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EXPLORATORY TEMPERATURE AND PRECIPITATION RECONSTRUCTIONS FROM THE QINLING MOUNTAINS, NORTH-CENTRAL CHINA

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ABSTRACT

February–April (FMA) temperature at Foping (1879–1989) and July–August (JA) precipitation at Xian (1895–1988) have been reconstructed using total ring width (TRW) and maximum latewood density (MXD) from trees in the Qinling Mountains, at the northern limit of the East Asian monsoon, in central China. The Xian JA precipitation reconstruction, albeit short, represents the first well-replicated, crossdated dendroclimatic reconstruction of summer monsoon precipitation for this region. Reconstructed Xian precipitation shows significant positive relationships with historical evidence from the region. The key feature of the precipitation reconstruction is prolonged summer drought during the late 1920s and early 1930s. The Foping reconstruction displays warmer-than-average FMA temperatures during this time period.

These exploratory reconstructions, along with a previous reconstruction from Huashan, demonstrate the complexity of attempting dendroclimatic reconstructions from this region. Our results indicate that further attempts to locate long-lived conifers from here can result in an extended well-calibrated and verified reconstruction of summer monsoon precipitation.

Keywords: China, Asian monsoon, temperature, precipitation, dendroclimatology.

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INTRODUCTION

Central China is a rich source of paleoclimatic information, including a network of historical document sites with seasonally resolved data for more than 500 years (State Meteorological Administration 1981; Zhang, J. 1988; Zhang and Crowley 1989) and annually resolved climatically sensitive tree-ring records (Hughes *et al.* 1994; Leavitt *et al.* 1995a). The Qinling Mountains of Shaanxi Province, central China, stand near the northern limit of East Asian monsoon penetration and form a natural division between the semiarid grasslands of northern China and subtropical forests to the south. A variety of conifer species with demonstrated annual growth increments can be found there (Hughes *et al.* 1994; Shao and Wu 1994; Wu 1995). Abundant opportunities exist for reconstructing summer monsoon precipitation and its associations with ENSO (Wang and Li 1990; Liang and Wang 1998), as well as temperature variations that display close associations with hemispheric temperature variations (Bradley *et al.* 1987). Reconstructions of these variations for large regions of northern and eastern China have been produced using documentary evidence (Wang and Wang 1990; Zhang 1991; Wang and Wang 1994), but such evidence relies heavily on source material with a bias toward recording extreme events (Zhang, D. 1988). Summer (July–August) precipitation has not been reconstructed for north-central China; moreover, summer precipitation reconstructions from other regions of China have been hampered by lack of crossdating and sufficient sample replication (Wu and Wang 1989; Wu 1992). Dendroclimatic reconstructions can provide independent corroboration of historical records, as well as new information about the past climate of China.

Here we report short reconstructions of February–April temperature at Foping in the central Qinling Mountains and summer monsoon precipitation at Xian. We compare these reconstructions with instrumental, documentary, tree-ring and isotope evidence from central and eastern China.

DATA AND METHODS

Site Descriptions

Tree-ring samples were collected from nine sites in the Qinling Mountains, between 1990–1993 (Figure 1 and Table 1). The terrain is highly dissected, with elevations between ~400 m and ~3200 m. The region is characterized by a monsoonal precipitation regime, with a single peak in

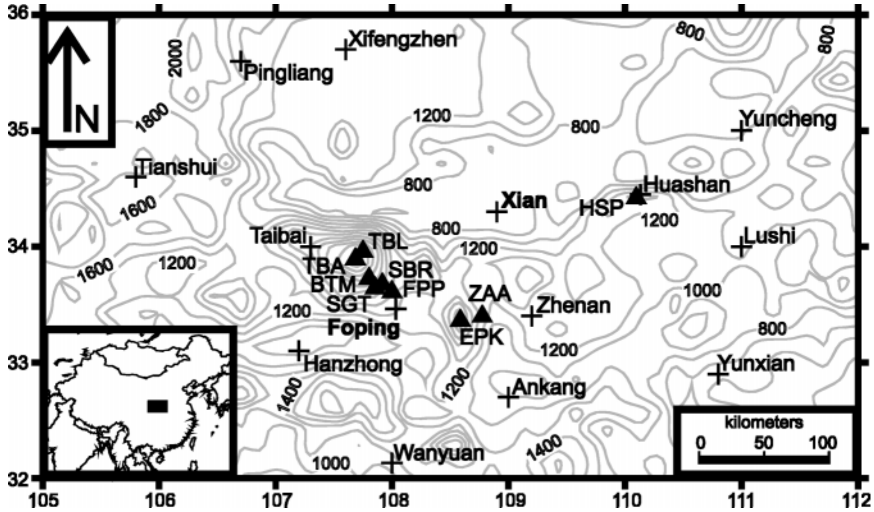

Figure 1. Central China meteorological station and tree-ring sampling sites. Tree-ring chronology sites are indicated with triangles (see Table 1 for site information); meteorological data stations are indicated with pluses. The contour interval is 200 m. Altitude estimates are from the United States National Geophysical Data Center TerrainBase Global Model (5’ x 5’) and are expressed in meters (Row *et al.* 1995).

Table 1. Qinling Mountains site information.

Site	ID	Species	Lat. (N)	Lon. (E)	Alt. (m)	Length (yr)		# Trees (cores)	
						TRW	MXD	TRW	MXD
Taibai (Huangbeiyuan)	TBA	*Abies chensiensis*	33°55′	107°41′	2,500	1801–1989	1871–1989	10 (20)	8 (13)
Taibai (Taibaishan)	TBL	*Larix chinensis*	33°59′	107°45′	3,300	1751–1992	1750–1992	20 (20)	20 (20)
Baretop Mountain	BTM	*Larix chinensis*	33°45′	107°48′	2,700	1600–1992	1632–1991	19 (39)	13 (18)
Sanguan Temple	SGT	*Tsuga chinensis*	33°39′	107°48′	1,900	1575–1992	1725–1992	18 (29)	16 (28)
Sangebao Ridge	SBR	*Abies chensiensis*	33°41′	107°50′	2,400	1842–1992	1841–1992	9 (14)	8 (13)
Foping (Longcaoping)	FPP	*Pinus armandii*	33°38′	108°00′	1,850	1861–1990	1861–1990	9 (9)	9 (9)
Eagle Peak	EPK	*Abies chensiensis*	33°25′	108°40′	2,440	1611–1992	1711–1992	19 (32)	10 (14)
Zhenan (Yinzuiyan)	ZAA	*Abies chensiensis*	33°25′	108°45′	2,200	1870–1989	1870–1988	12 (24)	10 (20)
Huashan	HSP	*Pinus armandii*	34°29′	110°05′	1,990	1540–1989	1525–1988	17 (34)	20 (34)

annual precipitation during the boreal summer (July–August), accompanied by a marked change in wind direction and increased moisture availability (Domrös and Peng 1988). Ecosystems range from semiarid grasslands to the north of the Qinling, through mixed deciduous broad-leaved forest at lower mountain elevations, and conifer forest at higher elevations. Our sampling sites are distributed throughout the coniferous forest zone, with *Larix chinensis* Beissner occupying much of the upper treeline. At the time of sampling, this region was little explored by dendrochronologists (Hughes *et al.* 1994; Shao and Wu 1994). In conjunction with sampling for isotope analyses from these and nearby ranges (Leavitt *et al.* 1995a, 1995b; Liu *et al.* 1996), we collected a variety of species from several locations. Two radial samples per tree were obtained. Some of the chronologies extend back into the 16th and 17th Centuries; however, adequate sample size and signal strength was not often achieved until the 19th Century (see below). The Foping, Huashan, Taibai and Zhenan chronologies were based on collections made by Chinese colleagues (Hughes *et al.* 1994; Shao and Wu 1994; Wu 1995).

Meteorological Data

Meteorological data for the Qinling Mountains region were selected from the Carbon Dioxide Information Analysis Center (CDIAC) database (Kaiser *et al.* 1993) and the U.S. National Climatic Data Center (NCDC) Global Historical Climatology Network (GHCN; Vose *et al.* 1992; Peterson and Vose 1997). Additional data (Foping, Zhenan and Taibai stations; Figure 1) were provided by Dr. Shao Xuemei (Institute of Geography, Chinese Academy of Sciences, Beijing, China).

All data were screened using statistical techniques specifically devised for detecting inhomogeneities in undocumented climatological time series (Potter 1981; Peterson and Easterling 1994; Easterling and Peterson, 1995). Where possible, station history records were consulted. The station history for Xian shows 13 changes in either location or time of observation, including a move of some kilometers at the end of 1936, and a 21-m change of elevation in 1942. Tests performed by

Hughes *et al.* (1994) indicate no significant inhomogeneity in the Xian record, although analyses performed by the NCDC show a significant outlier in Xian July 1957 precipitation. This data point was removed from our subsequent analyses (see Transfer Functions, in Results section below). Homogeneity analyses, using Potter's t-tests (Potter 1981), also showed an inhomogeneity in the 1988 Lushi temperature record; we eliminated 1988 from our Lushi data. It should be noted that the Potter's t-test method (Potter 1981), used to evaluate inhomogeneities at stations not in the CDIAC and NCDC databases (Foping, Taibai and Zhenan), is sensitive only to single discontinuities (Easterling and Peterson 1995). Missing precipitation data were estimated by the median ratio method (Bradley 1976) and temperature data were estimated by the mean difference method (Garfin 1992).

Chronology Development

All materials were visually crossdated (Stokes and Smiley 1968; 1996) and measured employing standard quality control (Holmes 1983). Total ring width (TRW), earlywood width, latewood width, minimum earlywood density, and maximum latewood density (MXD) were measured using X-ray microdensitometry apparatus and methods described by Lenz *et al.* (1976) and Schweingruber *et al.* (1978) as modified by Milsom and Hughes (1978).

All series were detrended, *i.e.* standardized into dimensionless indices by fitting a growth curve to the series and then dividing the series by the values of the growth curve (Fritts 1976). In most cases we used a cubic spline with 50% variance reduction function at 67% of the series length; for the Foping (FPP in Figure 1) and Zhenan (ZAA in Figure 1) chronologies we used a 128-year cubic spline. These procedures removed growth trends related primarily to age and bole geometry in these mesic sites with a wide range of segment lengths. We combined the series using a biweight robust estimate of the mean, in order to minimize the effect of outliers (Cook 1985). In order to remove the effects of non-climatic persistence from the detrended series (Meko 1981; Cook 1985), each series was prewhitened by autoregressive (AR) modeling using ARSTAN (Holmes *et al.* 1986). Caution was taken to conserve the signal of lowest possible frequency common to all samples at a site. For details of Huashan chronology development (HSP in Figure 1), see Hughes *et al.* (1994).

Response function and correlation analyses (not shown) and prior experience (Hughes *et al.* 1994) indicated that only the TRW and MXD chronologies demonstrated robust climate-tree-ring relationships; therefore, only these two variables were retained for further analyses. Relatively weak ($<33\%$) common signal, as indicated by the variance accounted for by the first principal component (PC) of tree-ring indices and the mean correlation between trees (Table 2), is recorded by the EPK and ZAA TRW chronologies and by the EPK, FPP, SGT and ZAA MXD chronologies. *Larix* chronologies exhibited the strongest common signals. In addition, the well-replicated chronologies from the northwestern-most sites, as well as the Huashan chronology from the northeastern part of the range display the highest common signal among the MXD chronologies. As intended, most of the autocorrelation has been removed from these residual (RES) chronologies.

Reconstruction Development

The model development strategy was as follows: (1) best subsets linear regression (Draper and Smith 1981) between tree-ring predictors and seasonalized meteorological data was used to suggest candidate models and combinations of predictors to be used in PCA; (2) tree-ring predictor and PC models were evaluated based on the following criteria: adjusted R^2 ($R^2_{adj.}$), F, Mallow's C-p (Draper and Smith 1981), residual analysis (Hoaglin *et al.* 1983), and parsimony; (3) the best models were cross-validated; (4) the most easily interpretable models that met these criteria were selected. Because of the short instrumental record length, all models were cross-validated using the PRESS R^2 (henceforth, R^2_{pre}) (Michaelsen 1987; Montgomery and Peck 1992), a ''leave-one-out'' method; the longer Xian precipitation models were also verified using split-sample correlation.

In order to render the significantly skewed

Table 2. Summary statistics for Qinling total ring width (TRW) and maximum latewood density (MXD) residual chronologies.

Total Chronology					Common Interval		
ID	Std. Dev.	AC (1)	1st Year SSS* > 0.85	Mean Sgmt. Length	Period	Mean Corr. Betw. Trees	% Var. 1st PC
TBATRW	0.14	0.02	1,879	106	1915–1989	0.37	42
TBLTRW	0.22	0.00	1,810	149	1866–1985	0.55	35
BTMTRW	0.24	−0.03	1,720	194	1861–1990	0.51	53
SGTTRW	0.10	0.00	1,731	182	1832–1992	0.38	43
SBRTRW	0.18	−0.05	1,870	97	1905–1991	0.46	55
FPPTRW	0.16	0.01	1,898	106	1904–1989	0.28	40
EPKTRW	0.21	−0.09	1,828	134	1889–1985	0.26	31
ZAATRW	0.12	−0.09	1,880	101	1904–1989	0.20	28
HSPTRW	0.19	−0.03	1,603	355	1676–1989	0.41	44
TBAMXD	0.06	−0.01	1,893	86	1919–1974	0.44	49
TBLMXD	0.11	0.01	1,821	140	1865–1985	0.48	54
BTMMXD	0.14	−0.02	1,793	135	1867–1991	0.48	53
SGTMXD	0.05	−0.03	1,799	142	1878–1987	0.21	28
SBRMXD	0.07	−0.05	1,871	99	1905–1991	0.37	47
FPPMXD	0.06	0.13	1,897	96	1902–1989	0.19	26
EPKMXD	0.08	−0.11	1,882	120	1917–1985	0.22	31
ZAAMXD	0.06	0.17	1,884	97	1912–1988	0.23	29
HSPMXD	0.10	−0.04	1,592	219	1714–1899	0.44	50

*SSS is Subsample Signal Strength (Wigley *et al.* 1984).

Xian JA precipitation data approximately normal, we applied a logarithmic transform ($x_i' = \log 10\ x_i$, where x_i' is the transformed tree-ring variable index, and x_i is the untransformed index). As neither instrumental data set exhibited significant autocorrelation at any lag, we used only residual chronologies and no lagged predictors.

Documentary Evidence

We used documentary evidence of central China climate to corroborate the accuracy and strength of the Xian precipitation reconstruction. A regional mean of the annual dryness/wetness index (DW) for 9 stations in the Xian region, as well as the raw DW values for Xian were used for comparison with the precipitation reconstruction (State Meteorological Administration 1981; Riches *et al.* 1992). Derivation of the raw DW index is given by Zhang and Crowley (1989), and a detailed examination of their construction and reliability is given by D. Zhang (1988). Derivation of the 9-station mean is described in Hughes *et al.* (1994). These data are recorded on a scale of 1–5, where a value of 1 indicates severe wet conditions (''flood'') and a value of 5 indicates severe dry conditions (''drought''). Spearman's rank correlation test was used to compare the DW values with the Xian July–August precipitation reconstruction.

RESULTS

Tree-Ring Characteristics

Subsample signal strength (SSS; Wigley *et al.* 1984) was used to assess the adequacy of sample replication in the early part of the chronology. This statistic was developed to measure the effect of using an n-sized core chronology to reconstruct past climate based on a transfer function derived from an N-sized core chronology (Wigley *et al.* 1984). A comparison between total chronology length (Table 1) and the first year with sufficient SSS (SSS > 0.85; Table 2) shows a substantial reduction in chronology length for most of the sites. Our reconstruction strategy (discussed above) was based on a trade-off of chronology length for adequate sample depth.

The strongest correlations between individual TRW and MXD chronologies (Table 3) are be-

Table 3. Correlations between total ring width residual chronologies (lower left; TRW–TRW) and between maximum latewood density residual chronologies (upper right; MXD–MXD), 1898–1988 ($p < 0.01$ in bold). The bold italic values represent correlation between TRW and MXD within a site.

	TBA	TBL	BTM	SGT	SBR	FPP	EPK	ZAA	HSP
TBA	***0.19***	0.13	**0.41**	0.24	**0.56**	**0.42**	**0.41**	**0.57**	−0.06
TBL	−0.05	***0.79***	0.13	−0.11	0.03	0.01	0.11	0.14	0.03
BTM	**0.31**	**0.31**	***0.74***	0.17	**0.37**	0.10	0.20	0.14	**−0.38**
SGT	0.08	−0.03	0.07	***0.65***	**0.51**	**0.45**	**0.45**	**0.29**	0.08
SBR	**0.48**	0.05	0.14	**0.52**	***0.33***	**0.41**	**0.54**	**0.52**	0.10
FPP	0.10	0.01	−0.05	**0.36**	**0.28**	***0.41***	**0.48**	**0.47**	0.06
EPK	**0.39**	0.00	0.17	**0.34**	**0.60**	**0.27**	***0.28***	**0.68**	0.07
ZAA	**0.29**	−0.06	0.03	**0.28**	**0.49**	0.20	**0.73**	***0.10***	0.04
HSP	0.01	−0.18	−0.26	**0.39**	**0.40**	0.16	**0.35**	**0.42**	***0.70***

tween the *Abies* chronologies (TBA, SBR, EPK, ZAA), and between the SGT *Tsuga* chronology and chronologies to the east of the SGT site (Figure 1). There are interesting negative correlations between the HSP *Pinus* chronology and other chronologies (see comments, in section on Transfer Functions—Biological Bases); we will comment further on these negative correlations, below. The lack of uniformly strong intercorrelation between chronologies and the relatively low amounts of strong common signal in these chronologies demonstrate the overall lack of coherence between sites and species in the Qinling range.

Transfer Functions—Statistical Basis

Response and correlation function calculations (Fritts 1976) for the 18 tree-ring chronologies and monthly temperature and precipitation at the 14 meteorological stations (not shown) indicated that February through April (FMA) temperature and July–August (JA) precipitation were the best variables to reconstruct. Multiple correlations between tree-ring chronologies and meteorological data, too numerous to display here, showed that 5 meteorological stations (Foping, Huashan, Lushi, Taibai, Xian) yielded reasonable chances of producing robust reconstructions. There are relatively weak correlations between tree-ring sites in the eastern (HSP, ZAA, EPK) and western (TBA, TBL, FPP) Qinling Mountains (Table 3); the mean of correlations between precipitation stations in the eastern and western Qinling Mountains ($r_{east–west} = 0.37$) confirms the relative lack of coherence seen in the tree-ring data. This characteristic demonstrates (1) the pronounced differences in the local climates of sites that occur in highly dissected terrain of the Qinling, and (2) the effect on precipitation distribution caused by the proximity of the Qinling to the northern border of summer monsoon penetration. Similarly, PCA of precipitation data from these stations demonstrated relatively poor spatial coherence. Temperature data exhibited stronger spatial and temporal coherence (mean $r_{temperature} = 0.76$; variance accounted for by unrotated PC $1 = 81\%$). The strongest relationships between meteorological data and individual tree-ring chronologies (not shown) were for Xian JA precipitation and Foping FMA temperature. Regional temperature and precipitation analyses were not used because (1) PCA of regional temperature data exhibited non-Gaussian distribution, and (2) precipitation data in the region were limited to a common time period from 1960 onward, whereas Xian station data are available for 1932 onward.

For the Foping February through April temperature reconstruction, calibration best subsets regression models were calculated for combinations of individual residual chronology predictors and for PC predictors. The most parsimonious model that displayed adequate calibration and cross-validation statistics included the Taibai *Abies* TRW and the Huashan *Pinus* TRW chronologies (Figure 2, top). Calibration R^2_{adj} was 31.4% ($p = 0.001$; $F = 8.31$) and $R^2_{prediction}$ was 34.8% (Table 4). Calibration period reconstructed data show significant positive correlations with all nearby temperature stations, except Xian (Table 5).

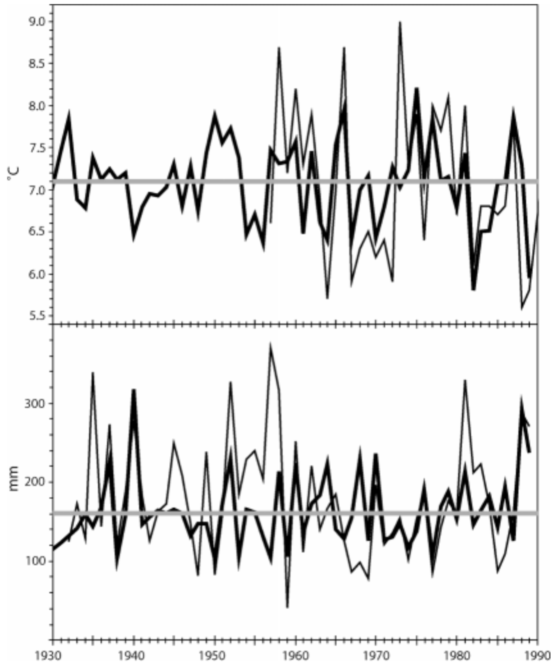

Figure 2. Top. Reconstructed (thick black line) and actual February-through-April temperature (thin line) at Foping. Foping 1957–1989 mean temperature is shown in grey. Bottom. Reconstructed (thick black line) and actual July–August precipitation (thin line) at Xian. Xian 1932–1988 mean precipitation is shown in grey.

For the Xian July–August precipitation reconstruction, Xian JA_{Log10} precipitation was the predictand variable. Calibration best subsets regression models were calculated for combinations of individual residual chronology predictors and for PC predictors. A subset of these calculations included only those chronologies that displayed significant individual correlations with the Xian instrumental record (1932–1992; Table 6). With the exception of BTMTRW, all highly correlated chronologies were MXD chronologies. After eliminating candidate models with undesirable regression characteristics (*e.g.* significant autocorrelation), we used the first PC of four chronologies (BTMTRW, EPKMXD, FPPMXD, TBAMXD) with desirable regression characteristics as the single predictor in our final model. This PC (hereafter, PCA4), accounted for 46% of the common variance.

We removed Xian July 1957 precipitation from our model, because both NCDC analyses and our analyses of regression residuals indicated a significant inhomogeneity. Our model, using PCA4, accounts for 33.5% of the calibration variance (R^2_{adj}; $p = 0.001$; $F = 29.2$) and displays comparable cross-validation $R^2_{prediction} = 29.5\%$ (Figure 2, bottom, and Table 4). The inclusion of other PC predictors in the model did not result in the addition of significant variance. Correlations between reconstructed values and instrumental JA precipitation from nearby stations indicate significant relationships with the Foping, Xian and Huashan stations (Table 7). The reconstructed values do not display as high a degree of spatial correlation as the Xian instrumental record (Table 7).

Transfer Functions—Biological Bases

Early spring, *e.g.* April, is a time when warmer temperatures, supported by adequate soil moisture, can enhance cambial division and expansion during the grand period of cell division (Fritts

Table 4. Calibration and cross–validation statistics. Foping February–April temperature 1957–1989 (top); Xian July–August precipitation 1932–1989 (bottom).

Model: Foping FMA (°C) = 4.92 − 1.19 HSPTRW + 3.38 TBATRW

		Calibration		Cross-validation
R^2	R^2_{adj}	p	F	$R^2_{prediction}$
35.70%	31.40%	0.001	8.31	34.80%

Model: Xian JA (mm) = 2.19 + 0.09 PCA4

		Calibration		Cross–validation		
R^2	R^2_{adj}	p	F	$R^2_{prediction}$	$R^2_{1932–1961}$	$R^2_{1962–1989}$
34.70%	33.50%	0.001	29.2	29.50%	40.10%	30.80%

Table 5. Comparisons between Foping FMA temperature reconstruction and instrumental data (left), and comparisons between Foping and other FMA instrumental temperature data (right). Values significant at $p \leq 0.05$ in bold.

	r recon-met	Period	r met-met	Period
Taibai	**0.51 ($p < 0.003$)**	1960–1989	**0.85 ($p < 0.001$)**	1960–1989
Foping	**0.56 ($p < 0.001$)**	1957–1989	—	1957–1989
Xian	0.29 ($p < 0.120$)	1957–1989	**0.81 ($p < 0.001$)**	1957–1989
Huashan	**0.43 ($p < 0.020$)**	1957–1989	**0.89 ($p < 0.001$)**	1957–1989
Lushi	**0.34 ($p < 0.050$)**	1957–1989	**0.81 ($p < 0.001$)**	1957–1989
Hanzhong	**0.55 ($p < 0.002$)**	1957–1989	**0.95 ($p < 0.001$)**	1957–1989
Ankang	**0.36 ($p < 0.050$)**	1957–1989	**0.57 ($p < 0.002$)**	1957–1989

1976). TRW, which is often a function of earlywood cell division and expansion (*e.g*. Hughes *et al.* 1994), is an appropriate variable to measure such effects. The TBATRW chronology displays a direct linear relationship with Foping FMA temperature, whereas the HSPTRW chronology displays an inverse relationship. Analyses of regional instrumental temperature and precipitation records (not shown) confirm that the inverse relationship between HSPTRW, which has a demonstrated positive relationship with pre-monsoon season precipitation (Hughes *et al.* 1994), and Foping FMA temperature is to be expected. This is because cool FMA temperatures would probably be associated with a lag in sensible heating over the Asian landmass, and a delayed monsoon onset. The HSPTRW chronology is known to display a poor relationship with July–August precipitation (Hughes *et al.* 1994).

The positive association between MXD and JA precipitation is intriguing. On one hand, increased precipitation frequently leads to further cell division and expansion during latewood production and should result in decreased MXD (Zahner 1968; Fritts 1976); on the other hand, high MXD may possibly result from prolonged cell maturation and, hence, increased density caused by thickened and more completely lignified cell walls (Cleaveland 1986). JA precipitation in central China is related in part to early monsoon onset, which in turn is related to: enhanced landmass heating (low snow cover), a more northern location of the East Asian tropospheric jet, and decreased Hadley cell circulation (Wang and Li 1990; Yang and Xu 1994; Meehl 1997; Liang and Wang 1998). Thus, warm spring-early summer temperatures can also contribute to the density-precipitation relationship by creating a longer growing season and thus longer length of cambial activity (Conkey 1986; Hughes 1992).

Reconstructions

Our relatively short reconstructions result in a significant addition to the instrumental climate records for this region. The Foping FMA temperature reconstruction is characterized by relatively low interannual variation (coefficient of variation = 0.07) and extended warm and cool periods. We selected series of warm and cold seasons (FMA) of at least three years above or below the 1957–1989 mean (Table 8). Most notable are warm periods during the late 1910s–1930s, early 1950s and mid-late 1970s and cool periods during the early

Table 6. Correlations between Xian July–August Log10 precipitation and residual tree–ring chronologies, 1932–1992 (significant at $p < 0.05$ in bold).

TRW	BTM	EPK	FPP	HSP	SBR	SGT	TBA	TBL	ZAA
Xian PPT	**0.32**	0.13	−0.18	0.01	−0.12	−0.12	−0.02	−0.04	0.09
MXD	BTM	EPK	FPP	HSP	SBR	SGT	TBA	TBL	ZAA
Xian PPT	0.12	**−0.42**	**−0.36**	0.08	−0.19	−0.22	**−0.40**	−0.11	**−0.44**

Table 7. Comparisons between Xian JA precipitation (PPT) reconstruction and instrumental data (left), and comparisons between Xian JA PPT instrumental data and other JA PPT instrumental data (right). Values significant at $p \leq 0.05$ in bold.

	r recon-met	Period	r met-met	Period
Taibai	0.29 ($p < 0.125$)	1960–1988	**0.72 ($p < 0.001$)**	1960–1988
Foping	**0.39 ($p < 0.036$)**	1960–1988	**0.80 ($p < 0.001$)**	1960–1988
Xian	**0.60 ($p < 0.001$)**	1960–1988	*	1960–1988
Huashan	**0.41 ($p < 0.028$)**	1960–1988	**0.62 ($p < 0.001$)**	1960–1988
Lushi	**0.40 ($p < 0.034$)**	1960–1988	**0.70 ($p < 0.001$)**	1960–1988
Hanzhong	0.00 ($p < 0.993$)	1960–1988	**0.58 ($p < 0.001$)**	1960–1988
Ankang	−0.08 ($p < 0.697$)	1960–1988	0.21 ($p < 0.278$)	1960–1988

1910s and early 1980s (Figure 3). The Xian JA precipitation reconstruction is characterized by moderate interannual variation (coefficient of variation = 0.28). The 1920s–1930s is the most notable dry period in the reconstruction (Table 8 and Figure 3).

Comparisons With Other Evidence

Warm springs (March through May; MAM) during the aforementioned periods are noted by instrumental mean temperature records for East Asia, which, prior to 1950, rely heavily on the long records of coastal stations (Hulme *et al.* 1994). Our reconstruction agrees well with the East Asia MAM temperature curve of Hulme *et al.* (1994), with the exceptions of variations during the 1960s and 1980s, when our reconstructed temperatures appear lower than the instrumental record. In addition, our record does not record the century-length trend in instrumental temperature, which culminates in extreme warmth during the 1980s (Hulme *et al.* 1994 [their Figure 3]; Yatagai and Yasunari, 1994 [their Figure 4]). This might be caused by a lack of urban heat trend (*e.g.* Wang

Table 8. Foping FMA reconstructed temperature runs (left) and Xian JA reconstructed precipitation runs (right) of three or more years above or below the mean. Temperature mean is based on 1957–1989; precipitation mean is based on 1932–1988.

Foping FMA TEM		Xian JA PPT	
Cool	Warm	Wet	Dry
1893–1895	1899–1902	1901–1904	1922–1935
1909–1914	1915–1922	1962–1964	1941–1944
1940–1944	1926–1929		1946–1950
1954–1956	1935–1939		1955–1957
1982–1985	1949–1953		1965–1967
	1957–1960		1971–1975
	1974–1979		
	1986–1988		

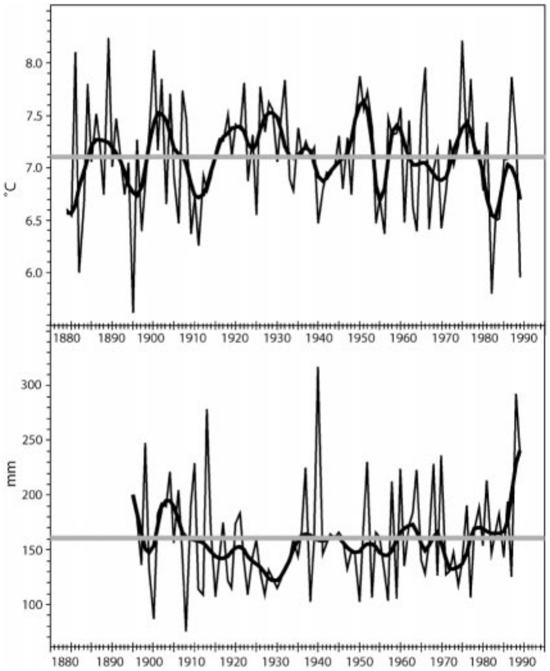

Figure 3. Top. Reconstructed raw (thin black line) and smoothed (thick black line) February–April temperature at Foping for the period 1879–1989. Foping 1957–1989 mean temperature is shown in grey. Bottom. Reconstructed raw (thin black line) and smoothed (thick black line) July–August precipitation at Xian for the period 1895–1988. Xian 1932–1988 mean precipitation is shown in grey. The smoothing algorithm employs a series of running medians (of 4, 2, 5 and 3 observations) and a three-weight running average ($0.25y_{t-1} + 0.5y_t + 0.25y_{t+1}$) (MINITAB 1994; Velleman and Hoaglin 1981).

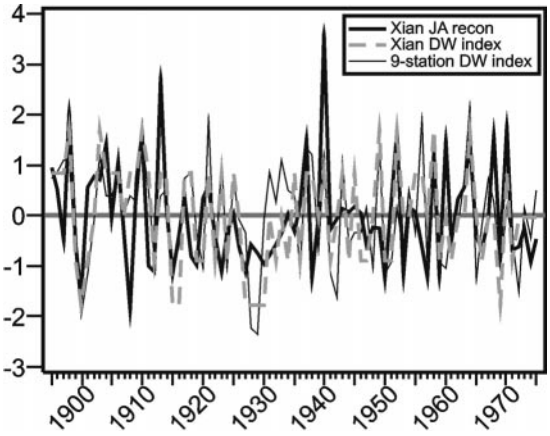

Figure 4. Reconstructed Xian July–August precipitation, Xian dryness/wetness (DW) index, and 9-station north-central China DW index. All data have been standardized into dimensionless indices. The DW data have been inverted to facilitate comparison.

Table 9. Correlations between Xian JA reconstruction, Xian JA meteorological data and Huashan reconstructions and meteorological data. The extension ''rec'' stands for reconstruction; the extension ''met'' stands for meteorological data. Values significant at $p < 0.05$ are in bold.

	HUA MJrec	HUA AJrec	HUA MJmet	HUA AJmet
Xian JArec	**−0.33**	**−0.39**	**−0.40**	−0.12
Xian JAmet	0.02	0.02	−0.15	0.28

et al. 1990) in Foping, a rural city of ~30,000 people. Long-term trends may well have been removed from our reconstruction by prewhitening the predictor series. Temperature reconstructions for northern and eastern China based on historical document evidence (Wang and Wang 1990 [their Figure 3]; Wang 1991 [his Figure 2]) show relatively cool decadal mean spring temperatures from 1880–1900 and an extended period of warm springs during the 1910s–1940s. However, these reconstructions do not record the warmth of the early 1950s evident in our reconstruction and the single chronology reconstruction of Liu *et al.* (2001). Our reconstruction does not show any significant agreement with Northern Hemisphere spring or winter temperature records shown in regional mean annual temperature records for China (Bradley *et al.* 1987 [their Figure 10]).

The 1920s–1930s dry period appears in instrumental studies (*e.g.* Hulme *et al.* 1994 [their Figures 5 and 6]), as well as in historical documentary evidence (*e.g.* Liang *et al.* 1995 [their Figure 1]). In addition, other written (Shaanxi Meteorological Station, 1979; Li and Quan 1987; Yellow River Management Committee 1991) and tree-ring (Hughes *et al.* 1994) sources document a period of severe drought, which culminates in the late-1920s.

In the absence of regionally specific instrumental records dating back to the mid-1890s, we examined relationships between our reconstruction and historical document-derived indices of annual dryness/wetness for Xian and for a 9-station region surrounding Xian. The DW index is derived from annals of extreme events during the course of an entire year, whereas we have reconstructed JA precipitation. Given that annual precipitation in this region is dominated by summer precipitation (Domrös and Peng 1988), comparisons between our reconstruction and the DW index are warranted. DW index data are not ratio scale, thus we used Spearman rank correlations (Snedecor and Cochran 1980). We obtained values of $r_{Spearman} = -0.51$ ($p < 0.001$) for the association between our reconstruction and the Xian DW index and $r_{Spearman} = -0.36$ ($p = 0.001$) for the association between our reconstruction and the 9-station mean (Figure 4). These values indicate significant correlations between the high-frequency components of these records. However, we note that the DW index records are more reliable recorders of spatial information than of individual station time series (Wang Shaowu, personal communication).

We also examined the degree of agreement between our reconstruction and May–June (MJ) and April through July (AJ) precipitation reconstructions at Huashan (Hughes *et al.* 1994). Our reconstruction has negative associations with both Huashan reconstructions (1895–1988) and with the Huashan meteorological record (1953–1988) for both MJ and AJ precipitation (Table 9). The Xian JA meteorological record has no association with either Huashan reconstruction (1932–1988), and weak associations with the Huashan meteorological station data (Table 9). We believe that agreement between reconstructed and instrumental Xian data in their negative associations with Huashan MJ precipitation (instrumental) is indicative of poor associations between spring precipitation and subsequent summer monsoon precipitation over central China. This conclusion is corroborated by weak negative correlations (not shown) between the Huashan reconstructions and the July Asian summer teleconnection pattern (ASTJ; Barnston and Livezey 1987), and weak positive correlations between the Xian reconstruction and ASTJ. Thus, the Huashan reconstructions, located farther east, might be better indicators of *pre-monsoon* precipitation and atmospheric flow, whereas the Xian JA precipitation reconstruction is associated with summer monsoon conditions (*e.g.* Liang and Wang, 1998). Huashan, some 200 km southeast of Xian, is located on a sheer exposure high in the mountains, in contrast to Xian, located in a broad flat valley to the north (on the eastern edge of China's Loess Plateau). The Huashan reconstruction is more indicative of mountain conditions recorded in the meteorological station (located mere meters from the trees), rather than the valley climate near Xian or other valley-based meteorological stations.

Finally, our Xian JA precipitation reconstruction displays a moderate negative association ($r = -0.32$, $p < 0.05$; 1932–1987) with $\delta^{13}C$ from EPK *Abies* specimens. Preliminary results indicate the EPK *Abies* $\delta^{13}C$ signal shows a significant positive relationship with growing season temperature (S. W. L. unpublished). This finding is consistent with negative correlations between temperature and precipitation at Xian and other stations nearby.

CONCLUSIONS

Using a variety of species, we have developed a network of rigorously crossdated tree-ring chronologies from the Qinling Mountains of central China. We have reconstructed February–April temperature and July–August precipitation for meteorological stations near the Qinling Mountains. We found reasonable correspondence between our temperature reconstruction and instrumental and documentary records. The precipitation reconstruction is the first well-calibrated and cross-validated dendroclimatic reconstruction of summer monsoon precipitation for central China. Reconstructed summer precipitation shows good agreement with documentary evidence of annual precipitation from this region, and fair agreement with instrumental data. The most prominent feature of reconstructed summer precipitation is the prolonged drought of the late-1920s and early 1930s, which also appears in a spring precipitation reconstruction from the region; this dry period coincides with warm springs in our temperature reconstruction.

These exploratory reconstructions almost double the length of the instrumental records from the region. The reliability of the transfer functions developed from our network of chronologies should be enhanced by tree-ring collection in this region, and will in a few decades be enhanced by the extension of meteorological data records. Based on the relatively long chronologies we developed (*e.g.* BTM, EPK, SGT) we have reason to believe that there is strong potential for the development of longer chronologies by further sampling from the Qinling Mountains. Increased sample replication within each site is likely to yield greater signal strength. *Larix* growing at high elevations and *Abies* growing on steep slopes are the most promising for future work. We believe that further dendroclimatic reconstructions from this region and along the PAGES/IGBP PEP II transect will provide corroboration for documentary evidence from central China.

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