NORTHERN ARKANSAS SPRING PRECIPITATION RECONSTRUCTED FROM TREE RINGS, 1023-1992 A.D.

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Abstract—Three baldcypress (*Taxodium distichum* (L.) Rich.) tree-ring chronologies in northeastern Arkansas and southeastern Missouri respond strongly to April-June (spring) rainfall in northern Arkansas. I used regression to reconstruct an average of spring rainfall in the three climatic divisions of northern Arkansas since 1023 A.D. The reconstruction was validated by comparing it to independent observed data. The reconstruction shows highly variable hydroclimatic conditions in the past, with considerable long-term low frequency variation. Managers who wish to know the "natural" state of ecosystems must consider ecosystem response to climate and the long-term changes in climatic averages and variability that have shaped the adaptability of the ecosystems. This adaptability may translate into resilience in the face of anthropogenic climate change.

INTRODUCTION

Climate varies considerably, not only at high frequencies, e.g., year-to-year, but at much lower frequencies, over decades and centuries (Bradley 1999, Crowley and North 1991). The observed (instrumental) data, rarely much longer than 100 years in the United States, give little insight into the nature of such low frequency climate variability, such as the occurrence of long duration extreme drought (e.g., Stahle and others 2000). Annual rings from climate-sensitive trees serve as proxies to investigate past climate (Cook and others 1999, Fritts 1976, Stockton and others 1985). The reconstruction presented here forms part of a network of long spring precipitation reconstructions (Stahle and Cleaveland 1992, 1996). Eventually these reconstructions will cover most of the Southeastern United States and the lower Mississippi Valley.

DATA

Tree-Ring Data

The tree-ring data come from baldcypress (a long-lived, deciduous conifer) at three sites (fig. 1, table 1). The samples were extracted with increment borers from many trees at each site above the basal swelling, a nondestructive sampling technique. Some cross-sections were cut from down trees to extend chronologies into the past. Core samples were glued into wooden mounts and the transverse surfaces of all samples sanded until polished.

Trees may not grow a ring everywhere when stressed, leaving a ring missing from the chronological sequence. On the other hand, many trees will occasionally form false rings, i.e., intra-annual features that look like real rings but create an error if included in the chronological sequence (Fritts 1976, Stokes and Smiley 1996, Swetnam and others1985). All samples were crossdated to detect false and missing rings. Crossdating involves pattern matching between many ring sequences at a site and nearby sites to ensure correct dating of each ring (Stokes and Smiley 1996). The dated series were then measured to 0.01 mm.

Tree-ring series contain nonclimatic growth trends that must be removed to make them statistically stationary (Fritts 1976). I used program ARSTAN (Cook 1985, Cook and others 1990) to fit an exponential curve declining to a constant or a regression line to each series, then divided each ring width by its corresponding curve value. The dimensionless indices derived by this process have a mean of 1.0 (eliminating differences in mean growth rates of the series) and relatively stable variance. Because the negative exponential curves and regression lines do an imperfect job of detrending in many cases, I further detrended the indices with a "stiff" cubic smoothing spline (Cook and Peters 1981, Peters and Cook 1981). The flexibility of the smoothing spline is controlled by setting a parameter equal to the wavelength of a sine wave which will have 50 percent of its variance removed by indexing (Cook 1985, Cook and Peters 1981, Peters and Cook 1981). For example, a 10-year spline

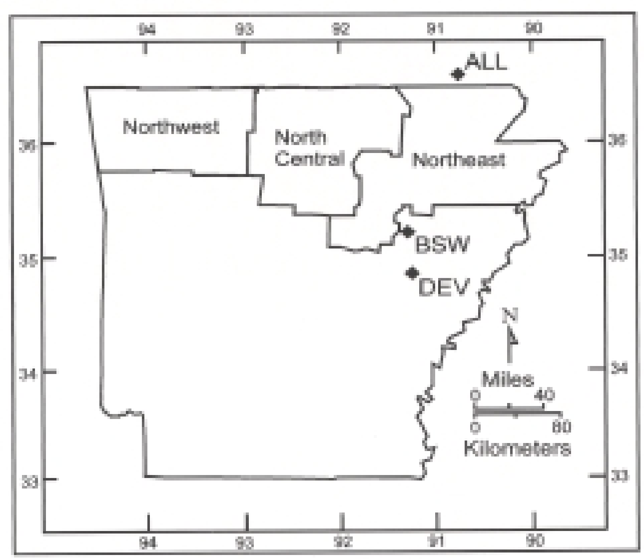

Figure 1—Locations of the tree-ring chronologies (table 1) used to reconstruct total spring (April–June) precipitation averaged from the three northern Arkansas climatic divisions.

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Table 1—Characteristics of tree-ring chronologies used to reconstruct spring (April-June) precipitation in northern Arkansas

Site/code name	Dates[a]	Latitude/ longitude	Standard deviation	Radii/ trees
All Lake, MO (ALL)	1188–1992	36^{0},34’N 90^{0},29’W	0.38	63/ 32
Black Swamp, AR (BSW)	1023–1980	35^{0},09’N 91^{0},18’W	0.39	61/ 31
Bayou DeView, AR (DEV)	1137–1985	34^{0},57’N 91^{0},13’W	0.42	60/ 28

[a] Residual (whitened) chronology (Cook 1985, 1987).

would fit the variation in a time series much more closely than a 100-year spline, the minimum stiffness used in detrending indices.

Tree-ring series usually contain persistence caused by physiology (Fritts 1976). Autoregressive (AR) modeling and removal of the persistence (“whitening”) make the climatic signal in tree rings clearer (Cook 1987, Meko 1981). The individual detrended series were AR modeled with the pooled multivariate AR model and the resulting whitened series were then averaged with an algorithm that weights values that fall near the mean higher than outliers (Cook 1985, Cook and others 1990). If significant AR persistence remained in the average, the chronology was rewhitened. The result was the “residual” chronology (Cook 1985). I averaged the three residual chronologies together to form a whitened regional tree-ring composite.

Climate Data

The precipitation data came from the National Climatic Data Center (NCDC) Historical Climatology series (Karl and others1983), a CD-ROM (NCDC n.d.) and updates to the CD-ROM. Exploratory correlations with the 12 months from the northern and central Arkansas and southern Missouri climate divisions showed that April-June rainfall in the three northern Arkansas climate divisions (Northwest, North Central and Northeast; fig. 1) correlated best with growth of the three tree-ring chronologies. Although the tree climate divisions reconstructed contain none of the tree-ring chronologies, they are nonetheless well correlated with the averaged tree growth because the trees respond to broad patterns of regional climate over hundreds of kilometers (Cook and others 1996). Monthly precipitation from the three northern Arkansas climatic divisions (fig. 1; NCDC n.d.) were averaged 1895-1992. The average of the three divisions was an AR-0 process, i.e., it contained no significant persistence (SAS Institute Inc. 1993).

CALIBRATION, RECONSTRUCTION AND VALIDATION

Calibration

Although the chronology average goes to 1992, I terminated the calibration period in 1985 because only one of the three chronologies extends further (table 1). I regressed (Draper and Smith 1981, SAS Institute Inc. 1989b) the regional tree-ring average against the northern Arkansas spring climate average for 1895-1985 and for two subperiods, 1895-1939 and 1940-1985 (fig.2, table 2). The 1895-1985 calibration equation used for reconstruction was:

$$Y_t = 113.7 + 241.7X_t \qquad (1)$$

where Y_t is the total April-June rainfall for year t (average of the three climate divisions) and X_t is the average of the three residual chronologies. The results were excellent, accounting for more than 64 percent of the climatic variance 1895–1985. The Durbin-Watson test (Draper and Smith 1981) showed the residuals from regression 1895-1985 to be significantly serially correlated (r = 0.18), as were the residuals 1940-1985 (r = 0.29). Nevertheless, inspection of scatterplots of the residuals (not shown) appear to contain no marked departures from linearity.

Reconstruction and Validation

The regression coefficients (eqn. 1) were applied to the entire tree-ring series to produce estimates of spring rainfall (fig. 3) from averaged annual growth. The other calibrations

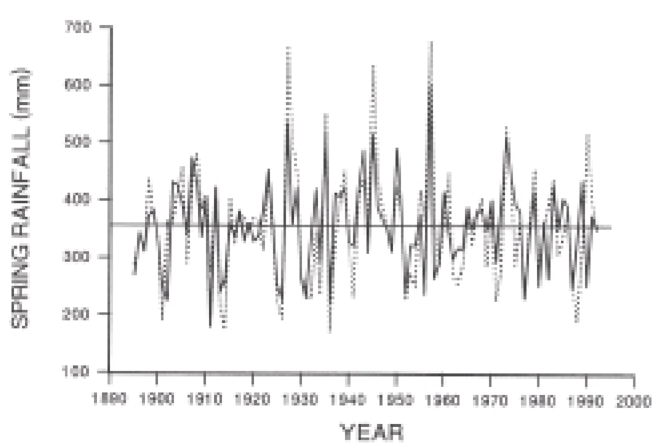

Figure 2—Observed (dashed line) and reconstructed (solid line) total spring (April-June) precipitation averaged from the three northern Arkansas climatic divisions, 1895–1992 (Karl and others 1983, NCDC n.d.).

Table 2—Calibration and validation statistics for reconstruction of spring (April-June) precipitation (mm) in northern Arkansas. B_0 and B_1 are the intercept and slope of the regression line, respectively. There is no significant difference (P > 0.05) between the parameters in the two subperiods, 1895-1939 and 1940-1985

Calibration period	R^2adj[a]	B_0	B_1	Residual autocorrelation[b]
1895-1985	0.644	113.7	241.7	0.18*
1895-1939	.673	107.2	250.4	.06NS
1940-1985	.604	120.2	233.5	.29*

Validation period	Correlation[c]	t-test diff. of means[d]	Sign test +/-[e]	Reduction of error[f]
1940-1985	.783***	.02NS	36/9***	.62
1895-1939	.825***	.00NS	36/9***	.68

* = P < 0.05; *** = P < 0.001; NS = P > 0.05, not significant

[a] Multiple correlation coefficient adjusted for loss of degrees of freedom (Draper and Smith 1981).

[b] Autocorrelation of residual tested with the Durbin-Watson statistic (Draper and Smith 1981, Neter and Wasserman 1974).

[c] Pearson product-moment correlation coefficient (Steel and Torrie 1980).

[d] Two-tailed paired observation test of difference between observed and reconstructed precipitation means (Steel and Torrie 1980); failure to find a significant difference is a good result.

[e] One-tailed test on the agreement between signs of departures from the means of the observed and reconstructed series (Conover 1980); positive shows agreement on the direction of the departures.

[f] The reduction of error statistic varies between negative infinity and positive 1.0; any positive number indicates skill at recovering paleoclimatic information (Fritts 1976).

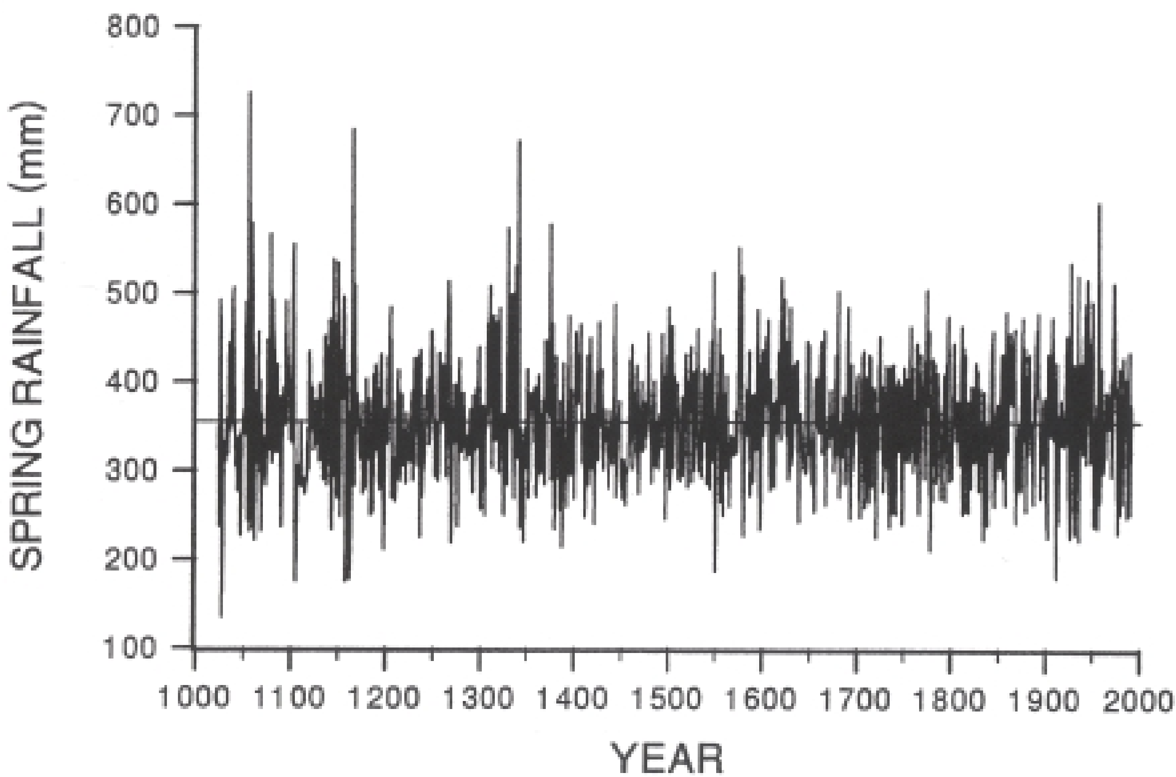

Figure 3—Reconstructed total spring (April-June) precipitation averaged from the three northern Arkansas climatic divisions, 1023–1992.

permitted validation of the series, because the observed data not used in the short calibrations could be tested for accuracy (Snee 1977). All tests of model estimates versus independent data indicate that the models have been validated (table 2). In addition, tests of the regression coefficients verify their essential equality in the two subperiods (Neter and Wasserman 1974, SAS Institute Inc. 1989a). The reconstruction variance appears quite high in the earliest three and a half centuries (fig. 3). This is probably an artifact of lower sample size in the early part of the time series, not a real phenomenon.

CLIMATIC VARIATION

It has been shown that average drought indices may vary over periods of several decades (Stahle and Cleaveland 1992, Stahle and others1988, 2000). Climate variability may also change considerably over decades (e.g., Cleaveland and others 1992, Cleaveland and Stahle 1996). One way of visualizing changes of climate is through cubic spline smoothing curves like those used to detrend tree-ring growth series. Figure 4 shows 10- and 30-year cubic spline curves for observed and reconstructed spring precipitation 1895-1992. The low frequency curves agree in their main features, although the last 30 years of the 30-year splines appear to be at least partially out of phase.

The spline curves offer insight into past variation (fig. 5). The addition of a very stiff 100-year spline derived from the long reconstruction shows quite clearly that there are century-long average-to-dry periods (e.g., 1100-1250 and 1370-1500; fig. 5) that might be expected during the Medieval Warm Period usually set from the ninth to the fourteenth or mid-fifteenth centuries (Hughes and Diaz 1994). On the other hand, in some places the Medieval Warm Period may have been both warmer and wetter than present, e.g., the Colorado Plateau in the southwestern United States (Petersen 1994). Petersen (1994) also characterizes the Little Ice Age (ca. 1500-1850) as colder and drier than present conditions in that region. This appears to have been a period of low variability in northern Arkansas, but the period 1645-1715, usually thought of as the heart of the Little Ice Age (Frenzel and others 1994) does not appear to have been anomalously dry (fig. 5). Stahle and others (2000) postulate a very long, extremely severe “megadrought” in the last half of the sixteenth century that appears to have affected northern Mexico and much of the United States. A very bad drought occurs in northern Arkansas during this period (fig. 5).

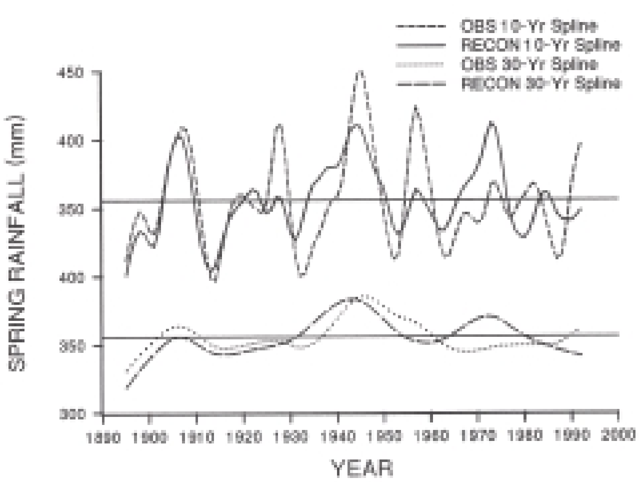

Figure 4—Smoothing spline curves showing variation from the long-term mean of observed and reconstructed total spring (April–June) precipitation averaged from the three northern Arkansas climatic divisions, 1895–1992.

Changes in variability and occurrence of extremes occur throughout the reconstruction. Two conspicuous periods of few extremes and low variability shown by the 10- and 30-year splines are ca. 1480-1550 and 1670-1810 (fig. 5). The twentieth century appears to have been a period of average to above average rainfall in northern Arkansas.

Another way to investigate the variability of climate is to look at the distribution of extremes. In table 3 the 100 wettest and 100 driest years (20.6 percent of the 970 reconstructed years) were classified by which century they fell into. The twentieth, eleventh and fourteenth centuries had more extremes than the other centuries. The balance was very different, however. The twentieth century had many more dry extemes than wet (18/9), while the eleventh century had 11 dry and 16 wet extemes. It is interesting to note that although most of the twentieth century 100-year spline curve is above average (fig. 5), this century has twice as many dry extemes as wet. The directions of anomalies in the smoothed curves do not necessarily govern the directions of anomalies in extreme values.

SUMMARY AND CONCLUSIONS

I used an average of three long tree-ring chronologies to reconstruct spring (April-June) total precipitation averaged from the three northern Arkansas climatic divisions. Tree-ring growth accounted for more than 64 percent of the climatic variance 1895-1985 and the regression model validated well against independent data.

Past spring precipitation varied considerably through time, with averages of long periods above and below the modern mean values. Several prolonged periods of drought exceeding anything in the twentieth century appear to have occurred in the past. The occurrence of extreme wet and dry years was unevenly distributed through time. Variability

Table 3—The reconstructed wettest and driest springs (April-June) in northern Arkansas, 1023–1992

Century	Wet	Dry	Total
11th (1023–1100)	16	11	27
12th (1101–1200)	10	12	22
13th (1201–1300)	6	6	12
14th (1301–1400)	14	11	25
15th (1401–1500)	7	6	13
16th (1501–1600)	9	6	15
17th (1601–1700)	12	5	17
18th (1701–1800)	6	14	20
19th (1801–1900)	11	11	22
20th (1901–1992)	9	18	27

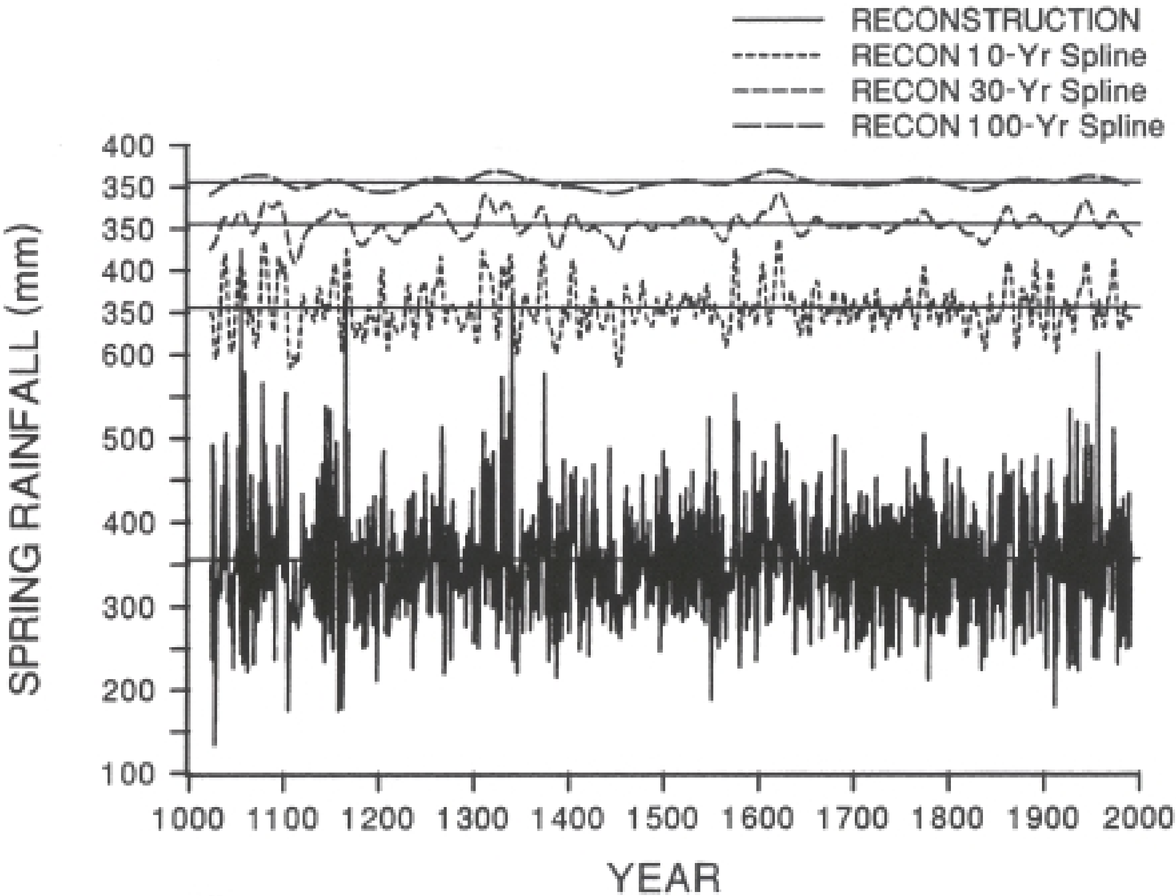

Figure 5—Smoothing spline curves showing variation from the long-term mean of reconstructed total spring (April-June) precipitation averaged from the three northern Arkansas climatic divisions, 1023–1992.

occurs on all scales, from year-to-year to centuries. Managers of natural areas can add another source of disturbance to their list of influences in the ecosystems they work with: Natural Climatic Change. However, ecosystems that have not been degraded may show a surprising degree of adaptability to anthropogenic change in climate (e.g., Houghton and others 1996), because those ecosystems have evolved with the highly variable climatic states seen in the reconstruction. This adaptation to climatic change is apparently a major source of biological diversity in ecosystems and ecosystems depend on biodiversity for their adaptive responses (McCann and others 1998, Polis 1998).

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