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Tree-Ring Width Chronologies and Their Response to Climate in the Qinling Mountains, China

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ABSTRACT

Six localities of tree-ring samples in the Qinling Mountains have been listed in this paper. They are scattered in the mountain area from Huashan in the east to Taibai in the west. The tree-ring width chronologies have been developed and their statistics have been discussed by author. The results of response functions indicate that the tree-ring growth in most sites mainly responds to precipitation's variation except one high elevation site located in the Taibai Mountain.

(Key words: Tree rings, Paleoclimate, China)

1. INTRODUCTION

The Qinling Mountains extend for more than 1,000 km across central China from southern Kansu province in the west to between the Huai River and Yangtze River in the east. However, the stretch in Shaanxi province is typical, with a height of 2,000-3,600 m above sea level (a.s.l.). While making it difficult for moist ocean air currents to penetrate deep into the northwest, the Qinling range also keeps the cold northern air from descending further south, so that southern Shaanxi and Sichuan provinces are hit less often by fierce cold waves. The Mountains form a natural dividing line between the warm-temperate and sub-tropical zones in China. Also, rivers on the southern slopes are longer, while on the northern slopes they are fairly short. Obviously, the Qinling Mountains are very important boundary of climate and geography in China.

Most studies on climatic change during historical times around the Qinling region are concentrated on the plains and hills by using historical documents and few research has been done on the mountain area. Here, author attempt to analyze some tree-ring specimens collected on the high mountains of the Qinling range. Some tree-ring width chronologies would become the useful proxy data for further study of past climate and/or environment variations in the mountain area.

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2. SITE DESCRIPTION AND SPECIES

Tree-ring specimens were collected from six sites of the Qinling mountains in Shaanxi province between 1991 and 1993. Figure 1 shows the locations of these sites. They are identified by HSP, ZAT, ZAA, FPP, TBL, and TBA, respectively (Table 1). The eastern most site is located on a steep peak named Huashan, and the western most site is nearby the highest point of the Qinling Mountains, Taibai peak. The other sites are scattered in Zhen'an and Foping counties. The altitude of the highest site is about 3,300 m where is near the timber line of the Qinling mountains. The dominant species at this height is composed of only *Larix chinensis* Beisen. *Abies chensiensis* can be seen around 3,200 m. The lowest site is FPP with an elevation of 1,850 m. The vegetation type at this altitude is the mixed deciduous broad-leaved and coniferous forest made up by *Quercus liaotungensis, Abies chensiensis, Betula platyphlla* and *Pinus tabulaeformis.* Sites in the mountains between the altitudes of 2,000 and 2,500 m are located in coniferous forest zone. The dominant species are *Pinus armandii, Pinus tabulaeformis, Tsuga chinensis* and *Abies chensiensis.*

It should be noted that the climate at each site is different from each other. As altitude increases, the temperature decreases. Therefore, the duration of growing season differs in different altitude. Growing season could last 4-5 months near the elevation of 2,000 m, and only 2-3 months near the elevation of 3,000 m and more. As for precipitation distribution, there is not only significant local features, but also a level of maximum precipitation with the altitude of 2,000-2,500 m. The annual total precipitation can reach up to 1,000 mm at the maximum (Agriculture and Livestock-Raising Department of Shaanxi Province, 1986).

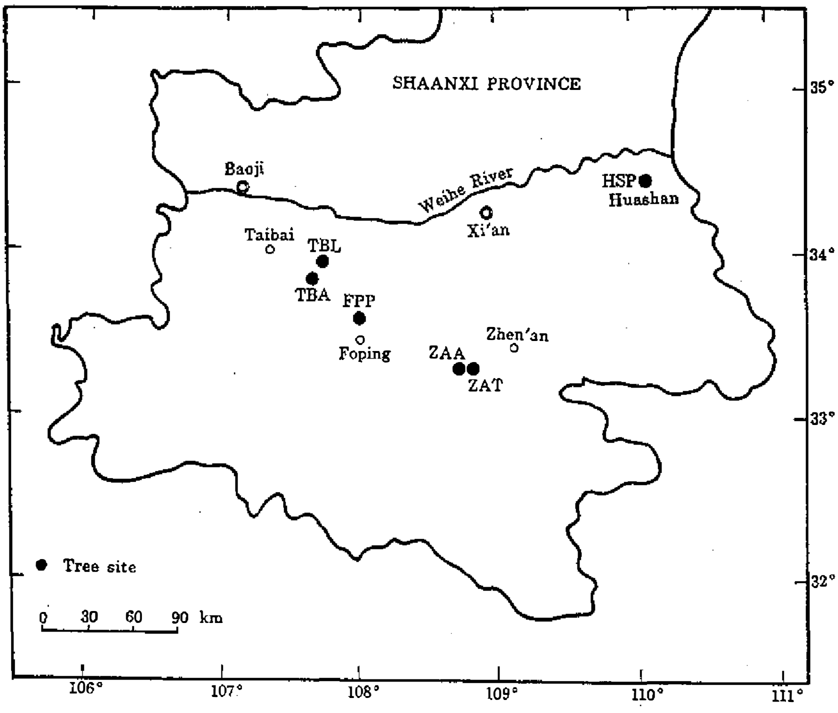

Fig. 1. Location of tree-ring sites in the Qinling Mts.

Table 1. Summary of six tree sites in the Qinling Mts.

Site	I.D.	Lat. (N)	Log. (E)	Elevn. (m)	Species	Number of cores		Length(Yr)
						Collected	Used	
Huashan Peak	HSP	34°29'	110°05'	2050	Pinus amandii Franch	42	34	1540-1989
Taibaishan	TBL	33°59'	107°45'	3300	Larix Chinensis Beisen	52	38	1705-1992
Huangbeiyuan, Taibai	TBA	33°55'	107°41'	2500	Abies chensiensis Van Tieghem	28	20	1801-1989
Longcaoping, Foping	FPP	33°38'	108°00'	1850	Pinus tabulaefomnis carr	20	9	1861-1990
Yinzuiyan, Zhen'an	ZAA	33°25'	108°45'	2500	Abies chensiensis Van Tieghem	26	24	1870-1989
Muwangping, Zhen'an	ZAT	33°25'	108°50'	2200	Tsuga chinensis Beisen	30	19	1618-1989

The species of our samples include *Pinus armandii, Larix chinensis, Abies chensiensis, Pinus tabulaeformis* and *Tsuga chinensis* in six tree sites of the Qinling Mts. According to Wu (1990), these species have been sampled in other areas of China for dendroclimatological study except *Pinus armandii.*

Number of trees sampled at each site is different one another. The maximum one includes 26 trees, 52 cores. The minimum counts up to 10 trees, 20 cores.

3. CHRONOLOGY DEVELOPMENT

General reviews of the use of dendroclimatic techniques in China are given by Wu *et al.* (1987), Wu and Zhan (1991a) and Wu (1992). Since the 1990s, modern dendrochronological techniques, which have been successful applied to mesic forest trees elsewhere in the world, have been used in China. Taking tree site Huashan as an example, authors have described the detail of building chronology HSP in another paper (Shao and Wu, 1994). A few key points will be.emphasized in this paper.

Cross-dating is one key in dendrochronological work. All ring width data are measured carefully and tested by program COFECHA (Holmes, 1983). Based on results from cross-dating, a few series, which contain some unusual rings or have unsure relationship with master chronology or have not enough length, were rejected from the final master chronology at each site. For example, 14 series had to be rejected in site TBL, and 38 series were adopted for establishment of the final tree-ring chronology.

Detrending is another key for chronological development. Very low-frequency trends and changes in tree growth can appear in an appropriate curve fitted to the data for each individual series by least-squares techniques. In order to minimize the influence of strong competition among trees on the high frequency signal, cubic smoothing spline function (Cook & Peters, 1981) was employed in the detrending procedure for our most specimens. Sometimes, spline function might be a better way for detrending when the ring growth appears as "Sine" or "U" patterns as shown by earlier studies (Wu & Zhan, 1991b). The optimum spline with a 50% frequency cutoff of the certain year which was varied from 50 to 250 years was chosen at each ring-width series. The selection of spline-function stiffness depends upon the value of signal-to-noise ratio (SNR) and our experience.

After detrending, a time series model was fitting to the individual series and residuals calculated. At last, three ring-width chronologies, standard (STD), autoregressive standard

(ARS) and residual (RES), were accomplished at each site using the program ARSTAN (Cook, 1985; Holmes, 1992). All chronologies except TBL were developed at Lab of Tree Ring Research, University of Arizona, Tucson, USA.

Some statistics for six ring-width chronologies have been shown in Table 2. They include the first order autocorrelation (a), mean sensitivity (M.S.) and standard deviation (S.D.) of three chronologies (STD, ARS and RES), the correlation coefficients (r_1–among all radii, r_2–between trees and r_3–within trees) and SNR of two sequences (De–detrending and Re–residual).

Table 2. Statistics for ring-width chronologies at six sites.

I.D.	SID			RES			ARS			r_1		r_2		r_3		SNR	
	a	M.S.	S.D.	a	M.S.	S.D.	a	M.S.	S.D.	De	Re	De	Re	De	Re	De	Re
HSP	0.25	0.21	0.22	-.03	0.22	0.19	0.16	0.21	0.20	0.26	0.41	0.25	0.40	0.51	0.63	5.68	11.51
TBL	0.53	0.25	0.30	-.06	0.29	0.25	0.52	0.26	0.30	0.57	0.54	0.57	0.54	0.70	0.69	25.03	22.26
TBA	0.54	0.16	0.24	0.02	0.14	0.14	0.58	0.15	0.23	0.33	0.38	0.32	0.38	0.54	0.54	4.75	6.02
FPP	0.34	0.18	0.20	-.05	0.20	0.17	0.34	0.18	0.20	0.23	0.32	0.23	0.32	-	-	2.33	3.84
ZAA	0.52	0.11	0.13	-.09	0.14	0.12	0.40	0.11	0.12	0.16	0.22	0.15	0.20	0.52	0.54	2.05	3.01
ZAT	0.47	0.19	0.23	0.01	0.17	0.15	0.57	0.18	0.24	0.26	0.32	0.24	0.30	0.56	0.62	2.86	3.86

It seems that there is no significant difference between chronologies at each site, based on the statistics a, M.S. and S.D. values. However, the values of r_1, r_2, r_3 and SNR for residual series are larger than those for detrending series at 5 sites (HSP, TBA, FPP, ZAA and ZAT). Among them, r_3 of FPP could not be calculated because of limited samples. It could be inferred that chronologies developed by residual series would be better than those by detrending series directly for all sites except TBL.

We tried to put all series of ZAA and ZAT together in order to compare their basic characteristics on ring-width variation. Adopting program COFECHA, the relationships between all series were analyzed. It could be found that almost all years in which narrow or missing rings appeared seem to be coincident for both chronologies of ZAA and ZAT. Considering the disposition of wide and narrow rings, it could be assumed the patterns of ring-width variation are very similar. If they were from the same species, we would combine all series of two chronologies into one chronology. It makes sense because the distance between two tree sites located in the same climate zone with a level of maximum precipitation is not far away, especially the altitude difference is only 300 m. In fact, the vegetation and environment at two sites are also similar. It is possible that their ring growth could be limited by the similar climatic factors.

Similarly, this comparison has been made for TBL and TBA. However, their ring-width patterns are quite different excepting a few narrow rings are coordinate in two chronologies. Obviously, this circumstance might be caused by different environment. TBL is located near upper tree line with low temperature. Its species is *Larix chinensis* which is hard to live in warm climate zone. TBA is located in a warm zone with the level of maximum precipitation. Its elevation is 800 m lower than TBL's. In addition to those, TBL and TBA are separated by the Taibai peak (3,767 m a.s.l.), i.e. they are located on the northern and southern slops, respectively. It is no doubt that the limiting factors of their tree growth should be different.

4. RESPONSE TO CLIMATE

Response and correlation functions have been widely used to estimate how ring-width growth responds to variations in monthly temperature and precipitation conditions (Fritts, 1976). Before the calculation, one of three ring-width chronologies at each site was chosen as representative of the tree site. The STD chronology seems to be suited for site TBL, and the RES chronology can be applied for other five sites. Another key is about the selection of near meteorological station as basic reference point. In this study, Huashan, Taibai, Foping and Zhen'an meteorological stations are considered as the points. Most of them are about 20-40 km distant from one or two tree sites. The nearest one is on the Huashan peak. Most increment cores were collected around the meteorological station.

As for the determination of climate factor number, it can be adopted for most sites to select monthly mean air temperature and total precipitation for 12 months starting with October of the last year. The total predictors amount to 24. Although 12-month length is also selected for TBL, the ending month is July rather than September because of the short growing season.

By carrying out analysis of an orthogonal transformation and all-step multiple regression on the tree-ring chronologies (Fritts and Wu, 1986), the response functions for them with coordinate climate data have been derived and the statistics summary are shown in Table 3.

Table 3. Statistics for response functions at six sites.

I.D.	Chronology	MCC	F Value	Significa Element			Total Factors
				tem.	ppt.	Total	
HSP	RES	0.80	5.55	4	5	9	24
TBL	STD	0.84	4.66	4	6	10	24
TBA	RES	0.86	2.86	4	0	4	24
FPP	RES	0.87	6.50	7	6	13	24
ZAA	RES	0.57	4.26	3	6	9	24
ZAT	RES	0.54	3.50	4	2	6	24

The multiple correlation coefficient (MCC) of final regression equation seems to indicate that the relationship between climate and tree growth for HSP, TBL, TBA or FPP is better than ZAA or ZAT. The former can reach 0.80 or more and the latter is lower than 0.60. The number of statistically significant element is quite different at each site. The maximum number can reach 13, and the minimum is only 4.

In order to explain the output of response function, we take two sites as examples in this section. First, the response function of HSP is shown in Figure 2. The significant factors are January, April, June and September for temperature and December, May, June, August and September for precipitation. In addition to this, the correlation coefficients, passing significance test at the 0.99 confidence level, between climate factors and each chronology (STD, ARS and RES) of HSP are selected. It can be found that temperature in April and June and precipitation in May and June are most significant factors.

High temperature in April would be benefit to cambium activity of trees and to shift the beginning of growing season to an earlier data. With starting growing season, positive relationship between tree growth and precipitation in May was significant. In June, high temperature which may be related with large evaporation and less water in soil may influence normal tree growth. The high temperature and less precipitation in June could lead to increased water stress in tree, which causes decrease of tree growth rate. Thus, there are significant negative response of temperature and positive response of precipitation in June. The high temperature and enough precipitation during rain season in July and August may satisfy the needs of tree growth. It seems that variations of temperature and precipitation is no longer the limiting factors of tree growth at Huashan (Shao and Wu, 1994). Further study indicates that the chronology of HSP can be used for reconstruction of total precipitation during May and June and/or from April through June.

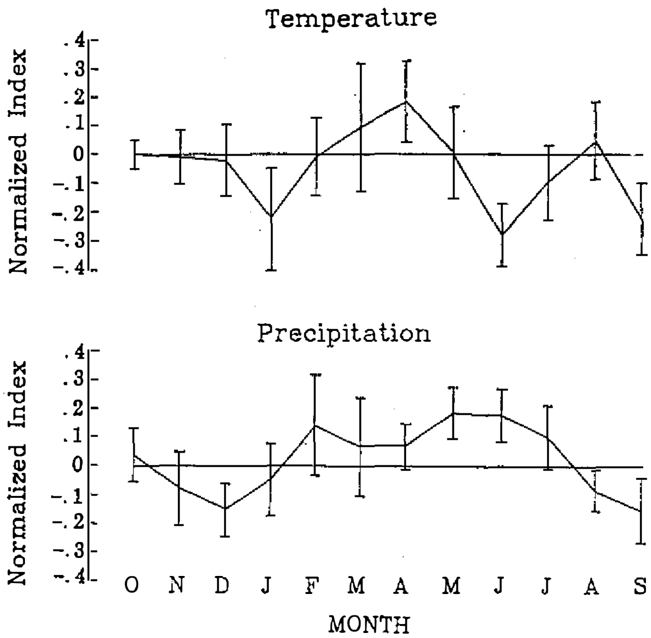

Fig. 2. Response function for chronology HSP with Huashan climatic data. The vertical lines designate the 0.95 confidence range.

Another example we will mention is TBL. Its response function is shown in Figure 3. It portrays that the main feature of response to precipitation is negative during the whole year except prior a couple of months. It suggests that high temperature by prior October would be of benefit to nutrition-material accumulation through photosynthesis. Thus, the positive response appears by then. As for the significant negative response in December and January, it demonstrates that high temperature might lead to the excessive expense of nutrition in tree and influence future tree growth in a few months. After then, response of ring-width growth to climate factors is not significant until June. It is obvious that June is the most important period of growing season and leads to formation of most part of the ring width. It supports that high temperature in June must be helpful to tree-ring growth. With coming of rain season in July, high temperature which is basically in accordance with less precipitation and strong evaporation may limit the normal growth of tree ring. Significantly, negative response of ring width to temperature in July appears. Based on those mentioned above, we can suppose that the tree growth of TBL located in the Taibai Mountain could be controlled by air temperature, especially in winter and growing season.

Other chronologies have been analyzed, similarly, by using response function. It seems, in varying degrees, that the response of tree growth in those sites to precipitation is significant and sensitive. However, it should be point out that there is no significant element of precipitation for TBA. Even though there are 13 significant elements for FPP, the chronology contains 9 cores only. In the further study, we should add more tree-ring samples and/or modify the response models for TBA and FPP.

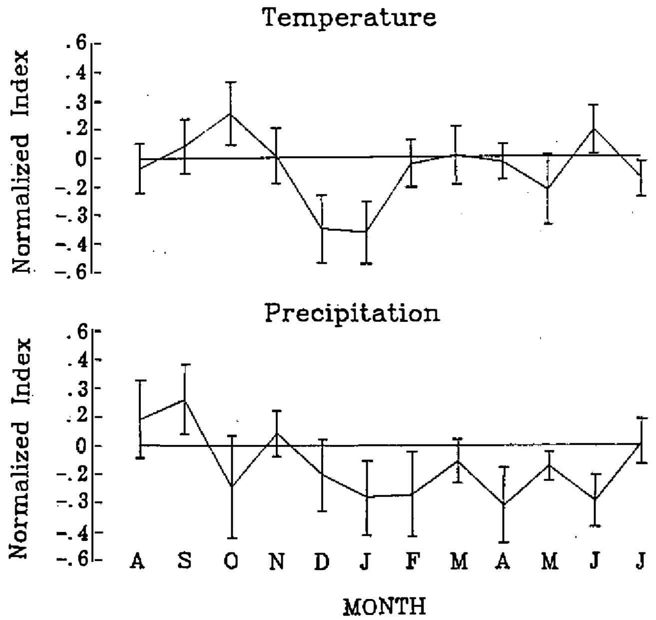

Fig. 3. Response function for chronology TBL with Taibai climatic data. The vertical lines designate the 0.95 confidence range.

5. CONCLUSION

This study has demonstrated the development of some ring-width chronologies and their response to climate in the Qinling Mountains, China. Some results could be summarized as follows:

(1) Tree growth of some species in the Qinling Mountains, such as *Pinus armandii, Pinus tabulaeformis, Larix chinensis, Abies chensiensis* and *Tsuga chinensis,* has significant response to climate factors, so that some of them could be used for dendroclimatological study.

(2) Considering the complicated environment for most tree sites below 2,500 m in the Qinling Mountains, the RES chronology may be adopted for the further climatological study.

(3) Tree growth of TBL located in an upper tree-line seems to be controlled by air temperature, but other chronologies with the elevation of 2,500 m or less are mainly positive in response to precipitation.

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