Journal of Arid Environments (1999) 42: 291–303
Article No. jare.1999.0507
Available online at http://www.idealibrary.com on IDEAL®

Dendrochronology in Jordan

Ramzi Touchan & Malcolm K. Hughes

Laboratory of Tree-Ring Research, The University of Arizona, P.O. Box 210058, Tucson, Arizona 85721, U.S.A.

(Received 13 November 1998, accepted 25 February 1999)

Dendrochronology is a valuable tool for the study of past climate and increases our knowledge of climate variability beyond the short period covered by instrumental data. Two annual tree-ring width chronologies were developed for northern Jordan (*Pinus halepensis* and *Quercus aegilops*), one chronology for Carmel Mountain, Israel (*Pinus halepensis*), and one chronology for southern Jordan (*Juniperus phoenicia*). The results of our study show that the northern site chronologies are significantly correlated, but the northern and southern sites are not. A relatively high correlation was shown between October–April precipitation and a *Pinus halepensis* chronology, and between October–May precipitation and *Quercus aegilops,* both in the north. October–May precipitation was reconstructed for the time span AD 1600 to 1995 from the *Juniperus phoenicia* tree-ring chronology. The longest reconstructed drought, defined as consecutive years below a threshold of 80% of the 1946–1995 mean observed October–May precipitation, was 4 years, compared with 3 years for the 1946–95 instrumental data.

Keywords: dendrochronology; tree rings; cross-dating; drought

Introduction

The discipline of dendrochronology, that is development and use of time-series by means of annual growth rings of trees, comprises a set of techniques by which the annual growth layers of trees may be assigned to a definite calendar year. The history of changes in the trees' environment may be reconstructed using various properties of tree rings. Tree-ring properties include width, cell size, wood density, trace element composition, and radioactive and stable isotope ratios. External environmental variables affect the physiological processes that control tree growth. The annual radial growth increment produces a permanent record of these effects. Since climate is the primary limiting factor to growth in the arid and semi-arid Near East countries, the sequence of narrow and wide rings in the tree-ring chronologies is a proxy record of year-to-year fluctuations in climate.

Dendrochronology was developed in North America in the early years of this century by the late Professor Andrew E. Douglass, founder of the Laboratory of Tree-Ring Research (LTRR) at the University of Arizona. Douglass performed most of his tree-ring investigations in the dryland regions of the south-western United States, where moisture is limiting and tree growth is related more to the quantity of moisture available than to competition from other trees. Tree ring width can thus be used as a proxy record

0140-1963/99/080291 + 13 $30.00/0

of precipitation. Since Douglass' research, these techniques have been used in many parts of the world to produce useful environmental information.

Tree-ring series can be used to reconstruct past variations in precipitation, temperature, soil moisture, river flow, the frequency of extreme droughts, forest fires, major forest pest outbreaks, and other variables over time spans of several centuries to, occasionally, millennia. What can be reconstructed depends on which factors limit tree growth. Many of these are relevant to the concerns of Near Eastern countries such as Jordan. Such data provide a standard against which to check the applicability of ideas and models to the natural conditions found in the region. Such observations can constitute a source of information for a better understanding of how the environment varied in the past, and hence how it might vary in the future.

Relatively few dendrochronological studies have been performed in the Near East. Bannister (1970) attempted systematic tree-ring dating of Near East archaeological sites. Since Bannister's investigations, various dendrochronological studies in the Near East have been performed. Some have used tree ring data to develop paleoclimate records (Liphschitz & Waisel, 1967; Shanan *et al.*, 1967; Chalabi & Serre-Bachet, 1981; Munaut, 1982; Parsapajouh *et al.*, 1986; Chalabi & Martini, 1989). Other studies have used tree-ring series to date archeological sites (Kuniholm & Striker, 1987; Kuniholm, 1990, 1994; Lev-Yadun, 1992). Another category of studies examined the cycle of cambial activity in a given tree species to determine which species exhibit annual growth rings (Liphschitz *et al.*, 1981, 1984, 1985; Liphschitz & Lev-Yadun, 1986; Fahn *et al.*, 1986).

Touchan *et al.* (1999) developed the first dendroclimatic reconstruction in the Near East for southern Jordan, a 396-year long preliminary reconstruction of winter precipitation based on two tree-ring width chronologies of *Juniperus phoenicia*. Some reconstructions are available for other parts of the Mediterranean region (e.g. Meko, 1985; Stockton, 1985; Chbouki, 1992), but their distance and the large spatial variability of climate in the region precludes their use for inferring climatic variations in Jordan.

This paper describes the development of tree-ring chronologies of Aleppo pine (*Pinus halepensis*) from northern Jordan and western Israel, *Quercus aegilops* from northern Jordan, and *Juniperus phoenicia* from southern Jordan. The inter-correlation of the different chronologies will be examined, as well as the effect of climate on tree ring growth. This paper will also discuss the use of the *Juniperus phoenicia* chronologies to develop the first precipitation reconstruction in the Near East derived from tree rings.

Study area

Six tree-ring sites were sampled (Fig. 1). Three of the sites are in northern Jordan in the Bani Kenana and Dibeen regions (Table 1). The two sites in Bani Kenana are Wadi Al-Muntamera and Heraj Al-ourthan. Another site is Carmel Mountain in western Israel. Two sites (Dana Reserve and Tor-Al Iraq) in southern Jordan were also sampled. Elevation of the sampled sites ranges between 400–1300 m a.s.l.

The soils at the sampled sites in Jordan are generally calcareous with reasonably good nutrient levels, but suffer from a deficiency of nitrogen and phosphorus and occasionally iron and manganese. The organic content is less than 1%. The texture is heavy loam to clayey with high water-holding capacity. Areas with deep soils have high fertility. Gravel content increases with slope. In the southern sites on steep slopes the soil is eroded, with sheet, rill, and gully erosion clearly visible (FAO, 1995). The soil characteristics in Carmel Mountain are similar to northern Jordan.

The climate of the study areas is Mediterranean semi-arid with sub-humid cold winters. Areas above 1000 m elevation have snowfall every year, and a meter of snow has been reported to cover some areas and last for more than 1 month (Bensada, 1985). Precipitation occurs only during the fall, winter, and spring (October–May), with a dry

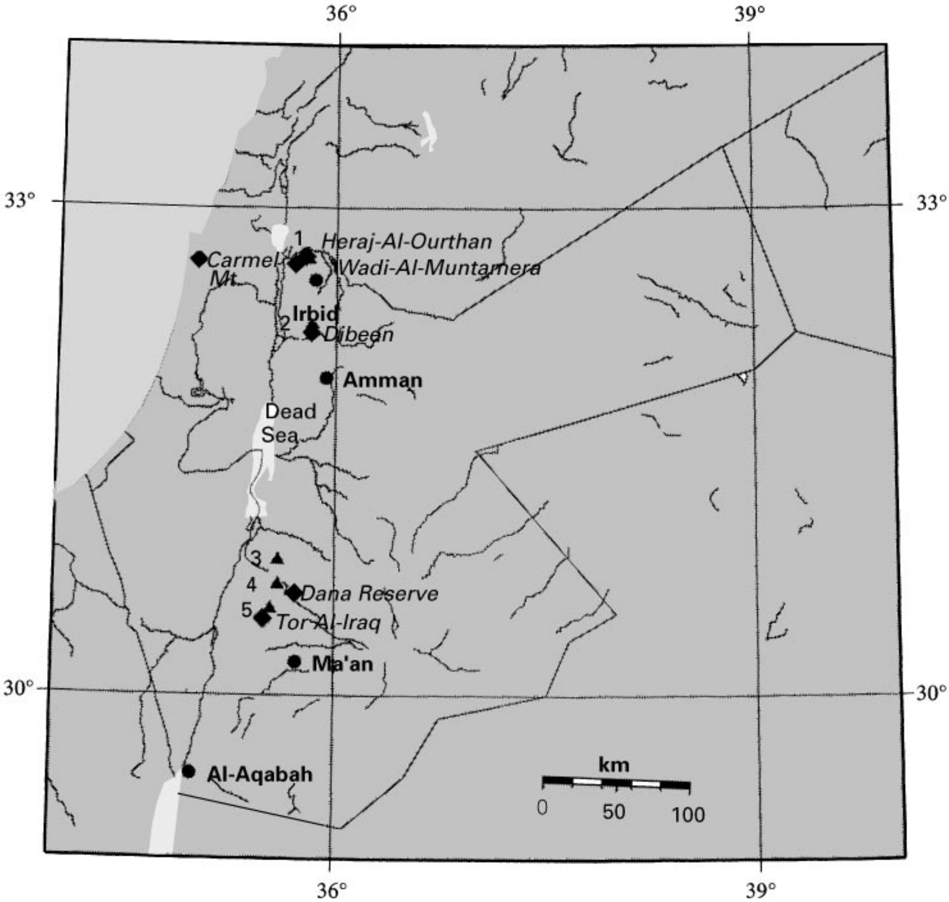

Figure 1. Locations of tree-ring sites (◆) and the five weather stations (▲) where 1, 2, 3, 4, and 5 represent Kufr Saum, Kitta, Tafile, Dana, and Shaubak, respectively.

summer (Fig. 2). Mean annual precipitation ranges from 270 mm in southern Jordan to 700 mm in northern Jordan and at Carmel Mountain.

Mean annual temperature ranges from 12·4°C in southern Jordan, where the meteorological stations are at a high elevation, to 21°C in northern Jordan. August is the hottest month with average mean daily temperatures of 21 to 25°C. January is the coldest month with average mean daily temperatures of 4 to 9°C. The highest mean maximum temperatures occur in August with values between 32·5 to 34°C; the lowest minimum recorded temperature is -14° in southern Jordan, and -5°C in northern Jordan and Carmel Mountain. The number of days with below freezing temperatures in this region varies between 75 days in Shaubak (southern Jordan) and 4·3 days in Irbid (northern Jordan).

The dominant trees at the sampled sites are as follows: deciduous forests (*Quercus aegilops*) in Bani Kenana to coniferous forest (*Pinus halepensis*) in Dibeen, *Juniperus phoenicia* in southern Jordan, and *Pinus halepensis* at Carmel Mountain. The Dibeen sites consist of a pure stand of *Pinus halepensis* and a mixed stand of *Pinus halepensis* and *Quercus coccifera*. The site in southern Jordan varies from pure stands of *Juniperus phoenicia* to areas mixed with *Pistacia atlantica* and *Quercus calliprinos*. The overstory at Carmel Mountain varies from pure stands of *Pinus halepensis* to areas mixed with *Quercus calliprinos* and *Pistacia palestina*.

Table 1. *Tree-ring chronology sites, listed from north to south*

Chronology name	Species*	Latitude	Longitude	Elevation (m)	Time span		Length (years)	Number of trees	No. of samples	
					earliest	latest			cores	cross-sections
Carmel Mountain	PIHA	32°40′ N	35° E	450	1915	1996	82	8	9	0
Bani Kenana	QUAE	32°39′ N	35°42′ E	300–410	1906	1995	90	12	0	12
Dibeen	PIHA	32°14′ N	35°49′ E	600–1134	1920	1994	75	14	14	0
Southern Jordan	JUPH	30°28′ N	35°43′ E	1100–1400	1469	1995	527	17	0	17

* PIHA = *Pinus halepensis; QUAE = Quercus aegilops* (developed from two sites in the Bani Kenana district); JUPH = *Juniperus phoenicia* (developed from two sites in southern Jordan).

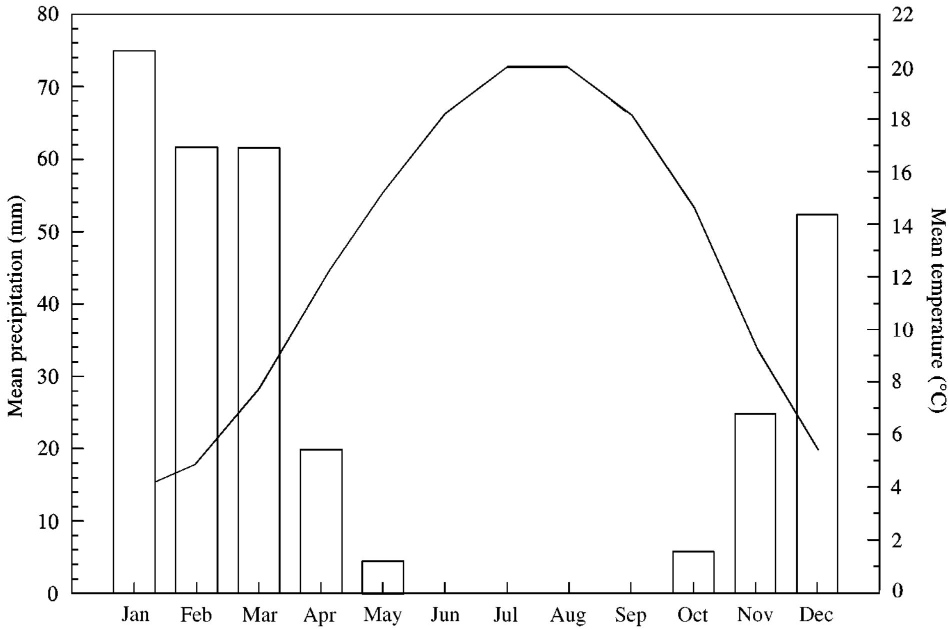

Figure 2. Climagram for Shaubak, southern Jordan, AD 1965–1995. (□) = Precipitation, (——) = temperature (from Touchan *et al.*, 1999).

Materials and methods

During 1995 to 1997 samples for four chronologies were collected from the six sites (Table 1). Increment borers (inside diameter of 4·3 mm) were used to sample the Aleppo pine trees. Full cross-sections of oak and juniper were cut with a chainsaw. In the laboratory, samples were fine-sanded to give a highly polished surface, making the annual rings easily visible under a dissecting microscope, and cross-dated using standard dendrochronological techniques (Stokes & Smiley, 1968). Cross-dating involved the identification of common patterns of inter-annual variation in the width and other features of growth layers to such a degree that each growth layer may be confidently assigned to a specific calendar year. Cross-dating ensures that each growth layer on every sample is assigned to an exact calendar year. Great difficulty was found in cross-dating some of the juniper samples due to the high incidence of locally absent rings (approximately 0·71%) and intra-annual boundaries (false rings) in some of the samples. Fisher (1994) reported that *Juniperus excelsa* from Oman has a similarly high proportion of locally absent and false rings. Visual cross-dating and computer based quality control showed such strong similarities between Wadi Al-Muntamera and Heraj Al-ourthan from Bani Kenana, northern Jordan, that these oak data were combined into a single chronology. Dana Reserve and Tor-Al Iraq juniper sites from southern Jordan showed equally strong cross-dating characteristics and were also combined into a single chronology.

The width of each annual ring on the cores and cross-sections was measured to the nearest 0·01 mm. The long-term trend was removed from each time series of ring width measurements by fitting a curve and calculating an index defined as the actual ring width for each year divided by the curve-fit value. This is a standard technique used by dendrochronologists to remove non-climatic age and size trend, and the effects of stand dynamics (Cook & Kairiukstis, 1990). The first de-trending used either a modified negative exponential curve or regression line. In the case of pine from northern

Jordan, it was necessary to carry out a second de-trending, and a more flexible fit of curve to data was achieved by using a cubic smoothing spline designed to remove variability on time scales of 60 years and longer. Each ring-width series of oak in northern Jordan was de-trended by using a spline designed to remove variability at wave lengths two-thirds the length of the series or longer. The Aleppo pine ring width measurements in Carmel Mountain were de-trended by fitting a modified negative exponential curve or a regression line. Each time-series of ring measurements for the *Juniperus phoenicia* was de-trended by fitting a cubic smoothing spline designed to remove variability on time scales of 200 years and longer. The level of correlation between ring-width index values for adjacent years is higher than would be expected on the basis of inter-annual correlations in climate. This effect may be described as 'non-climatic persistence'. This is removed from the tree ring data by a technique known as 'prewhitening' (Cook, 1985). These 'prewhitened' time-series were then combined into a single chronology by a technique known as 'biweight robust estimate of the mean' designed to reduce the influence of isolated outlier values (Cook, 1985). The various standardization methods were designed to deal with the specific effects of tree age, tree size, and stand interaction found at each site.

Subsample signal strength (SSS) was used to assess the adequacy of replication in the early years of the chronology (Wigley *et al.*, 1984) (Table 2). The SSS is computed from data on sample size and between-tree correlations. It is a guide to assessing the likely loss of reconstruction accuracy that occurs when a chronology made up of a few series is used to reconstruct past climate with a transfer function derived from a chronology with a greater number of series (Wigley *et al.*, 1984).

Two meteorological stations with precipitation records were selected near the sampled tree-ring sites in northern Jordan (Fig. 1). Kufr Saum station was near the *Quercus aegilops* site in Bani Kenana, and Kitta was near the *Pinus halepensis* site in Dibeen. The *Pinus halepensis* site in Carmel Mountain, western Israel, was not tested with climate data. Here, the stations surrounding the site all revealed records with missing data and short series. In southern Jordan, the average of three weather stations (Tafile, Dana, and Shaubak) was used because the inter-station correlation of October–May precipitation for the period from 1946 to 1995 exceeds 0·90, $N = 50$, $p \leq 0{\cdot}0001$, indicating a strong regional climate signal.

Results and discussion

Relationship between chronologies

The average correlation coefficient between trees for each site demonstrates a moderate common growth signal among trees. A comparison between the four chronologies is shown in Fig. 3. The correlation between Dibeen and Carmel Mountain, approximately 110 km west, is $r = 0{\cdot}53$, $N = 70$, $p \leq 0{\cdot}01$. There was also a significant correlation between Dibeen, Carmel Mountain, and Bani Kenana. However, the correlation between Dibeen and Bani Kenana ($r = 0{\cdot}46$, $N = 70$, $p \leq 0.01$) is higher than the correlation between Bani Kenana and Carmel Mountain ($r = 0{\cdot}35$, $N = 70$, $p \leq 0{\cdot}01$), which suggests that the factor that could account for the high correlation in tree growth over such a broad region is climate. It is difficult to conceive of any other factor that could influence tree growth in such a coherent manner.

Tree-ring growth and climate

Climatic influence on the growth of trees has been the major focus of this work in Jordan. Correlations between the tree-ring chronologies of northern and southern Jordan and

Table 2. *Summary statistics for the four chronologies from computer program ARSTAN*

Chronology name	Total chronology				Common intervals			
	Standard deviation	Skewness	Kurtosis	1st year SSS★ >0·85 (AD)	Time span (AD)	Total no. of years	Mean correlation among Radii	Variance in first principal component (%)
Carmel Mountain	0·28	0·34	0·23	1924	1942–1996	55	0·38	47
Bani Kenana	0·26	0·54	0·43	1923	1936–1994	59	0·31	37
Dibeen	0·24	– 0·35	– 0·14	1929	1939–1990	52	0·34	42
Southern Jordan	0·29	– 0·36	0·48	1549	1713–1994	282	0·37	45

★SSS is the subsample signal strength (Wigley *et al.*, 1984).

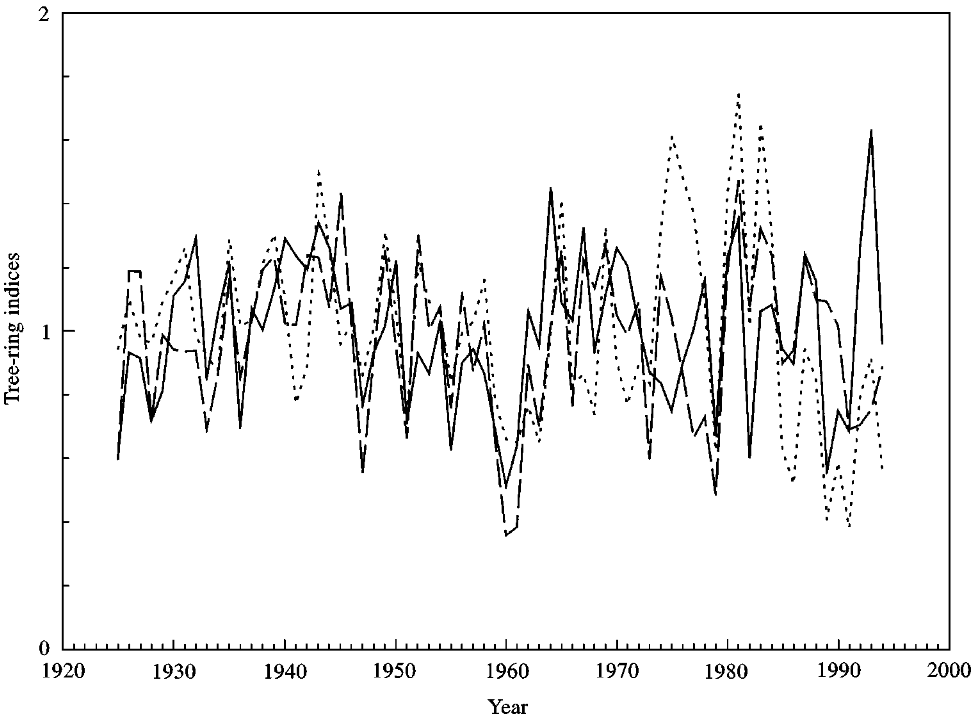

Figure 3. The relationship between *Pinus halepensis* in Carmel Mountain (- - - -), *Quercus aegilops* in Bani Kenana (———), and *Pinus halepensis* in Dibeen (— — —).

precipitation data from weather stations close to the sites were calculated (Fig. 4). A high correlation ($r = 0{\cdot}75$, $N = 53$, $p \leq 0{\cdot}0001$) was found between October–April precipitation and the *Pinus halepensis* chronology of northern Jordan (Fig. 4). The correlation between October–May precipitation and the *Q. aegilops* chronology was $r = 0{\cdot}71$, $N = 53$, $p \leq 0{\cdot}0001$. These results demonstrate the strong relationship between tree growth and precipitation. There is great promise for reconstructing past climate in the northern region if old trees (200–300 years) can be found. At this time, the northern chronologies are too short to use to reconstruct past climate variation. However, Touchan *et al.* (1999) were able to develop the first dendroclimatic reconstruction in the Near East region using *Juniperus phoenicia* in southern Jordan (Fig. 5). They reconstructed October–May precipitation from the *Juniperus phoenicia* tree-ring chronology in southern Jordan to gain a long-term (AD 1600–1995) perspective on runs of consecutive dry years and on time series fluctuations in precipitation averaged over several years. The reconstruction equation, derived by regression of log-transformed precipitation on tree-ring indices, explains 44% of the variance of observed precipitation. Cross-validation using the PRESS procedure (Weisberg, 1985) indicated that the model performs well in estimating precipitation data not used to fit the model ($R^2_{\text{prediction}}$ of 0·41).

As shown in Fig. 5, juniper tree growth responded extremely poorly to the two wet years of 1964 and 1965. In December 1963 a single storm accounted for 62% (352 mm) of the total (567 mm) October–May rainfall. In January 1965, another storm produced 66% (350 mm) of the total annual rainfall (527 mm). Large surface runoff from

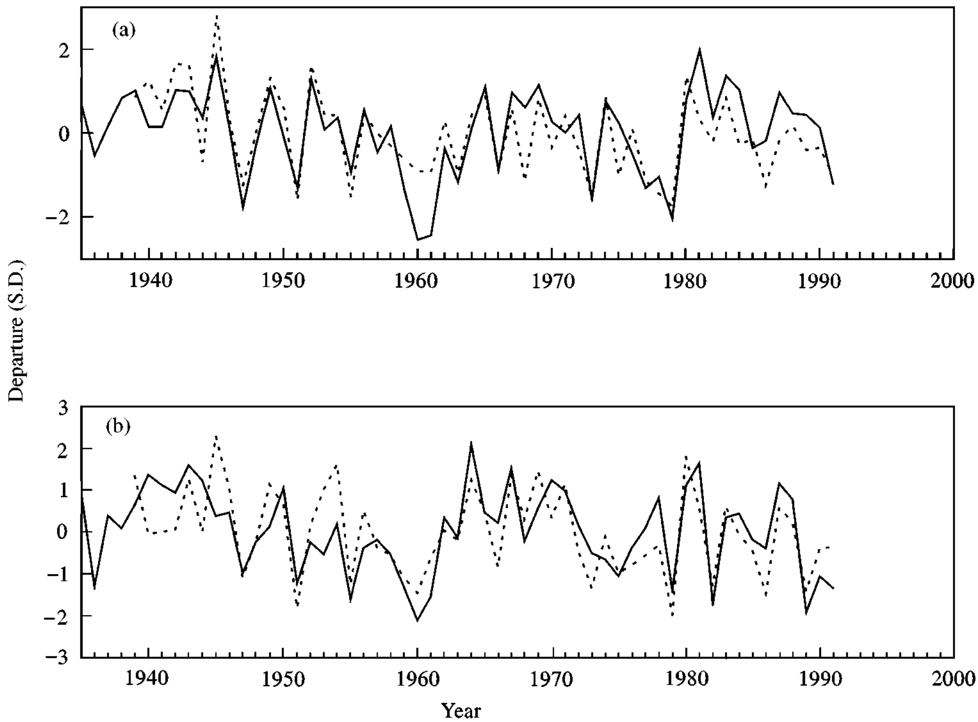

Figure 4. The relationship between tree-ring growth and precipitation in northern Jordan. (a) The relationship between *Pinus halepensis* tree-ring index (———) and October–April precipitation (- - - -) for Kitta station ($R = 0{\cdot}75$, $N = 53$, $p \leq 0{\cdot}0001$), and (b) the relationship between *Quercus aegilops* tree-ring index (———) and October–May precipitation (- - - -) for Kufr Saum station ($R = 0{\cdot}71$, $N = 53$, $p \leq 0{\cdot}0001$). All series are normalized.

these two events likely resulted in little increase in the soil moisture available for tree growth. An alternative model was tested by treating the years 1964 and 1965 as outliers and omitting them from development of the regression equation. Doing so raises theadjusted R^2 to 0.58 (58% of variance explained). However, the years 1964 and 1965 were included in the calibration of the reconstruction model because the possibility that similar events have happened in the past cannot be discounted.

The short-term drought properties in this series were summarized by runs analysis (Sadeghipour and Dracup, 1985). An arbitrary threshold of 217·4 mm was used to define a 'drought year' (Fig. 6). This threshold is 80% of the 1946–1995 mean observed October–May precipitation. By this method of tabulation, the long-term reconstruction (AD 1600–1995) contains 93 drought years with an average interval between droughts of 4·2 years and a maximum interval of 16 years (1664–1680). Fifty-five drought events had a duration of 1 year, seven a duration of 2 years, four a duration of 3 years, and three a duration of 4 years.

Touchan *et al.* (1999) found that in their Monte Carlo analysis designed to account for uncertainty in their reconstruction, drought periods of longer than 5 years are unlikely to happen in southern Jordan, and that the maximum severity of 3-year drought is considerably greater in a long-term context than suggested by the short instrumental records.

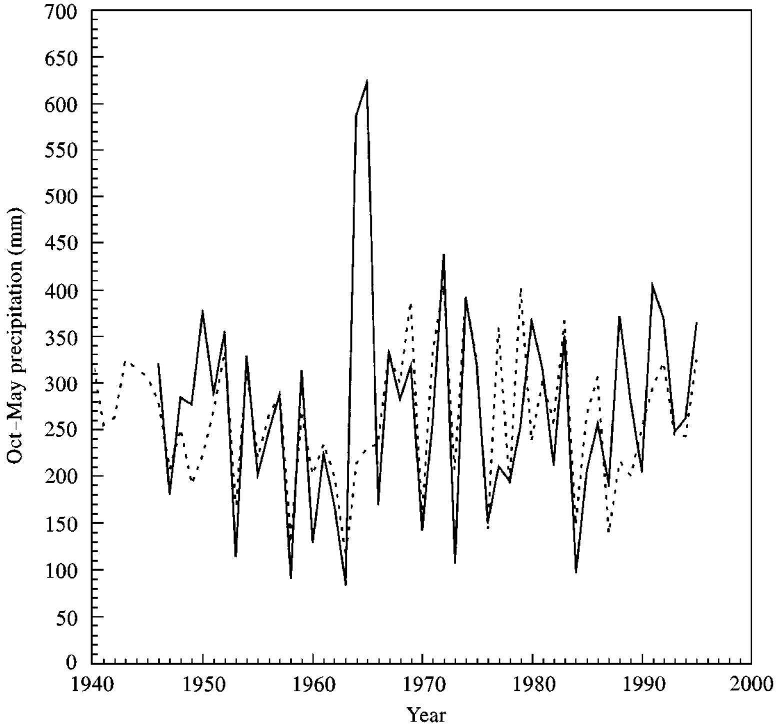

Figure 5. Comparison between actual (———) and estimated (- - -) October–May precipitation for southern Jordan from AD 1946–1995. Calibration R^2 is 0·44, the corresponding value for cross-validation is 0·41 (from Touchan *et al.*, 1999).

Conclusion

Dendrochronology is a valuable tool with which to study past climate variability. Understanding the effects of this variability is important for the management of water, agriculture, and other resources because it will help to implement low-risk, long-term plans to achieve conservation and sustainable use of water and other natural resources. The results indicate that precipitation reconstructions, such as the one presented in this paper, provide important information for natural resource management.

This work showed that there was a significant correlation between the Dibeen, Carmel Mountain, and Bani Kenana sites. The only factor that could account for the high correlation in tree growth over such a broad region is climate. The tree-ring growth of the northern sites and the southern sites did not show any correlation. This lack of correlation is probably due to the differences in climate between northern and southern Jordan, or perhaps other site-specific factors such as species response to the climatic condition, topography, soil depth, and slope. The study demonstrates a strong relationship between tree growth and precipitation. The calibration and verification statistics for the tree-ring reconstruction of southern Jordan are moderate for dendroclimatological studies of arid and semi-arid conifers. The reconstruction indicates that the longest period of continuous reconstructed drought during the past 400 years is 4 years. However, 4-year droughts occurred only three times during the four centuries.

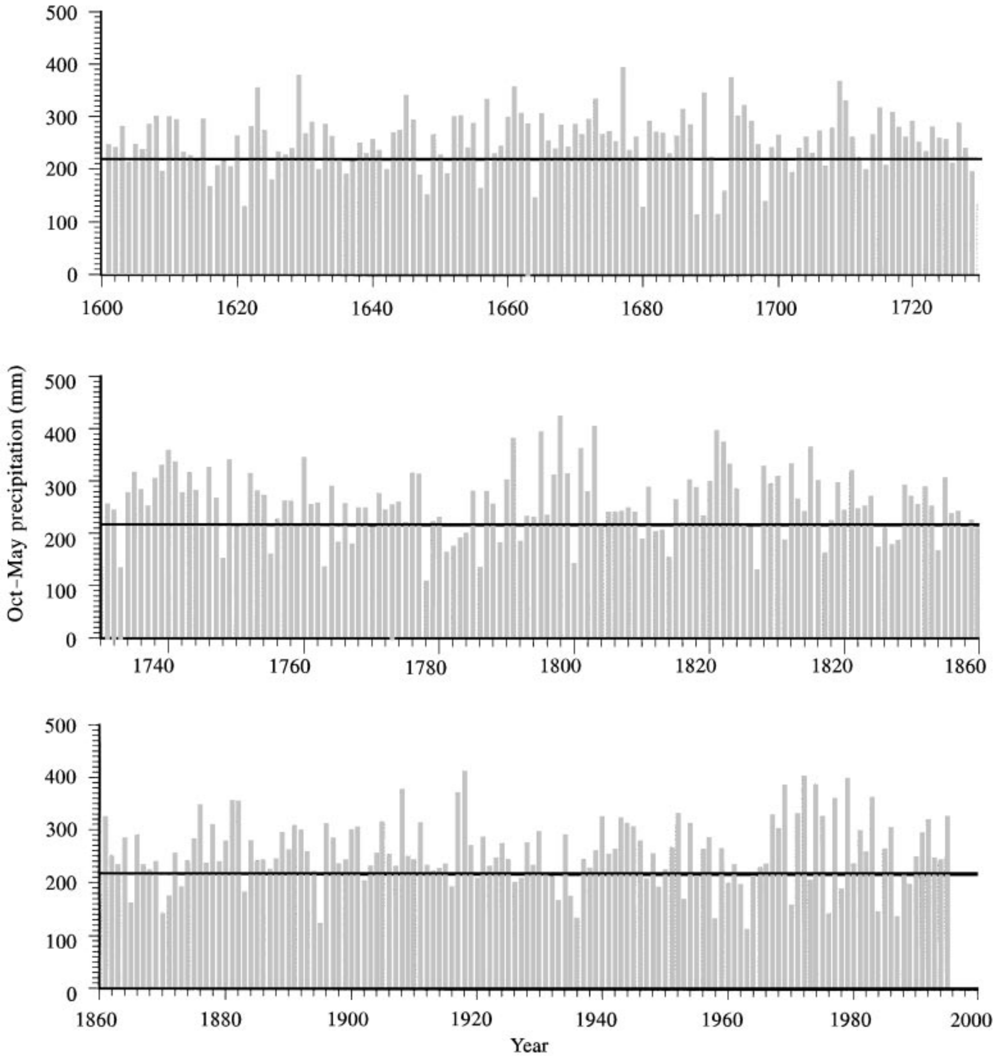

Figure 6. Time-series plot of reconstructed October–May precipitation, AD 1600–1995. The horizontal line is an arbitrary drought threshold of 217·4 mm (from Touchan *et al.*, 1999).

More sampling is needed from northern Jordan to increase the length of the chronologies in order to be able to reconstruct past climate. More samples are also needed from southern Jordan in order to increase the length and the reconstruction accuracy. Additional sampling from neighboring countries such as Syria, Lebanon, and Turkey is needed to gain a better understanding of past climate variation in the whole region. We intend to address the aforementioned needs in future research.

We thank the Ministry of Agriculture in Jordan, specifically His Excellency the Minister of Agriculture Mr Mijhim Al-Khraisha, His Excellency the Deputy Minister of Agriculture Mr Hashem Al-Shboul, His Excellency the former Deputy Minister of Agriculture Mr Ghalib Abu-Orabi, Director of International Cooperation Unit Mr Maher Abu-Ja'far, and the Director of Forestry and Range Mr Mousa Al-Abadi for making this study possible.

We would like to thank the Royal Society for Conservation of Nature in Jordan for their great help and support. We would like to thank the Ministry of Water Authority in Jordan for providing us with all precipitation data. We would like to thank Jim Speer for his valuable field assistance. We also would like to thank Peter Ffolliott, Gregg Garfin, Gary Funkhouser, Richard Waren, and Richard Holmes for their advice and suggestions. Funding was provided by the National Science Foundation (Foundation grant No. ATM 95-27740) and Mrs Agnese Haury.

References

Bannister, B. (1970). Dendrochronology in the Near East: current research and future potentialities. *Proceedings of the Seventh International Congress of Anthropological and Ethnological Sciences*, 5: 336–340.

Bensada, A. (1985). *Cuppressacea* of Dana Nature Reserve. Unpublished UNDP/World Bank report-Gef Project for the Conservation of Dana Wildlands. Amman, Jordan.

Chalabi, M.N. and Martini, G. (1989). Etude Dendroclimatologique de l'*Abies cilicica* (Ant. et Ky) de Syre. *Research Journal of Aleppo University*, 12: 57–89.

Chalabi, M.N. and Serre-Bachet (1981). Analyse dendroclimatologique de deux stations syriennes de *Quercus cerris* ssp *pseudocerris*. *Ecologia Mediteranea*, 7: 3–21.

Chbouki, N. (1992). Spatio-temporal characteristics of drought as inferred from tree-ring data in Morocco. Unpublished Ph.D. dissertation, University of Arizona, Tucson.

Cook, E.R. (1985). A time series analysis approach to tree-ting standardization. Unpublished PhD. dissertation, University of Arizona, Tucson.

Cook, E.R. and Kairiukstis, L.A. (1990). *Methods of Dendrochronology:* applications in the environmental sciences. Boston, MA: Kluwer Academic Publishers. 394, pp.

Fahn, A., Werker, E. & Baas, P. (1986). *Wood Anatomy and Identification of Trees and Shrubs from Israel and Adjacent Regions.* Jerusalem: The Israel Academy of Sciences and Humanities. 221 pp.

FAO (1995). *Training in management of forest and range lands.* Unpublished report, Amman, Jordan.

Fisher, M. (1994). Is it possible to construct a tree-ring chronology for *Juniperus excelsa* (bieb) subsp, *Polycarpos* (K. Koch), Takhtajan from the northern mountains of Oman? *Dendrochronologia*, 12: 119–127.

Kuniholm, P.I. (1990). Archaeological record: evidence and non-evidence for climate change. *Philosophical Transactions of the Royal Society of London A*, 330: 645–655.

Kuniholm, P.I. (1996). Long tree-ring chronologies for the eastern Mediterranean. *Proceedings of the 29th International Symposium on Archeometry*, Turkey, pp. 401–409.

Kuniholm, P.I. & Striker, C.L. (1987). Dendrochronological investigations in the Aegean and neighboring regions, 1983–1986. *Journal of Field Archaeology*, 14: 385–398.

Lev-Yadun, S. (1992). The origin of the Cedar beams from Al-Aqsa Mosque: botanical, historical and archaeological evidence. *Levant*, XXIV: 201–208.

Liphschitz, N. & Lev-Yadun, S. (1986). Cambial activity of evergreen and seasonal dimorphics around the Mediterranean. *IAWA Bulletin* n.s., 7: 145–153.

Liphschitz N. & Waisel, Y. (1967). Dendrochronological studies in Israel. *Quercus boisseri* of Mt. Meron region. *La-Yaaran*, 17: 78–91, 111–115. (In Hebrew.)

Liphschitz, N., Lev-Yadun, S. & Waisel, Y. (1981). The annual rhythm of activity of the lateral meristems (cambium and phellogen) in *Cupressus sempervirens L. Annals of Botany*, 47: 485–496.

Liphschitz, N., Lev-Yadun, S., Rosen, E. & Waisel, Y. (1984). The annual rhythm of activity of the lateral meristems (cambium and phellogen) in *Pinus halepensis Mill.* and *Pinus Pinea L. IAWA Bulletin* n.s., 5: 263–274.

Liphschitz, N., Lev-Yadun, S. & Waisel, Y. (1985). The annual rhythm of activity of the lateral meristems (cambium and phellogen) in *Pistacia lentiscus L. IAWA Bulletin* n.s., 6: 239–244.

Meko, D.M. (1985). Temporal and spatial variation of drought in Morocco. In: *Drought, Water Management and Food Production, Conference Proceedings held in Agadir* (Morocco), 21–24 November 1985.

Munaut, A.V. (1982). The Mediterranean area. In: Hughes, M.K., Kelly, M.P., Pilcher, J.R. & LaMarche, V.C. (Eds) *Climate from Tree Rings*, pp. 151–154. Cambridge: Cambridge University Press, 223 pp.

Parsapajouh, D., Bräker, O.U. & Schär, E. (1986). Étude dendroclimatologique du bois de taxus baccata du nord de l'Iran. *Schwizerische Zeitschrift für Forstwesen*, 137: 853–868.

Sadeghipour, J. & Dracup, J.A. (1985). Regional frequency analysis of hydrologic multiyear droughts. *Water Resources Bulletin*, 21: 481–487.

Shanan, L., Evenari, M. & Tadmor, N.H. (1967). Rainfall patterns in the central Negev desert. *Israel Exploration Journal*, 17: 163–184.

Stockton, C.W. (1985). Current research progress toward understanding drought. In: *Drought, Water Management and Food Production, Conference Proceedings held in Agadir (*Morocco), 21–24 November 1985.

Stokes, M.A. & Smiley, T.L. (1968). *An Introduction to Tree-ring Dating.* Chicago: University of Chicago Press. 73 pp.

Touchan, R., Meko, D.M. & Hughes, M.K. (1999). A 396-year reconstruction of precipitation in southern Jordan. *Journal of the American Water Resources Association*, 35: 49–59.

Weisberg, S. (1985). Applied Linear Regression (2nd Edn). New York: John Wiley. 324 pp.

Wigley, T.M.L, Briffa, K.R. & Jones, P.D. (1984). On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. *Journal of Climate and Applied Meteorology*, 23: 201–213.