The same trends appeared in previous research in Changbai Mountain (Shao and Wu 1997). In the 1960s, annual total precipitation and mean temperature were not above the long-term according to the study on climate change in northeast of China. The seasonal and monthly climatic variables which affect tree growth are more obvious than yearly climatic variables.

Discussion

Compared the results with the other tree species in previous studies by Shao (1997), Erman's birch chronology might be somewhat less informative than those of spruce and larch chronologies, as spruce (*Picea jezoensis(Sieb. Et Zucc.)*) and larch has a slightly stronger signal-to-noise ratio. But the mean sensitivity of Erman's birch chronology is higher than those of spruce and larch chronologies, it implies that the responses of Erman's birch growing in tree line on climatic factors is more sensitive than those of other trees species in the mountain.

Current summer temperature is not main climatic influence factor on Erman's birch growing at tree line, unlike what has been reported for many other species (D'Arrigo *et al.* 1992). Previous winter temperature also influences ring-width growth. Our study sites are located in northeast of China, warmer winter might avoid the frost damage which can do harm to the winter sprout (Cullen *et al.* 2001), and then increase photosynthetic rate by keeping more leaves before the current growing season.

The effect of precipitation on Erman's birch growth suggested that moisture stress might be the dominant climate influence factor (Robertson *et al.* 1988; Hofgaard *et al.* 1999). This result has not been our experience in other high-elevation studies with abundant precipitation. However, it may be the physiological difference between coniferous and deciduous trees. Since Erman's birch growth needs a plenty of water supply (Liu 1989), a little change in water condition could be expressed in the radial growth (Ljoyd and Graunlich 1997). Although the annual precipitation is quite high in the study area, most of them centered on growing season. Due to this area are characterized by thin soil depth, high content of volcanic float stone, and low in soil moisture content. In addition, high solar radiation and relative open canopy (about 0.4) may have resulted in high evaporation rate and fast loss rate of soil moisture, thus the water supply to Erman's birch growth mainly comes from snow of previous winter and precipitation of current spring.

The significant negative correlation between humid index and ring-width index appears to be contradictory with the precipitation effects. In fact, it indicates a co-effect of temperature and precipitation on evaporation. Precipitation influences the temperature of air and soil, and temperature influences the effective water content in soils through evaporation. The correlation between ring-width index and humid index could be biologically explained. The high correlation with humid index may reflect the fact that warm conditions towards the end of the growing season are conducive to the formation of buds and the production of carbohydrates, which result in strong leafing-out and growth in the sequent summer (Schweingruber 1996). Furthermore, in October, November and December, humid index may indicate some influences on the frozen depth of soil, which directly affects the activity of the root system. The temperature in March and April during the beginning of the growing season accelerates the snow melting and soil thawing, and then extends the growing season.

The larger scale of climate warming in the last 100 years in northeast of China has occurred (Wang *et al.* 2002; Richard *et al.* 2002). However, the temperature or precipitation in a certain month may be above the long-term mean value, but the mean temperature or total precipitation in the whole year was not higher, the reverse is also true. If so, the model based on the correlation between the monthly variables and tree ring-width may reflect the growth trend of tree. It is the reason why at the increase of the growth in the 1960s, we did not find the evident of increase in temperature and precipitation. At the other hand, it appears that using only the yearly temperature and precipitation data to simulate the effects of global change on Erman's birch tree growth and distribution may not be accurate.

So far, broad-leaved and deciduous tree species used for studying climate-growth relations are still few. Differences between broad-leaved and conifer species (e.g. Shao and Wu 1997; Shen *et al.* 2001) may indicate the physiological differences between the broad-leaved and conifer species, and this requires further study.

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