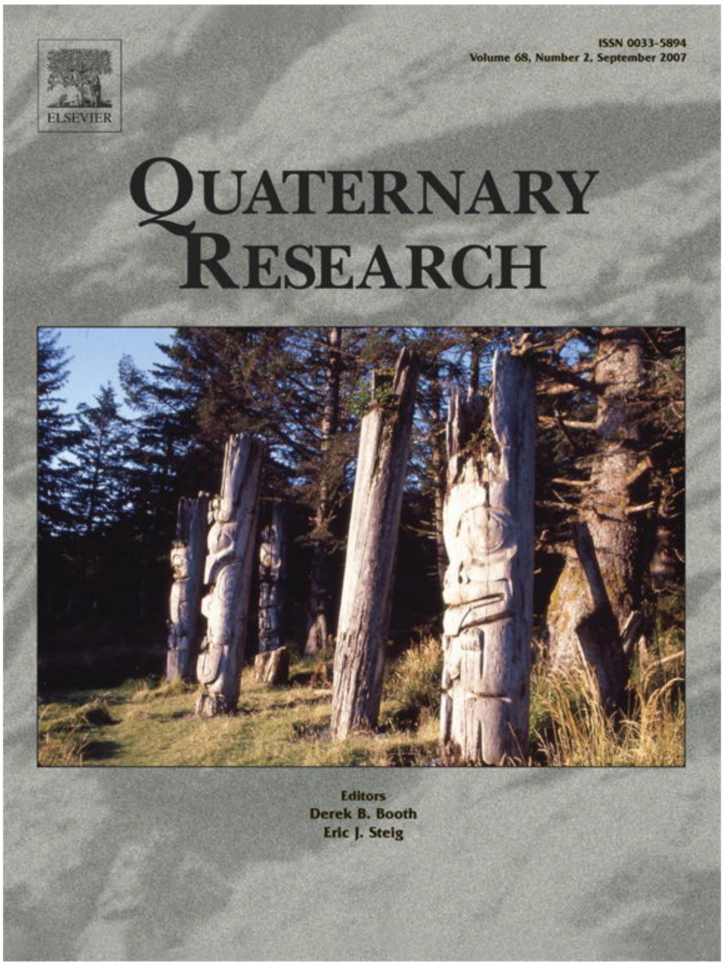
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Short Paper

May–June precipitation reconstruction of southwestern Anatolia, Turkey during the last 900 years from tree rings

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Abstract

A May–June precipitation reconstruction (AD 1097–2000) has been developed for southwestern Anatolia in Turkey, the longest reported to date in this region. The reconstruction was derived from a regional *Juniperus excelsa* chronology that was built from material sampled at four sites in the Antalya and Mersin Districts. The regional tree-ring chronology accounts for 51% of the variance of instrumentally observed May–June precipitation. The years AD 1518 to 1587 are the most humid period in the reconstruction, coinciding with a major shift in European climate. The driest 70-year period in the reconstruction is AD 1195 to 1264. The period AD 1591–1660 represents the third driest and was characterized by instability climatically, politically, and socially in Anatolia.

Keywords: Tree rings; Chronology; Reconstruction

Introduction

The use of tree rings to reconstruct past precipitation regimes has only recently been applied systematically in the Middle East and eastern Mediterranean region (Touchan et al., 1999, 2003, 2005a,b; Akkemik, 2000; Hughes et al., 2001; D'Arrigo and Cullen, 2001; Akkemik and Aras, 2005; Akkemik et al., 2005). Our aim is to develop a regional dendroclimatic network by measure of extensive field sampling and chronology development. This has already resulted in several reconstructions with start dates between AD 1251 and 1885 (Touchan et al., 2005a,b).

Here we present the longest reconstruction (AD 1097–2000) for the region so far, in which tree-ring material from four *Juniperus excelsa* sites is used to reconstruct each year's total May–June precipitation (in mm). It provides useful information on May–June precipitation variability over most of the last millennium for southwestern Anatolia, which is related to century-scale patterns of climate variability in Europe and neighboring regions. It will also help natural resource and water resource managers to implement low-risk, long-term plans to achieve conservation and water and other natural resource sustainability.

Site description

Four *Juniperus excelsa* sites were sampled from the Antalya and Mersin districts (Fig. 1 and Table 1). The soils of the area are primarily calcareous and shallow. These soils are suitable for root development and tree growth because the surface bedrock is cracked horizontally, allowing the deposition of organic soil (Turkish Ministry of Forestry, 1997). The tree-ring sites are located in two distinct rainfall regions based on the classification by Türkeş (1996, 1998) and Türkeş et al. (2002). These are the Mediterranean climate region (MED) which includes the Antalya site, and the Continental Central Anatolia region (CCAN) which includes the Mersin sites. The MED region is characterized by dry, hot summers and cool, rainy winters (Türkeş 1996; Türkeş et al. 2002) with a total annual rainfall of around 750 mm. CCAN is characterized by cool rainy springs, cold rainy winters, and warm and fairly dry summers with a total annual precipitation of 400 mm. Mean temperature

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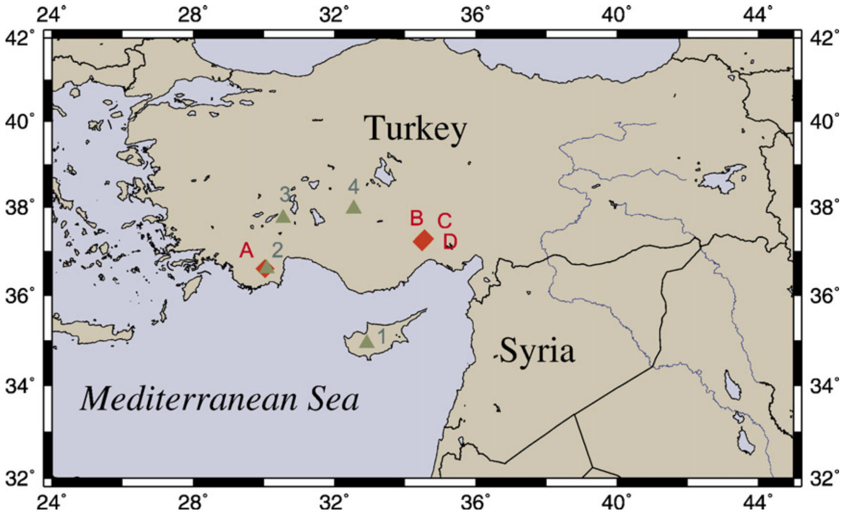

Figure 1. Locations of tree-ring sites (♦). The letters represent groups of sites (A = Elmali, Antalya district B; C; and D = South Central Turkey, Mersin district (Ananardiç, Silpişli, Neşeli). Weather stations (▲). The numbers represent climate stations (1 = Pano Amiantos, 2 = Elmali, 3 = Isparta, 4 = Konya).

between May and August in the two regions ranges between 15 and 27 °C.

Materials and methods

Tree-ring data

Increment cores were taken from *Juniperus excelsa* living trees from four sites in the Antalya and Mersin districts in Turkey (Fig. 1). Full cross sections were also taken from stumps and logs. Samples were fine-sanded and crossdated using standard dendrochronological techniques (Swetnam, 1985; Stokes and Smiley, 1996). The width of each annual ring on the 182 cores and cross sections from 112 trees were measured to the nearest 0.01 mm. Of these 182 series, in the work reported here we used only those with more than 250 rings, namely 72 series from 63 trees. We excluded the shorter series in order to conserve as much low-frequency variability as possible (Cook et al., 1995).

Each of the 72 series of tree-ring width measurements was fit with a 67% cubic smoothing spline with a 50% cutoff frequency, and each year's ring width was divided by the year's value of the fitted curve to give a dimensionless index with a mean of 1. This was done to remove non-climatic trends due to tree age, size, and the effects of stand dynamics (Cook and Briffa, 1990). Even after this detrending, the ring-width series contain autocorrelation; that is to say, 1 year's ring width is correlated with that of the year before, and to a greater extent than, for example, an interannual time series of precipitation. Methods to identify and remove this non-climatic autocorrelation from tree-ring data use the techniques of time-series statistics (Meko, 1981; Cook, 1985). Low-order autoregressive models were fit to the detrended ring width series, and the residuals from these models retained as the "prewhitened index" version of the series to remove persistence not related to climatic variations. The individual series' indices were first combined into average series for each tree and then into a single average regional chronology using a bi-weight robust estimate of the mean (Cook, 1985) designed to minimize the influence of outliers.

We used the subsample signal strength (SSS) to assess the adequacy of replication in the early years of the chronology (Wigley et al., 1984). The number of series making up the early years of a tree-ring chronology is often smaller than in the instrumental period, which is when the chronology is calibrated against climate measurements. SSS gives a guide to evaluating probable loss of reconstruction accuracy, which occurs when a chronology made up of a few series is used to reconstruct past climate with a calibration developed from a chronology with more series.

Table 1
Juniperus excelsa site information for Southwestern Anatolia

Site name	Site code	District	Elevation (m)	Latitude	Longitude	Time span (year)		Total no. of years	Total no. of trees	No. of cores	No of trees used
						Earliest	Latest				
						AD					
Ananardiç	ANA	Mersin	1762–1868	37° 16′ N	34° 33′ E	1330	2001	672	18	23	6
Silpişli	SILJ		1727–1851	37° 16′ N	34° 33′ E	1350	2001	652	17	22	6
Neşeli	NESJ		1708–1741	37° 12′ N	34° 28′ E	1235	2001	767	24	29	18
Elmali	ELMJ	Antalya	1853–2022	36° 36′ N	30° 01′ E	1017	2001	985	53	108	33

Climate data

Monthly precipitation and temperature data for three meteorological stations were obtained from Turkey (Elmali, Isparta, and Konya) and one from Cyprus (Pano Amiantos) (Fig. 1). We have chosen these four stations to develop regional climate series. The four stations are located near to and at similar elevation to the tree-ring sites. The time span for the precipitation data ranges between AD 1968 and 2000, 1931 and 2000, 1931 and 2000, and 1917 and 2000, respectively, in Elmali, Isparta, Konya, and Pano Amiantos stations. The length of the available temperature records ranges between AD 1968 and 2000 (Elmali) to AD 1950 and 2000 in the other stations. Given the various time spans of availability of the meteorological data, and in order to avoid depending on a single station, we selected the period 1931–2000 for our calibration analysis. The four precipitation datasets were screened for inhomogeneity by double-mass analysis, a graphical technique (Kohler, 1949). We used the *t*-test suggested by Potter (1981) to screen the temperature data for the four stations. We applied the method of Jones and Hulme (1996) to average the precipitation and temperature records for each month since the climate data were not the same length.

Response function analyses (RFA)

In the exploration of relationships between a tree-ring chronology and monthly or seasonal climate data, it is necessary to take account of the correlations between different meteorological variables, and between different monthly or seasonal averages or totals of the same variable. Thus, in some regions, summer temperatures and total summer precipitation may be either positively or negatively correlated. Many such correlations may exist within any one meteorological data set. This condition is known as "multicollinearity". Its presence violates the assumption that the predictors are independent of one another, and hence may be treated as additive. This may not be important if the regression equation is to be used only for prediction, but it does matter when the equation is used for interpretation as in this case (Vaganov et al., 2006, pp. 191–199). It is not appropriate to simply calculate correlations between all possible pairs of the predictand (tree-ring series) and the predictors (meteorological variables).

The RFA developed by Fritts et al. (1971) solved this in an elegant way, by conducting orthogonalized regression with monthly temperature and precipitation for a set of months leading up to the end of the growing season, and performing the necessary matrix algebra to express the regression coefficients in terms of the original, physical, variables. This RFA method, with subsequent improvements, was carried out using the program developed by Biondi and Waikul (2004). In this case, the predictors were monthly mean temperature and monthly total precipitation for each of the 13 months starting in October of the year prior to growth at the Elmali, Isparta and Konya stations and the predictand was the tree-ring chronology. The temperature record at Pano Amiantos was too short to allow the calculation of a full temperature and precipitation response function.

Transfer function development and testing

As a single tree-ring series, the regional chronology was to be used as proxy for a single climate series, the May–June total precipitation, a regression equation between them was calculated for the calibration period 1931–2000. The frequency distributions of the two variables were examined to see if it was appropriate to use them untransformed. It was. The validity of this equation as a transfer model for converting tree-ring values to precipitation values was examined using usual regression and correlation statistics, with the addition of the PRESS procedure used for cross-validation (Weisberg, 1985; Fritts et al., 1990; Meko, 1997; Touchan et al., 1999, 2003, 2005a,b).

Model stability was also verified using a split-sample procedure (Snee, 1977; Meko and Graybill, 1995; Touchan et al., 2003, 2005a,b) that divided the full period (AD 1931–2000) into two subsets of equal length. The roles of these periods as calibration and verification periods were then reversed, and the result examined for a consistent level of variance explained in each and broadly consistent regression coefficients. In the two verification periods, Reduction of Error was calculated. If this statistic is greater than 0, the reconstruction has greater skill than would be obtained by simply using the mean of the calibration period as the value for each year of the reconstruction (Fritts, 1976). Unlike R-squared, it is very sensitive to changes in mean between the calibration and verification periods.

Once the transfer function has been calculated, it was applied to the regional chronology to produce the time series of reconstructed May–June total precipitation for as many years as the degree of replication of the chronology allows.

Results

Chronology

The tree-ring series of the four sites show strong similarities in terms of visual crossdating of the wood and computer-based quality control (not shown). Individual trees of this species in this region share a high degree of common variation and so are prime candidates as recorders of climate.

The combined chronology covers 985 years (AD 1017–2001). Average series intercorrelation among all radii is 0.34. The mean sample segment length (MSSL) of the chronology is 404 years and is adequate to investigate centennial but not multicentennial climate variability (Cook and Peters, 1997).

To ensure the reliability of the reconstructed precipitation, we limited our analysis to the period with an SSS of at least 0.78, 0.82, and 0.85. These thresholds correspond to a sample depth of 5, 6, and 8 trees, and allow for reconstruction for the periods AD 1097 to 2000, 1113 to 2000, and 1127 to 2000 (Fig. 3).

Climate data analyses and May–June precipitation reconstruction

Response functions accounted for between 52 and 55% of the variance of the regional tree-ring series in the case of the three

Turkish meteorological stations where both precipitation and temperature data were available for sufficient years. Response function elements significant at the 95% level were found for a positive (+ve) effect of May and June precipitation at Elmali, a negative (−ve) effect of July temperature, November precipitation (−ve) and May precipitation (+ve) at Isparta, May precipitation (+ve) at Konya, and May (+ve) and June (+ve) at Pano Amiantos (only calculated for precipitation). Thus, even taking into account temperature as well as precipitation, precipitation in May and/or June emerges most consistently as a controlling factor of tree-ring growth in our regional chronology.

The regression equation between the tree-ring indices (predictors) and May–June precipitation (predictand) for the calibration period 1931–2000 is significant (F=73.6, $P<0.0001$). The regression model for the calibration period is:

$$Y = -66.0 + 137X$$

where Y=May–June Precipitation (mm) and X=Tree-Ring Indices. The predictor variable accounts for 51% of the variance (Fig. 2 and Table 2). The PRESS procedure was used for cross-validation (Weisberg, 1985; Fritts et al., 1990; Meko, 1997; Touchan et al., 1999, 2003, 2005a,b) (Table 2). Model stability was also verified using a split-sample procedure (Snee, 1977; Meko and Graybill, 1995; Touchan et al., 2003, 2005a,b) that divided the full period into two subsets of equal length (Table 2). Results indicate that the adjusted R^2 is similar in the two verification periods. In addition, the RE results do not indicate any bias in the different calibration/verification exercises.

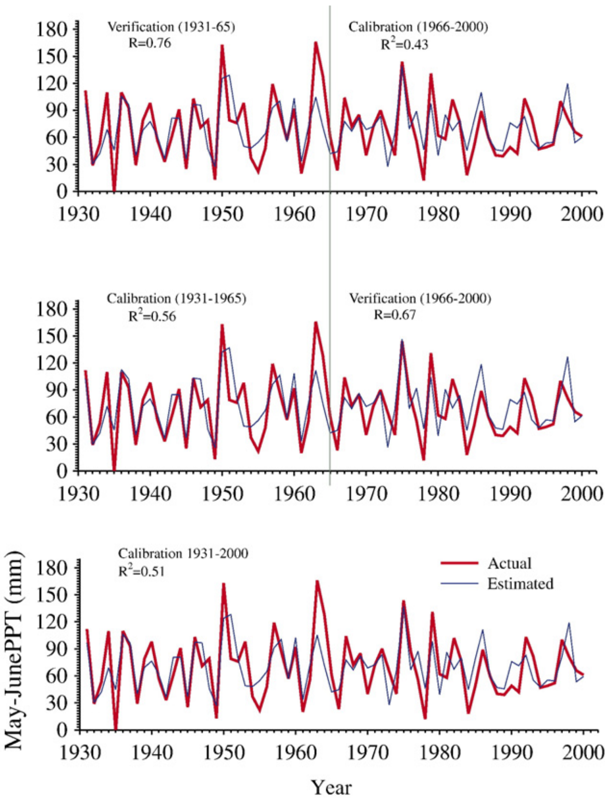

Figure 2. Time series plots of actual and reconstructed May–June precipitation for the calibration and verification periods of the split sample procedure.

Table 2
Results of the statistical calibration and verification between May–June precipitation and tree-ring growth for the reconstruction

	1966–2000 Calibration	1931–1966 Verification	1931–1965 Calibration	1966–2000 Verification	1931–2000
Adjusted R^2	0.43		0.56		0.51
Reduction of error (RE)		0.53		0.41	
PRESS test					0.49
PCC		0.76		0.67	
Sign test	$26^+/9^-$	$28^+/7^-$	$28^+/7^-$	$26^+/9^-$	$54^+/16^-$
P	0.001	0.001	0.001	0.001	

Dates are in years AD.
PCC = Pearson Correlation Coefficient.

The May–June precipitation reconstruction is presented in Figure 3. We used Türkeş (1996) classification rainfall index to determine dry and wet thresholds. Türkeş used the normalized rainfall index to develop a table that categorize various degrees of the wet and dry threshold. The dry and wet threshold is the average of Türkeş (1996) below and above normal index ((−0.51)–(−0.85), 0.5–0.85) which is ±0.68. The long-term reconstruction for the period AD 1097–2000 contains 235 dry events and 215 wet events according to these criteria.

We developed a May–June 70-year moving average of the precipitation reconstruction (Fig. 4A) to compare the reconstruction to the period of the instrumental data (1931–2000). The three most humid 70-year periods in the May–June precipitation reconstruction were between AD 1518 and 1587, 1098 and 1167, and 1743 and 1812, respectively. The three driest 70-year periods for May–June conditions in the reconstruction were between AD 1195 and 1264, 1434 and 1503, and 1591 and 1660 respectively. Interannual variability was high in these periods of wetter Mays and Junes, especially AD 1518 to 1597, whereas the lowest standard deviations were associated with the driest periods (Fig. 4B).

Discussion

Tree-ring records of past climate both suffer and benefit from their nature as indirect archives of climate as seen through plant response to environmental conditions. On the one hand, they typically have a more or less limited seasonal response to the climate variable of interest, but on the other, they are a record of plant response and so have relevance to the use of water resources.

Thus, in spite of its being only 9% of water year precipitation at Elmali (and 11% in the four-station mean series), the importance of May–June precipitation for wood growth is shown by our response function calculations, and the results of other analyses involving more extensive regional networks (Hughes et al., 2001; Touchan et al., 2005b). Please note that these RFA results are based on analyses of the growth of a plant tissue in relation to temperature and precipitation variability over several decades. It would be reasonable to expect conditions in this part of the growing season to be important

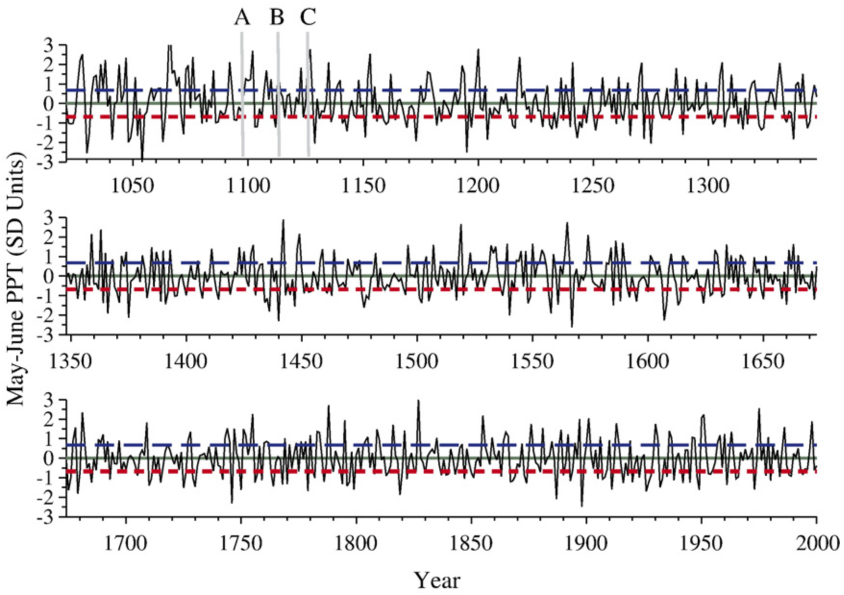

Figure 3. Time series plot of reconstructed May–June precipitation, AD 1097–2000. Solid line is the mean of the observed data. Dotted line is the dry threshold. Dashed line is the wet threshold. A, B, and C is SSS ≥ 0.78 (AD 1097), 0.82 (AD 1113), and 0.85 (AD 1127) respectively.

for crops and other plants of importance to society, especially those used in rain-fed agriculture.

Although the majority of precipitation does not typically fall in May and June, these months are critical for growth of plants such as wheat in a Mediterranean climate (Öztürk, 1999; Öden et al., 2002). May–June precipitation is also rather variable in comparison to water year precipitation. For example, at Elmali the total coefficient of variation (mean, standard deviation) of May–June and water year (prior October–September) precipitation was 0.6 (64.8 mm, 38.9 mm,) and 0.29 (715.9 mm, 208.4 mm) respectively.

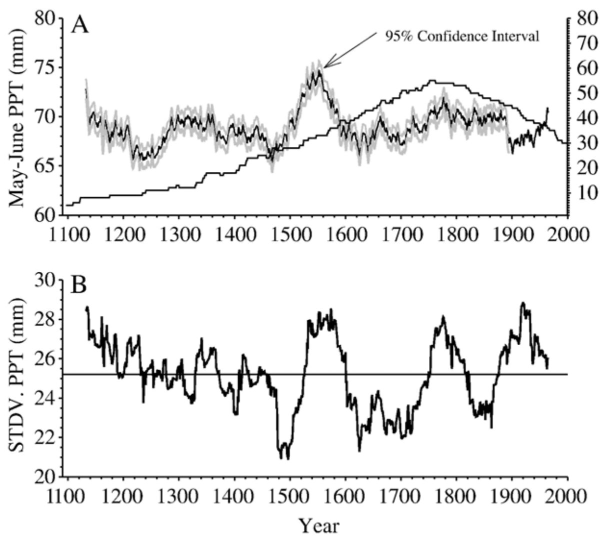

Figure 4. (A) Seventy-year running mean of reconstructed May–June precipitation for the period AD 1097–2000. Uncertainty in reconstructed values is shown by two standard errors. (B) Seventy-year running standard deviation for the reconstruction.

Therefore, it is not surprising that several extreme events in the reconstruction correspond with major historical events in the region (Table 3). On longer time scales, the dry period between AD 1591 and 1660 coincides with the findings of Kuniholm (1990) and Griswold (1977, 1983, 1989) who report that the late 16th and early 17th centuries in Anatolia were characterized as an unstable period politically, socially, and climatically, to which they attribute large-scale change in land use and large sudden fluctuations in urban populations. These authors also

Table 3
Records of reconstructed extreme and historical events

Dates AD	Historical events	Dry events	References
1567	Widespread food shortage during the Ottoman Empire	+	Kuniholm, 1990
1585	Food shortage in Anatolia	+	Kuniholm, 1990
1595	Famine in the Aegean and Syria	+	Kuniholm, 1990
1660	Very dry summer and fires in Anatolia	+	Kadioglu, 2001; Kuniholm, 1990; Zachariadou, 1999; Purgstall, 1983
1725–1726	Major drought in Anatolia and Syria	+	Panzac, 1985
1756–1757	Drought and famine in Anatolia and Syria	+	Panzac, 1985; Inalcik, 1997
1873–1874	In the province of Ankara, a drought occurred of such devastating proportions that 81% of the cattle and 97% of the sheep died. Of the population of 52.000, some 7.000 moved out of the district and 20.000 died	+	Quataert, 1968; Kuniholm, 1990
1887	Great drought and famine in Anatolia	+	Ottoman Archive
1925–1929	Drought in Anatolia	+	Kadioglu, 2001

report that the cumulative drought during that period is said to have played a major role in food shortage and famine. Clearly, our results suggest that this issue merits further investigation by climate historians with detailed knowledge of this region and these particular times.

Whereas the sustained droughty May–June conditions of the period AD 1591 to 1660 that we reconstruct are reflected in the historical record, the reconstructed period of greater May–June precipitation from AD 1518 to 1587 corresponds to a significant shift in the climate in Europe as reconstructed from historical documents (Pfister et al., 1999). This was a period of generally cooler conditions over much of the continent that had profound effects on environment and society. It must, necessarily, have been associated with major shifts in circulation patterns likely to affect conditions in our (downwind) region of interest.

Pauling et al. (2006) reconstructed average June–August precipitation (AD 1500–2000) for the region between 28.25°E–36.75°E and 36.25°N–37.75°N. They used multiple proxies to reconstruct precipitation at each of 72 grid points in this area and averaged them to produce a mean for the whole block. Their data set and ours are independent of one another. Unfortunately, the maximum possible fraction of variance in common between their reconstruction and that reported here is only 24%, as estimated from the square of the correlation coefficient between May–June and June–August total precipitation in the four-station mean instrumental series used here ($R=0.494$, $n=70$, $P<0.0001$). In fact, the common signal in the two reconstructions amounts to 16% ($R=0.4$, $n=500$, $P<0.0001$). This comparison has limited value when evaluating the reliability of our reconstruction, because measured precipitation totals for the seasons used in the two reconstructions are not strongly correlated.

Conclusion

The 904-year May–June precipitation reconstruction for southwestern Anatolia represents an extension and enhancement of the climate record for this region. This reconstruction provides information concerning precipitation variability in southwestern Anatolia for a season that is important for plant growth. Understanding past climate variability is important for water, agricultural, and other resource managers and planners to sustain and conserve water that is the foundation of social, political, and economic systems in the region.

The three most humid 70-year periods in the May–June precipitation reconstruction were between AD 1518 and 1587, 1098 and 1167, and 1743 and 1812, respectively. Interannual variability was high in these periods of wetter Mays and Junes, especially AD 1518 to 1597, whereas the lowest standard deviations were associated with the driest periods. The three driest 70-year periods for May–June conditions in the reconstruction were between AD 1195 and 1264, 1434 and 1503, and 1591 and 1660 respectively.

The 16th century period of reconstructed wetter May–June conditions coincides with a significant shift in European climate. The late 16th to mid 17th centuries period of dry May–June conditions was characterized by climatic, political, and social instability in Anatolia.

The precipitation reconstruction and the tree-ring data used to produce it is available at the NOAA Paleoclimatology web site (http://www.ncdc.noaa.gov/paleo/treering.html).

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