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Dendrochronologia 24 (2007) 91–95

DENDROCHRONOLOGIA

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ORIGINAL ARTICLE

A millennium-long tree-ring chronology of *Sabina przewalskii* on northeastern Qinghai-Tibetan Plateau

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Received 15 December 2005; accepted 25 May 2006

Abstract

Long tree-ring records on the Qinghai-Tibetan Plateau (QTP) are important for understanding better the Asian monsoon variability and its linkage with other global climate systems such as El Niño/Southern Oscillation activities. Here we report a 1017-year tree-ring chronology of *Sabina przewalskii* Kom. from the northeastern QTP. Climate–growth response function and correlation analyses show that radial growth of *Sabina* trees is positively associated with total precipitation in May and June of the growth year. Multidecadal variation in Delingha tree-ring chronology exhibits similar pattern with those of Dulan and Wulan chronologies of the nearby areas, suggesting that spring precipitation is a major factor limiting the growth of *Sabina* trees over a large spatial scale. Corresponding to the Little Ice Age, the three chronologies indicate spring droughts during 1440s to mid-1510s, mid-1640s to 1720s, late 1780s to late 1820s, and around mid-1870s. Examination of the tree-ring record in two largest historically documented El Niño events of 1789–93 and 1877–79 reveals that these very strong El Niño events were associated with conditions of spring droughts, and weakening of pre-monsoon circulation may precede occurrence of El Niño in some cases. The relationship between reduced monsoonal precipitation and very strong El Niño activity is, however, much complex and worth further study by spatio-temporal expansion of data coverage in the future.

Introduction

The Qinghai-Tibetan Plateau (QTP) has an average elevation greater than 4000 m asl, with several mountain peaks soaring above 8000 m asl. It acts as a mechanical barrier to mid-latitude atmospheric circulation and as an elevated thermal regulator that modulates Asian monsoon circulation (Tang et al., 1979; Murakami, 1987). Observed climatic records in this vast area are, however, short and incomplete, making it difficult to evaluate the full range of climate variability in the region. Therefore, development of long-time series and high-resolution climate proxy data on the plateau is of significance for understanding better the past natural climate variability.

Previous studies (Kang et al., 1997) showed that there is a great potential for building millennium-long tree-ring chronologies from living trees of *Sabina przewalskii* Kom. on the QTP, and for extending the chronologies to two-millennium long records with the aid of archaeological wood (Xu, 2002). Given the longevity of *Sabina* trees and their sensitivity to climate change, we undertook a dendroclimatological study of this species in Dulan, Wulan, and Delingha areas of the northeastern QTP in the autumn of 2001. To date, we have established a 2326-year ring-width chronology for

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doi:10.1016/j.dendro.2006.10.009

Dulan area (Zhang et al., 2003) and a 680-year chronology for Wulan area (Huang and Zhang, 2006). In this paper, we report a 1017-year ring-width chronology of *S. przewalskii* for Delingha area of northeastern QTP, and compare it with other chronologies in the nearby areas to gain insights into the regional climate variation in the past millennium. Particularly the tree-ring record allows us to examine the regional climate in the Little Ice Age and to increase our knowledge about the relationships between Asian monsoon and El Niño events.

Materials and methods

Our study area is located in Delingha, Haixi prefecture of Qinghai province, China (Fig. 1). Based on the climate data in the meteorological station of Delingha (37°22′N, 97°22′E, 2981.5 m) for the period from 1956 to 2000, mean annual air temperature is 3.6 °C, with a mean temperature of 16.7 °C in July and −11.9 °C in January. Mean annual total precipitation is 158.0 mm, with a mean monthly sum of 34.0 mm in June. The annual climatic regime (Fig. 2) for the area shows that precipitation mainly occurs during May–August, and temperature is below 0 °C from November to March of the following year.

The tree-ring samples used in this study were collected from living *Sabina* trees on south-facing mountain slopes in northeast of Delingha city. The geographic location of our sampling site is 37°27′N, 97°56′E. The *S. przewalskii* is a coniferous tree species that belongs to the family of *Cupressaceae*. It is a single dominant tree species growing sparsely in open stands at an elevation between 3500–3900 m in our study area. Trees with a large diameter stem were selected for sampling, and one core per tree was extracted at breast height (two cores were extracted from a few exceptionally long-lived trees). The selection of trees was based on examination of local conditions, such as coarse-textured soil on a slope, and minimal competition from neighbouring trees (Fritts, 1976). A total of 62 increment cores were collected from 42 trees.

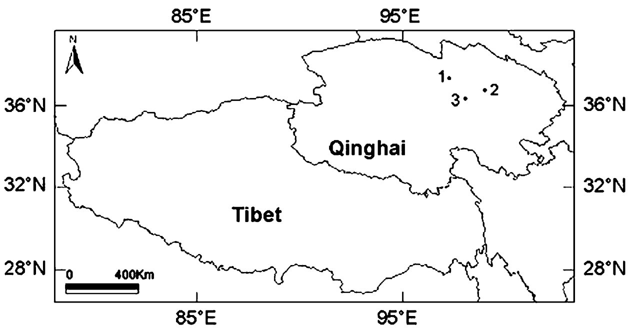

Fig. 1. Locations of tree-ring sampling sites in Delingha (1), Wulan (2) and Dulan (3) on the northeastern Qinghai-Tibetan Plateau.

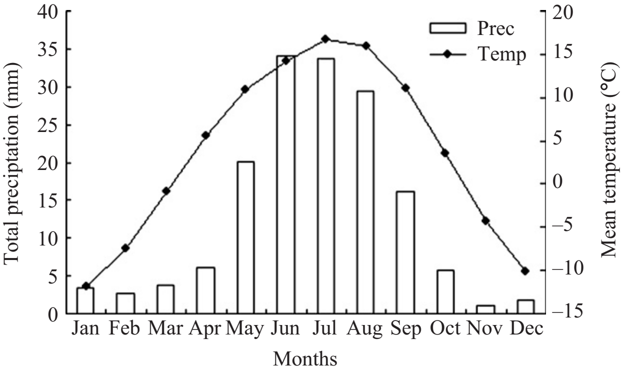

Fig. 2. Annual climatic regime for Delingha, Qinghai province, China (Averaged for AD 1956–2000 from Delingha meterological station).

In the laboratory, the increment core samples were mounted in grooved wooden boards and polished by hand with a series of sandpaper grits up to 600. Ring widths of these samples were measured to the nearest 0.001 mm with a Lintab tree-ring measurement system. The measured ring-width sequences were then crossdated by a variety of means such as examination of the samples under microscope to identify the pointer years, matching ring-width time series among the samples on a plot, and quality-checking with the software COFECHA (Holmes, 1983). Samples that could not be crossdated due to an excess of missing rings and poor quality (such as fragmented or rotten parts) were excluded from further analyses. For the trees with more than one core, only the best-quality one was selected for chronology building to make each sample statically independent. In total, 37 increment cores were crossdated and selected for construction of tree-ring chronology.

The crossdated ring-width sequences were standardized to remove the age-related growth trend using the software ARSTAN (Cook and Holmes, 1996). The detrending curve selected was a negative exponential curve, a horizontal line or a straight line with negative slope. The standardized ring-width sequences were then averaged together by year across different samples. The resulting tree-ring chronology represents growth variations caused by common environmental forcing, most likely the climate. The interval of standard chronology, from AD 984 to 2000, has at least six sample replications and is used for further climatic analyses.

Relationships between tree-ring chronology and climatic variables were identified by means of response function and correlation analyses. The response function, a linear multiple regression technique that uses the principal components of monthly climatic variables to estimate tree-ring growth, was computed using the software PRECON (Fritts, 1994). The predictor variables were monthly mean temperature and total monthly precipitation in a 14-month period, starting from August of the previous year to September of the growth year. Significance test of the response coefficients was conducted using a bootstrap method (Guiot, 1991) in which we used 1000 replications. The correlation analysis was helpful in understanding the climate–growth relationships by directly calculating Pearson correlation coefficients from month to multimonth seasons. The climate data were obtained from the meteorological station in Delingha for the period from 1956 to 2000. Climatic interpretation of the tree-ring chronology was based on the results of climate–growth relationships and on the comparisons with other proxy data in nearby areas.

Results and discussion

A 1017-year ring-width chronology of *S. przewalskii* was developed for Delingha area (Fig. 3). Mean sensitivity of the tree-ring series was 0.39 and mean inter-series correlation coefficient was 0.76 (Table 1), indicating that the tree-ring samples contain sufficient common climatic signals (Fritts and Shatz, 1975). The chronology is capable of preserving much of the climate variance on time scales from interannual to a few hundred years because the average length of the 37 samples is 594 years (Cook et al., 1995).

The results of climate–growth response function analysis show that radial growth of *Sabina* trees is positively associated (at $p < 0.05$) with precipitation in May and June of the growth year (Fig. 4). The response function represents 77.5% of the variance in tree-ring chronology. Simple correlation analyses show that the tree-ring indices are most strongly correlated with the total precipitation in May and June ($r = 0.59$, $p < 0.001$), a result similar to that observed in dendro-climatological studies of the same species in Dulan ($r = 0.58$, $p < 0.001$) (Zhang et al., 2003) and Wulan ($r = 0.46$, $p < 0.01$) (Huang and Zhang, 2006), suggesting that the radial growth of *Sabina* trees in these areas respond in the same manner to variations in spring precipitation (Fig. 1).

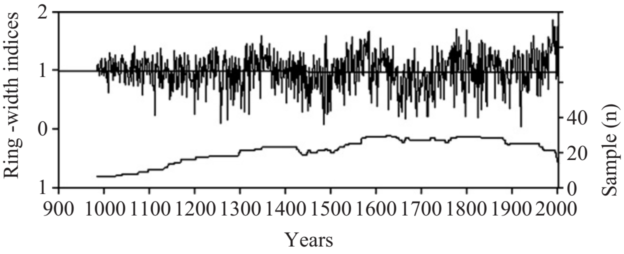

Fig. 3. The 1017-year ring-width chronology of *Sabina przewalskii* Kom. and the number of samples for each year in Delingha area of northeastern Qinghai-Tibetan Plateau.

The chronologies in Delingha, Dulan and Wulan show a similar pattern in low-frequency variation in the common interval AD 1322–2000 (Fig. 5). The three chronologies reveal that prolonged spring droughts occurred regionally during 1440s to mid-1510s, mid-1640s to 1720s, late 1780s to late 1820s (although not very evident in Delingha), and around mid-1870s. Above average spring precipitation at decadal to multidecadal scales occurred regionally during mid-1350s, 1530s–1570s, 1740s to mid-1760s, around the turn of the 19th to 20th century, and the last two decades of the 20th century. The periods of low spring precipitation coincided with intervals of the Little Ice Age (LIA) that was shown by low δO^{18} values in ice cores on the QTP (Yao et al., 1997). This observation suggests that the precipitation regime of the LIA in our study area was characterized by occurrence of episodic spring droughts, rather than a sustained dry condition. The general pattern in our tree-ring data agrees with that in tree-ring records obtained in other study sites of the same region in the northeastern QTP (Shao et al., 2004; Sheppard et al., 2004). These agreements among different areas suggest that the tree-ring growth in this region is subject to variation in spring precipitation over large spatial scale.

It has been reported that failure of southwest Asian monsoon has a relationship with strong El Niño activities (Charles et al., 1997), but it is not clear whether or not this relationship holds true on QTP. Examination of the Delingha tree-ring record in periods of two largest historically documented El Niño events in 1789–93 (followed by moderate El Niño events in 1794–1797) and 1877–79 (Quinn et al., 1987; Grove, 1998; Ortlieb, 2000) shows that the spring precipitation decreased in these periods. For example, in the extended El Niño activities of 1789–1797, the spring precipitation was below the average from 1789 to 1797 and, particularly, in 1789, 1792, 1794, 1796 and 1797 as evidenced by obviously narrow rings in the samples (Fig. 6). Because reduced spring precipitation is a

Table 1. Dendrochronology characteristics of *Sabina przewalskii* Kom. in Delingha of northeastern Qinghai-Tibetan Plateau

Chronology length	No. of trees	No. of trees with signal strength of 0.80 attained	Mean sensitivity	Mean serial correlation
984–2000 AD	37	6	0.39	0.76

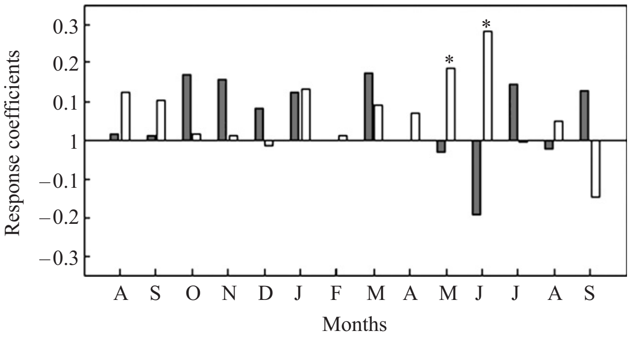

Fig. 4. Response function coefficients showing the relationships between radial growth of *Sabina przewalskii* Kom. and monthly mean air temperature and total monthly precipitation in Delingha area of northeastern Qinghai-Tibetan Plateau. Black bars stand for temperature, white bars for precipitation, and the star sign for significance at the 0.05 level as tested by bootstrap method.

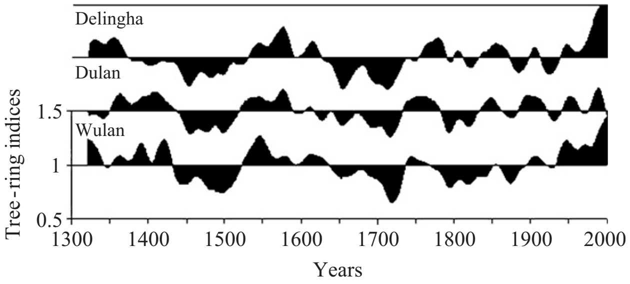

Fig. 5. Smoothed tree-ring chronologies of *Sabina przewalskii* Kom. for Delingha, Dulan, and Wulan areas of northeastern Qinghai-Tibetan Plateau. The smoothed curves were derived from a cubic spline passing 50% of the variance in a sine function with a wavelength of 32 years.

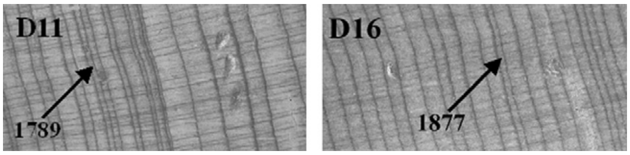

Fig. 6. Example of tree-ring samples showing the narrow rings (indicated by arrows) corresponding to the intense El Niño events in 1789–93 (followed by moderate El Niño activity in 1794–97) and 1877–79. The codes on the top left of the pictures indicate the labels of the samples.

reflection of weakened pre-monsoon circulation, the pattern in our tree-ring data from 1789 to 1797 suggests that weakened pre-monsoon on the northeastern QTP is likely associated with strengthened El Niño event. High dust and chloride concentrations in ice core data from QTP in this interval also showed major monsoon failures and an association with the El Niño events (Thompson et al., 2000).

The frequent occurrence of droughts and El Niño events during 1789–1797 precludes us from further examining the temporal linkage between the weakening of monsoon and occurrence of El Niño because it is hard to tell if a weakened monsoon is the cause of the following El Niño or the result of the preceding El Niño. In the historically documented large El Niño event in 1877–79, trees in our study area exhibited narrow rings in 1877 (Fig. 6). This observation suggests that the weakening of pre-monsoon might precede the occurrence of El Niño. Further examination of other El Niño events and the Delingha tree rings, however, did not produce a statistically consistent relationship between the monsoon and El Niño activities. This phenomenon suggests that the relationship between monsoon and El Niño is much complex and may not be stable through time.

Conclusions

Tree-ring reconstruction of late Holocene climate over hemispheric scale requires long data sets covering extensive and diverse areas of the world (Briffa, 2000). Our millennium-long tree-ring chronology in Delingha area adds a new climate proxy record for the recently expanded tree-ring network of northeastern QTP (Shao et al., 2004; Liu et al., 2006). Our observation that the tree-ring chronologies in Delingha, Dulan, and Wulan areas show a similar pattern in low-frequency variation suggests that the growth of tree rings in this region is subject to variation in spring precipitation over large spatial scale. The very strong El Niño events during 1789–93 and 1877–79 corresponded with intervals of reduced pre-monsoonal precipitation on the northeastern QTP, but the relationship between monsoon and El Niño activities seems to vary through time. Expansion of tree-ring data coverage on the QTP and accumulation of precisely dated, high resolution and long continuous proxy data of El Niño activities are needed to better understand the nature of the monsoon–El Niño relationships.

Acknowledgments

We thank Mr. Xingcheng Kang, Jianguo Huang, Xiaowen Pang, Zhanjun Yang, and Jinxin Du for field assistance. Fundings were provided by the Key Project 90102005 from the National Natural Science Foundation of China, the Innovation Project 210087 from the Cold and Arid Regions Environmental and Engineering Research Institute, and the Project C907 from the Institute of Botany of the Chinese Academy of Sciences.

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