Int J Biometeorol (2005) 49:297–302
DOI 10.1007/s00484-004-0249-8

ORIGINAL ARTICLE

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A preliminary reconstruction (A.D. 1635–2000) of spring precipitation using oak tree rings in the western Black Sea region of Turkey

Received: 19 April 2004 / Revised: 14 November 2004 / Accepted: 30 November 2004 / Published online: 6 January 2005

Abstract Tree-ring data for Turkey are crucial to the understanding of the climatological effect of drought and rainfall from one era to the next. To this end, the present study reconstructed precipitation patterns in the western Black Sea region of Turkey. Tree-ring widths of oak trees were used to reconstruct March–June precipitation patterns for the years A.D. 1635–2000. According to the findings, during the past four centuries drought events in this region persisted for no more than 2 years, and extreme dry and wet events occurred generally in 1-year intervals. Historical records of droughts in Anatolia and neighboring countries corroborate the data furnished by tree-ring widths to indicate that major droughts and famine events occurred in 1725, 1757, 1887, 1890–1891, 1893–1894 and 1927–1928.

Keywords Reconstruction · Oak chronology · Dendroclimatology · Black sea region · Turkey

Introduction

In arid and semi-arid regions, rainfall is limited and interannual variability in rainfall amounts is great. To understand the nature of drought and flood extremes, we need to evaluate climate variability according to long-term time scales of decades to centuries. The instrumental data for many areas in the Mediterranean goes back only a few decades at best. For this reason paleoclimate records derived from tree-rings offer important information on past fluctuations and can aid efforts to anticipate the probability of future episodes (Cherubini et al. 2003). Analysis of long-term tree-ring data has implications, accordingly, for the planning of water resources and, as a result, for the political and economic stability of Turkey and its neighbors.

Several dendroclimatological reconstructions in Turkey (D'Arrigo and Cullen 2001; Touchan et al. 2003) demonstrate that the duration of dry years generally extends for 1 or 2 years and rarely for more than 3 years. For example, the years 1887, 1890, 1927–1928 were extremely dry years. In these years significant famine events were recorded throughout Anatolia (Ottoman Archives 1850–1930; Inalcik 1997; Purgstall 1983). Apart from dendroclimatological studies, researchers have conducted several analyses of climate variability in Turkey during recent years, including studies of the effects of North Atlantic Oscillation (NAO), El Niño and La Niña in Turkey (Cullen and de Menocal 2000; Kahya and Karabörk 2001). The data from these studies indicate that during positive NAO years, Turkey experiences significantly cooler and drier weather conditions; whereas, during negative phases of the NAO warmer and wetter conditions dominate. Cherubini et al. (2003) conclude that to understand the long-term effects of drought and rainfall tree-ring data from coastal and low-elevation Mediterranean sites are urgently required. Given the dearth of past climatic information for the western Black Sea region, dendroclimatological reconstruction becomes extremely important.

In the western Black Sea region oak trees grow at lower altitudes and produce highly sensitive tree-rings (Akkemik and Güzel 2004). The aim of the present study is to reconstruct precipitation patterns in the western Black Sea region of Turkey by using tree-ring widths of oak trees to understand the patterns of drought, particularly regional patterns of dry and wet years.

Materials and methods

Tree-ring data

The study area is located in the western Black Sea region (Fig. 1). The region contains climatically varying transects from the coastal

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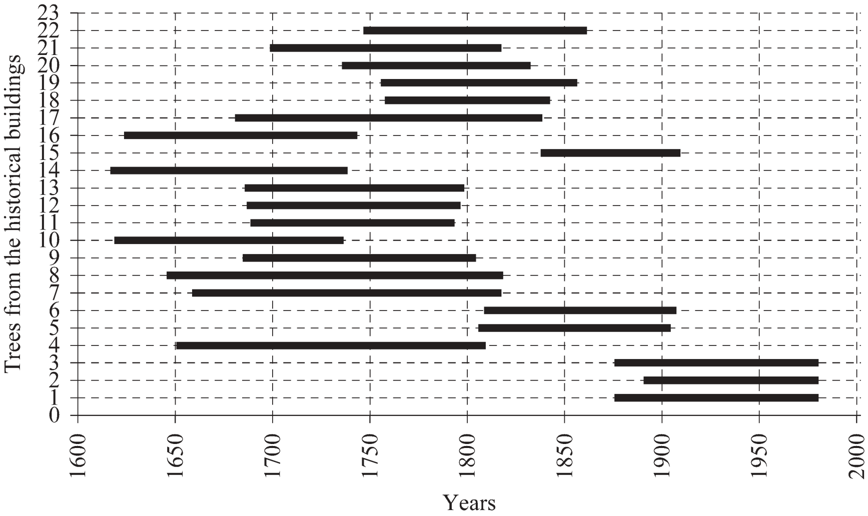
Fig. 1 Location of study region

Fig. 2 Time spans of old materials taken from historical constructions



zone to the highland interior. Due to the presence of high mountains running parallel to the coast, the precipitation abruptly decreases on the southern, interior slopes of the coastal range and the mountains further inland. The study area, Kastamonu-Pınarbaşı and its vicinity, is located on the southern side of the Küre Mountains. The altitude of the site is 1,050 m a.s.l., the aspect is west, and the climate type is humid. Latitude and longitude are 32°30′–33°10′ and 41°25′–41°40′E. Stem discs were cut from 23 oak trees in the sampled location. For some of the trees studied, the tree rings of some periods were very narrow and their borders were unclear. For this reason the stem discs from 3 trees with excessively narrow rings were excluded from the analysis in favor of 20 stem discs from living trees.

Hughes et al. (2001) have proposed that historical and archaeological chronologies from Anatolia can also be used to identify ancient signature years in tree rings. These signature years in turn hold potential value to our understanding of climatic influences on human history. Based on Hughes et al.'s (2001) conclusions, in addition to the stem discs from the 20 living trees mentioned above, we also collected more than 50 oak stem discs from various historical buildings in the study region (Akkemik and Güzel 2004). Twenty-two of these were selected for further analyses because of their sensitive tree-rings. Their time spans are presented in Fig. 2. In all, some 42 stem discs, 20 from living trees and 22 from old constructions were used to build a regional chronology and to investigate climatically extreme years through reconstructive analysis.

Chronology computation

Tree-ring widths were measured to the nearest 0.01 mm. Each ring-width series was standardized by means of a negative exponential or linear regression to remove non-climatic trends due to age, size, and the effect of stand dynamics. The program COFECHA was used to ensure the accuracy of crossdating and measuring (Grissino-Mayer et al. 1996). Using the ARSTAN program three versions of chronologies, standard, residual, and arstan, were constructed. The residual version is generated in the same manner as the standard version, with the only difference being that the series produced are residuals from autoregressive modeling of the detrended measurement series. The indices from individual cores were then combined into a master chronology using a bi-weight robust estimate of the mean (Cook et al. 1990a, b).

Dendroclimatological reconstruction

Climatic data from Kastamonu, used in reconstruction processes, were obtained from State Meteorology Service of Turkey. In reconstruction, as a preliminary step, the relationship between tree-ring indices and monthly precipitation was investigated through simple correlation coefficients. Monthly correlation-coefficient plots identified the March–June precipitation as the most appropriate predictand for reconstruction. The subsample signal strength (SSS), which is computed from data on sample size and between-tree correlation, is a guide to assessing the likely loss of reconstruction accuracy, which occurs when the chronology is formed from a limited number of series. SSS >0.85 (Briffa and Jones 1990) corresponds to a minimum sample depth of eight trees (SSS >0.881 corresponds to eight trees), and allowed for reconstruction for the period A.D. 1635–2000. Linear regression and analysis of variance (ANOVA) were used to develop the reconstruction. In order to test the stability of the model by using a split sample procedure, we divided the period into two equal segments, first calibrating over the period 1931–1965 and verifying over the period 1966–2000, then calibrating over 1966–2000 and verifying over 1931–1965. The reconstruction is well validated using statistics widely used to evaluate dendroclimatic reconstruction. The reduction of error (RE) statistic provides a highly sensitive measure of reliability (Fritts 1976). Correlation coefficients were used as additional comparison between actual and estimated values. The reconstructed values were compared with those of previous dendroclimatological studies (D'Arrigo and Cullen 2001; Hughes et al. 2001; Touchan et al. 2003) to find regional dry and wet years. The climatically extreme years were also combined with available Ottoman records (Ottoman Archives 1850–1930; Inalcik 1997; Purgstall 1983) to determine the relationships between recorded famine years and tree-ring widths.

Results and discussion

Chronology computation

A 390-year master chronology, from 1611 to 2001, was constructed using ARSTAN (Fig. 3). Due to a higher degree of between/within-tree correlations in the residual version than the standard version (Table 1), the residual version was selected for further dendroclimatological reconstruction. In this version, the correlations within trees (0.536; $P \leq 0.001$), between trees (0,336; $P \leq 0.001$), with master (0.585; $P \leq 0.001$), and with signal-to-noise ratio (10.111) were higher than those generated by the standard version (Table 1).

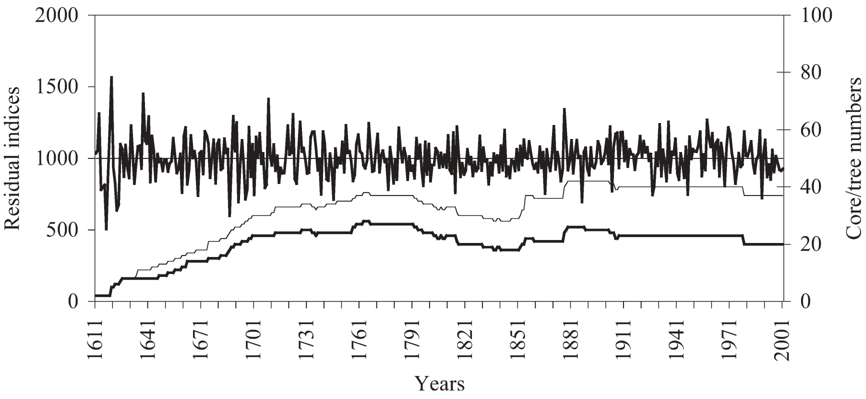
Table 1 Statistical results from ARSTAN program

Chronology type (1607–2001 42 trees 59 radii)	STNDRD	RESID	ARSTAN
Mean	0.9915	0.9959	0.9923
Median	0.9896	0.9948	0.9919
Mean sensitivity	0.1390	0.1405	0.1365
Standard deviation	0.1453	0.1227	0.1384
Skewness	0.2502	0.1155	0.0740
Kurtosis	14.928	0.4085	0.7429
Autocorrelation order 1	0.2727	–0.0201	0.2366
Partial autocorr order 2	0.1767	–0.0633	0.1181
Partial autocorr order 3	0.0163	0.0088	0.0413
Common interval time span 1756–2000 245 years 20 trees 28 radii			
Mean correlations	Detrended	Residuals	
Among all radii	0.310	0.339	
Between trees	0.305	0.336	
Within trees	0.613	0.536	
Radii vs mean	0.561	0.585	
Signal-to-noise ratio	8.766	10.111	
Agreement with population chron	0.898	0.910	
Variance in first eigenvector (%)	35.51	38.68	
Chron common interval mean	0.988	0.995	
Chron common interval standard deviation	0.119	0.109	

Dendroclimatological reconstruction

First, the correlation coefficients between the residual chronology and monthly precipitation data for the years 1931–2000, were calculated (Fig. 4). The precipitation was significantly positive in March–June. This result

Fig. 3 The residual version of the master chronology, and core and tree numbers



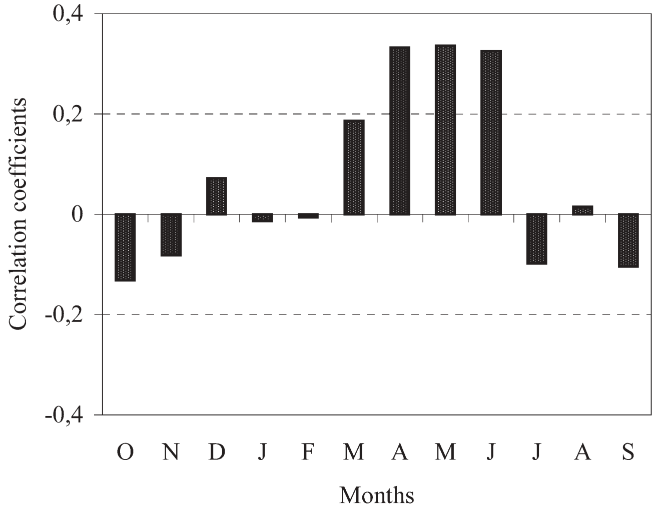


Fig. 4 The correlation coefficients between monthly total precipitation and tree-ring widths

showed that low rates of precipitation in these months limited the size of tree-ring widths of the oak trees in the region. A visual comparison of the residual chronology and total March-June precipitation was also performed. The correlation coefficient between the two series was 0.59 ($P \leq 0.001$). This result indicates that March–June precipitation was the most appropriate predictand for dendroclimatic reconstruction.

To develop the reconstruction using a linear regression, total precipitation of March–June from 1931 to 2000 was used as the predictand, and the residual chronology from 1635 to 2000 served as the predictor. According to the results of ANOVA of the first model (1931–1965), the adjusted R and F values were 0.48 and 32.06 ($P \leq 0.001$), respectively, whereas R and F values of the second model (1966–2000) were 0.16 and 7.456 ($P < 0.05$), respectively. RE values were 0.29 for first model and 0.24 for second model. The value of RE may theoretically range from minus infinity to +1.0. As Fritts (1976) noted, this is a very rigorous statistic and any positive value indicates the existence of worthwhile information in the reconstructions. The Pearson correlation coefficients between March–June precipitation data and their estimates were 0.69 ($P \leq 0.001$) for the calibration period (1931–1965) and 0.52 ($P \leq 0.001$) (1966–2000) for the verification period. Due to higher R^2, F and reduction of error (RE) values, the first model was selected for reconstruction. The sign test, as indicated by the number of positive versus negative values, furnishes an indication of how well the tree-ring estimates correctly track the direction of change from year to year in the instrumental record (Fritts 1976). The sign test results likewise proved significant, achieving a 0.05 confidence level (25+/10–). The equation of the first model was

$$y_r = -198.386 + 0.4104 \times X$$

The estimated values are presented in Fig. 5. As used by D'Arrigo and Cullen (2001), the values beyond the inner horizontal lines (±1 SD) indicate dry and wet years, and those beyond the outer horizontal lines (±2 SD) indicate extremely dry and wet years. Dry and wet years fall out generally as individual years, sometimes as 2-year intervals and very rarely as 3-year intervals (Fig. 5). A 3-year duration event was determined only as wet years in the years 1733–1735 during the reconstruction period. Two-year duration events occur several times in the region, in 1696–1697, 1707–1708, 1724–1725, 1742–1743, 1890–1891, 1927–1928, 1941–1942 as dry years, and 1661–1662, 1673–1674, 1740–1741, 1906–1907, 1909–1910, 1970–1971 as wet years.

Regional dry and wet years in the past

When the data obtained from our analysis is compared with that obtained from at least one previous dendroclimatological study, one finds significant similarity between years considered dry or wet. The list below includes dry and wet years during the period 1635–1930, a period that predates meteorological records:

The driest years (below 2 SD)	1687[a], 1692[a], 1687[a] 1696[a], 1701[a], 1739[a], 1746[a,c], 1887[a–c,e], 1927[a,c–f]
Dry years (below 1 SD)	1642[c], 1645[a], 1660[a], 1676[c], 1679[c], 1707–1708, 1715[a], 1724[T]–1725[c], 1742–1743[a,c,d], 1757[a,e,f], 1777[c], 1780[a], 1782[c], 1797[a], 1846[c], 1866[c], 1875[a], 1904[a,e], 1928[a–c,e,f]
Wet years (over 1 SD)	1643[a], 1661–1662[a,c], 1665[a,c], 1673–1674, 1678[a,c], 1720[c], 1727[a,c], 1733–1735[c], 1753[c], 1760[a], 1766[a], 1771[a,c], 1783[a,c], 1811[a], 1816[a,c], 1871[a], 1881[a,b], 1896[a–c], 1901[a–c], 1906–1907[a,c], 1909–1910[a,b]
The wettest years (over 2 SD)	1638[c], 1641[c], 1689[a,c], 1709[a], 1723[c], 1877[c]

[a] D'Arrigo and Cullen (2001)
[b] Hughes et al. (2001)
[c] Touchan et al. (2003)
[d] Ottoman Archives (1850–1930)
[e] Purgstall (1983)
[f] Inalcik (1997)

Some historical records of drought for Anatolia and neighboring countries corroborate the occurrence of major droughts and famine events in 1725, 1757, 1828, 1861, 1864, 1887, 1890–1891, 1893–1894, 1908 and 1927–1928 (Ottoman Archives 1850–1930; Inalcik 1997; Purgstall 1983). From these years, 1725, 1757, 1887 and 1927–1928 were very dry, and precipitation was lower by one or two standard deviations from the mean. Given the humid conditions in the study region, the other years 1828, 1861, 1864, 1890–1891, 1893–1894 and 1908 are seen as years with low growth on the regional chronology, and reconstructed precipitation was lower than the mean, but only by as much as one or two below the standard deviation. The year 1816 was described as "a year without summer" in the records. This year occurs as a wet year in the simulated reconstructions.

The results of our analysis demonstrate that drought events during the last four centuries in this region were

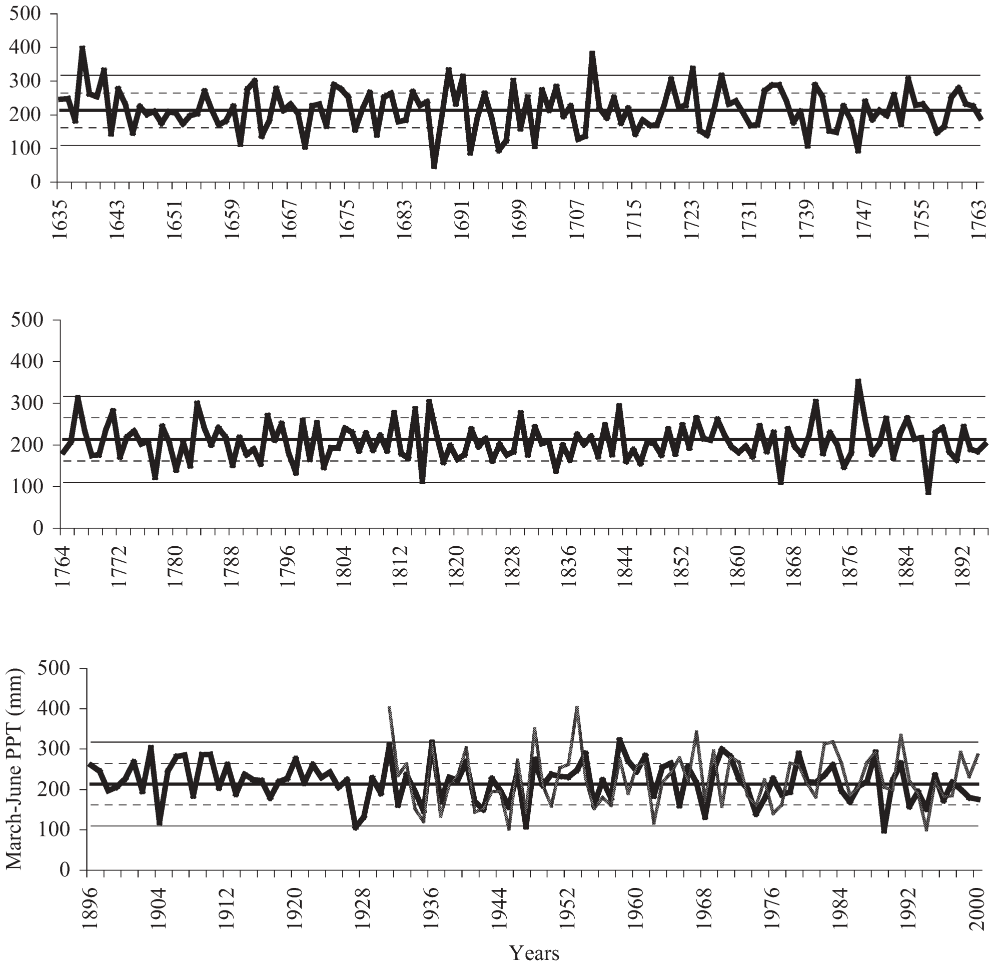


Fig. 5 Estimated values (1635–2000) and records (1931–2000) of total March–June precipitation. *Central horizontal line* shows the mean of the estimated values; *inner horizontal lines* (*dotted lines*) show the border of one standard deviation, and *outer horizontal lines* two standard deviations

never more than 2 years' duration. Wet periods with 3-year duration occurred once in this time span (1733–1735). Most extreme events occurred generally as individual years. Due to the humid and semi-humid climatic conditions, the duration of extreme events in this region appears shorter than that of typical Mediterranean conditions. Touchan et al. (2003) state that the drought events of more than 3 years are very rare in the Mediterranean basin and occurred only during 1476–1479. Three-year duration events are also very rare. However, individual-year extreme events are frequent. Using our methods, the determination of regionally dry and wet years conforms remarkably well with the results of previous studies. Given our high similarity with previous studies, all the results of the present study, including likelihood of droughts, their durations, their distribution, and their severity, offer useful criteria for the planning and management of resources in and around the study region. Our results are preliminary and require confirmation from ongoing national and international dendroclimatological projects and studies. Continued work in this direction should enable us to understand better the nature of drought and rainfall in and around Turkey.

Acknowledgements We are grateful to Sercay Güzel, the forest engineer in Forest Service of Kastamonu-Pinarbasi, for assistance in the fieldwork, to Prof. Nicholas Rauh from Purdue University, for editing the English language of the manuscript, and to two anonymous referees for their comments that improved the paper.

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