A CLIMATE HISTORY OF BOONE COUNTY, MISSOURI, FROM TREE-RING ANALYSIS OF EASTERN REDCEDAR

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ABSTRACT

A ring-width index, constructed from analyses of eastern redcedar (*Juniperus virginiana* L.) trees, for central Boone County, Missouri, is presented. Correlations between summer temperatures, spring rainfall and the index are shown. Some possible interpretations of past climate history, based on the index, are listed for selected time periods back to 1650 AD.

Keywords: Dendrochronology, redcedar, ring-width index, temperature, rainfall.

INTRODUCTION

Dendrochronology, the study of the variation between annual growth increments in trees, utilizes patterns in tree-ring widths to study such things as tree growth, date archaeological wood, investigate fire histories and reconstruct past climate. In the latter use, known as dendroclimatology, a relationship between climate and growth is established and then used to gain insight into past climate beyond existing meteorological records. Sample trees used in dendroclimatology are selected for the strength of their climate "signal" and the length of their ring-width record. Each ring width is measured and then the ring-width series is standardized in order to remove nonclimatic variations. Each ring-width series is then averaged into an index that is correlated with climatic variables to create a statistical model linking climatic variables and growth.

This study investigated the problems and potential for using the wood of eastern redcedar (*Juniperus virginiana* L.) to reconstruct a climatic record in Boone County, Missouri. It was an open-ended study in that a tree-ring chronology can be improved by the addition of more samples. The addition of older trees (and remnants of trees) over a greater area will improve not only the temporal and geographic range of the chronology, but will also strengthen the growth-climate relationship.

Redcedar has many desirable qualities for studies in dendrochronology. Trees grow to relatively old ages, at least 600 years old. This provides a sufficient time period to be of significant interest in studying climate change. These trees grow in generally undisturbed microenvironments where logging or other human activ-

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ity that might complicate growth rates are at a minimum. Usually they are found in relatively open stands and this minimizes the influences of competition on growth. The heartwood is very resistant to decay, thus leaving much old wood in well-preserved condition. Some of this heartwood can be crossdated to extend tree-ring chronologies further back in time. Also, because of decay resistance, it is more likely to be preserved in historical and archaeological situations where it might be used in dating.

Eastern redcedar trees also can be located relatively easily. Old trees grow almost exclusively on south- or west-facing bluff sites, which can be located on topographic maps. This cuts down considerably on the time involved in finding sample trees. Because they are located on bluffs in more or less barren rock, there is little to burn underneath them; this accounts not only for their longevity but restricts the influence of fire on growth. Finally, the most important attribute for dendroclimatological work is that bluff site trees grow in a climatically limiting environment.

Microclimate

The microclimate that these trees "experience" is our link with the macroclimate of the past. A tree responds selectively to climatic conditions. Some conditions have a strong influence on tree growth and ring-width whereas other conditions have very little influence. Thus, the climate signal in a tree's ring-width is filtered by its physiological responses. This filtered signal is the "window" (Fritts 1976) through which we can "view" past climate.

An understanding of the microclimate of the bluff site is crucial to a reconstruction of past climate. The extent to which growth is limited by microclimatic factors determines the strength of the climatic "signal" recorded in a tree's radial growth. Three important classes of microclimatic factors that occur on central Missouri bluff sites are precipitation, temperature, and wind.

Bluff sites, especially those on a "backbone" in an entrenched meander, are well drained. Figure 1 shows a profile of a typical site. Runoff is high because of the steep slope and Karst topography. The high exposure of the bluff rocks to solar radiation, microthermals, and prevailing wind increases the evaporation potential of the bluff and tree foliage surface. These factors combine to make the bluff soil dry rapidly and create a condition of potential moisture stress.

Temperature can limit ring width by being too high or low for optimum photosynthesis. Bluff edges are subject to extreme changes in temperature. The high amount of radiation received during the day and the high rate of reradiation by the bluff rock at night can subject redcedar to radical diurnal variations in temperature. Microthermals that form along the south- and west-facing bluffs can be a factor in raising the temperatures of leaves and soil enough to limit photosynthesis in the growing season or to cause desiccation in the winter.

Prevailing winds on bluff sites play an important role in the transpiration of plant moisture. Wind passing over a leaf surface can cause an increase in the evaporation of plant water. Water loss is increased by the exposure of the redcedar to prevailing wind, and by the increase in wind velocity at the bluff edge due to the constriction of air flow by the bluff face.

Other factors that can influence ring width are damage to foliage by animals,

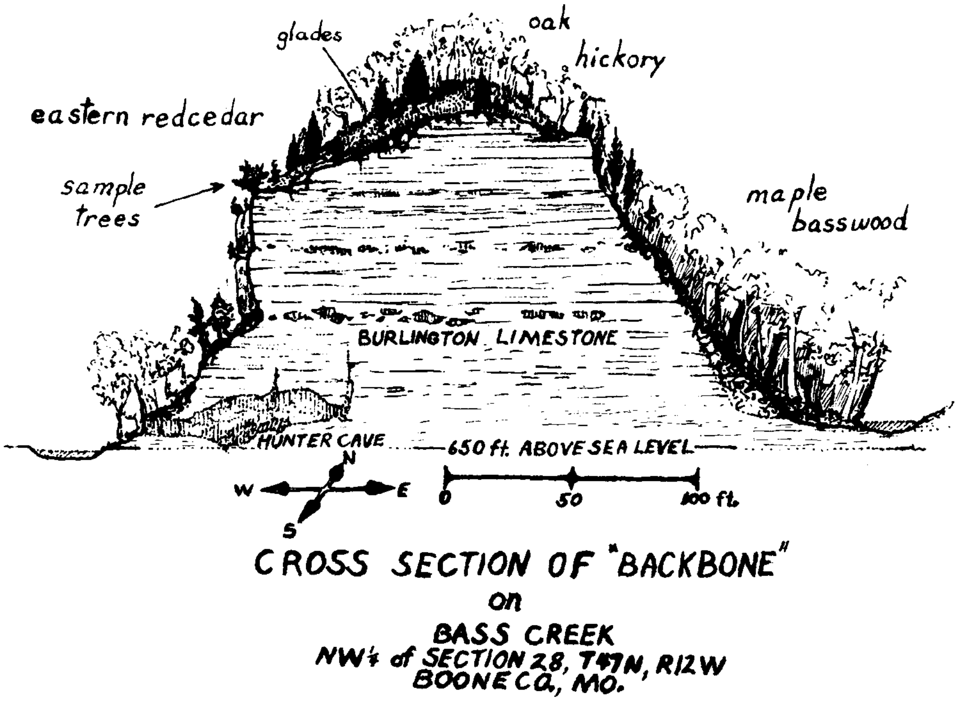

FIG. 1. Sketch of a typical cross section of a "backbone" in Boone County. Sample trees were usually located on site conditions similar to that shown in the sketch on the west face bluff edge.

fire, physiological processes such as reproduction and changes in the site. To the dendroclimatologist these factors are the "noise" in the ring-width signal.

MATERIALS AND METHODS

Species

The trees that grow on central Missouri bluff sites are probably hybrids of *Juniperus virginiana* and the Rocky Mountain juniper *Juniperus scopulorum* (Van Haverbake 1968). Although individual trees may vary widely in the degree of hybridization, there is a definite trend toward *Juniperus virginiana*. Figure 2 illustrates the growth form of these old trees. Figure 3 illustrates a cross section of a typical sample tree.

Sampling

All the trees in this study are located in central Missouri. The main site, with twelve trees, lies along a half mile of west-facing bluff on Bass Creek in Boone County, Missouri. Two other trees, one on Cliffton Creek, and one on Devil's Backbone along Cedar Creek, were sampled. All were on the very edge of Burlington limestone outcrops with a sheer drop of 15 to 100 feet to the west or south, and the trees grow in the open with full exposure to the sun. Little or no visible soil was present at the base of these trees where they anchor into cracks in the limestone.

FIG. 2. Sketch of a typical old (approximately 400 years) eastern redcedar growing on a bluff site in central Missouri.

Ring-width series were taken from cores of living trees with a 4-mm increment borer. Two remnants (dead wood) were dated and used. The contorted form of the trees and the limited access to the bluff side of the trees determined the place where the cores were extracted. Thus both sample height and tangential location on the hole were quite variable. The cores rarely contained the pith or center of the tree because of heart rot. The absence of juvenile wood in the ring-width series is of little consequence since this wood tends to be more unreliable in its climate signal (Fritts 1976).

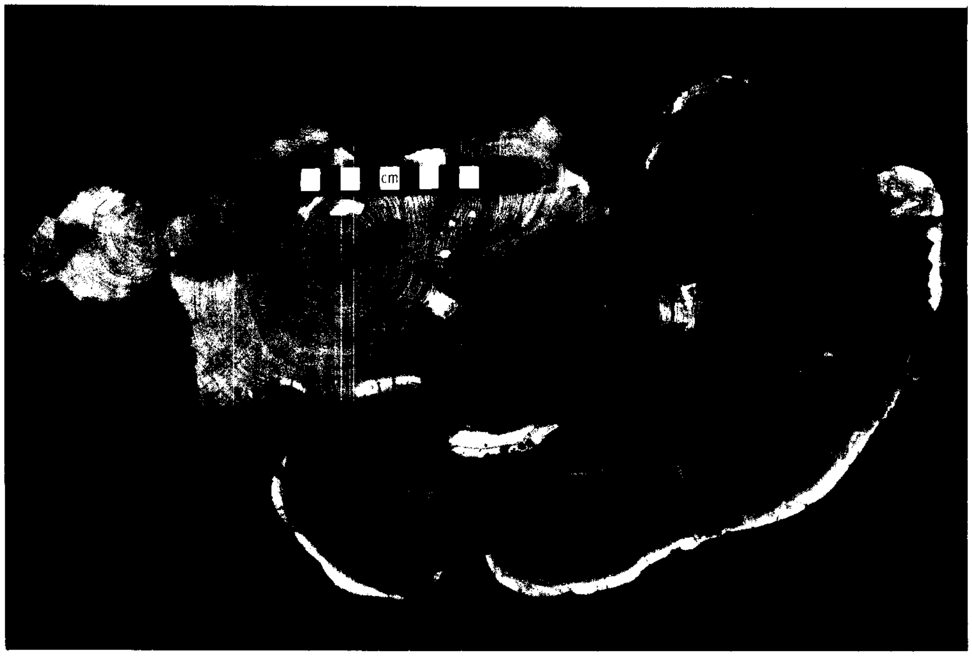

FIG. 3. Cross section of an older eastern redcedar showing convolute form of bole.

Measurements

Cores were mounted and the end grain was cut with a razor blade and sanded. Each ring width was measured under a Filar micrometer-equipped light microscope to ± 0.01 mm. Every 10th ring was marked for reference. Measurements were checked for accuracy every 40 rings. Serial order, the correct number of rings, the relative ring width (the width of a ring in comparison to adjacent ring widths) and key punching were checked for error at least every 10 rings. All measurements were made perpendicular (true radial plane) to the rings.

Crossdating

In order to insure that each ring in a sample corresponded to a true annual increment, each sample had to be crossdated. Crossdating is the matching of ring-width variations between trees (Stokes and Smiley 1968).

Each series of ring-width measurements was plotted through time. These graphs (Fig. 4) were overlayed on each other on a light table to facilitate the matching of ring-width patterns between samples. Ten cores were found to crossdate without any false rings or missing rings from 1880 to 1977. These cores were used as a base for dating the rest of the cores in this period. This procedure was used for the preceding period, 1784 to 1880, and then again for the remaining earlier periods. When a problematical ring was found in the dating, the cores were further examined under a microscope for any structural features which might aid in dating.

Crossdating has typically been a test for the strength of the climate signal, that

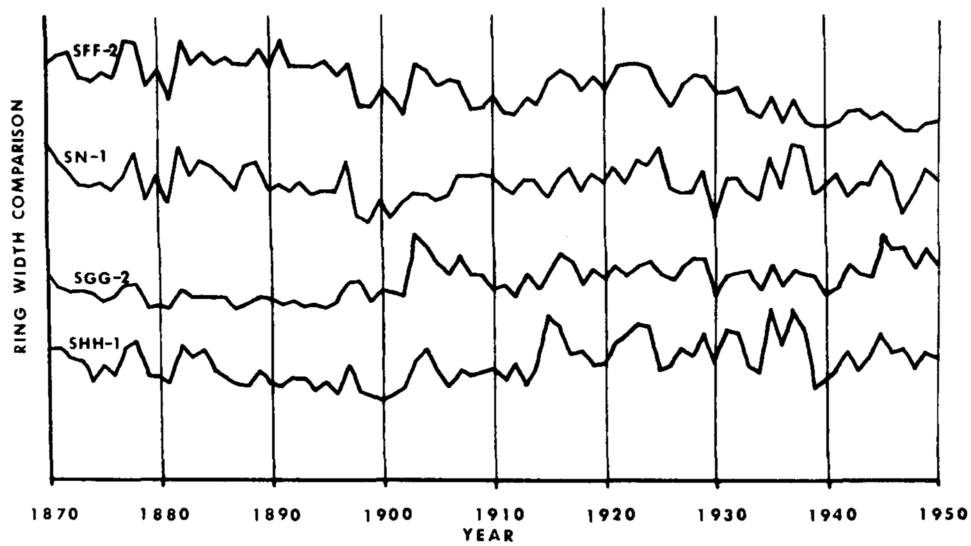

FIG. 4. Example of crossdating ring-width patterns from the increment cores of four sample trees.

is, the more limiting climate is upon growth, the better the tree-ring widths match up with each other (Douglass 1941). A certain degree of ring-width matching in crossdating is necessary to be able to locate false or locally absent rings. Figure 4 illustrates the crossdating in four Boone County eastern redcedars.

False rings in eastern redcedar are abundant in healthy vigorous trees but are uncommon in trees growing on bluff sites. Those that do exist are usually identifiable by their anatomical structure (Kuo and McGinnes 1973). Crossdating was used to identify some confusing false rings. In several samples, rings were locally absent. These were located by crossdating and were usually associated with some sign of injury to the tree.

Standardization

In chronology building, the ring widths of all the sample trees are combined into a single average in order to establish a record of growth with a climate signal beyond the individual variations of any particular tree. Before this can be done, however, each ring-width series must be standardized in order to remove differences between trees due to age, unique site disturbances, and tree vigor. For example, as a tree grows older, its rings generally become narrower. Since the age of the sample trees will differ, this trend must be removed in order to avoid one sample weighting the average of all the trees too greatly in a particular section of the chronology (Fritts 1976). To accomplish this, each ring-width series was fitted with a curve or trend line to approximate the expected growth due to age. Then the actual ring width for each year was divided by the expected ring width to compute a unit less index value.

All of the samples in this study were fitted with an exponential curve to reflect change in ring width due to age except for two which were fitted with a polynomial curve to compensate for apparent growth anomalies. This process also gave each

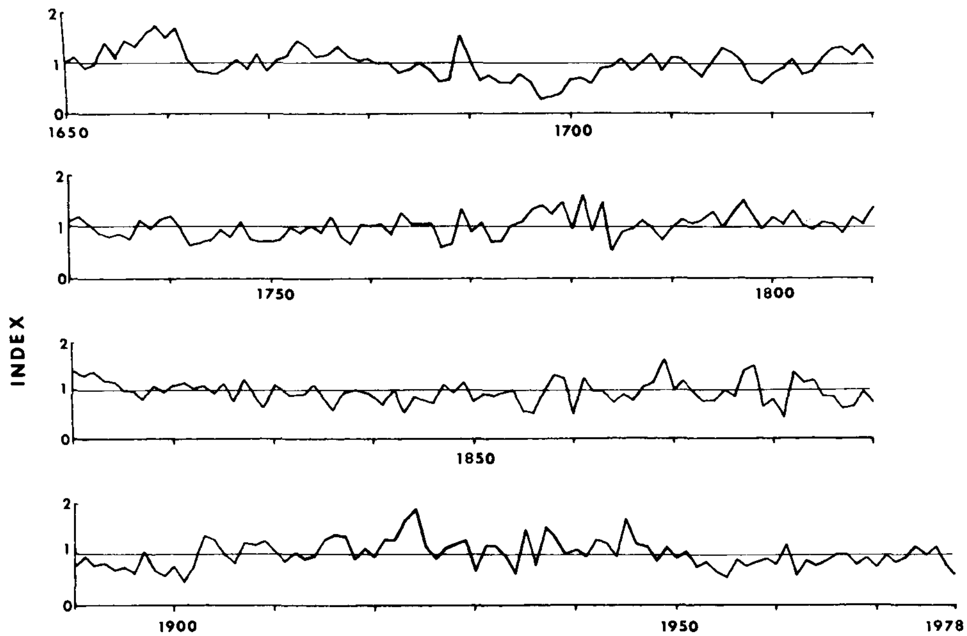

FIG. 5. Ring-width index of eastern redcedar from central Missouri. The ring-width index is composed of at least 20 samples to 1800, at least 10 to 1700 and at least 7 to 1650.

sample a mean index value of approximately one. Thus trees of greater vigor were made equal to trees with smaller ring widths which were often more sensitive. All twenty-eight of these indices were then averaged for each year. The result, called a master index (Fig. 5), could then be used to link climate and tree growth.

RESULTS AND DISCUSSION

Correlation between ring width and climate

Table 1 shows the simple correlation coefficients found for ring width and significant climatic variables. Many other variables and combinations were tried unsuccessfully. The climatic variables were derived from weather data for Columbia, Missouri, which were recorded seven to fifteen miles from the tree sites. Figure 6 illustrates this correlation for index, temperature, and precipitation. Slight positive correlations also were found for the temperature of the winter (November–February) preceding the growing season. Scatter plots of January and February temperatures indicated that an average monthly temperature of below 23.5 F (−4.7 C) limited the growth of the following season. Above this threshold temperature, there was no clearly defined relationship.

An index that estimates the departures from normal soil moisture, the Palmer drought index (Palmer 1965), was correlated with ring width. There was a correlation of 0.6 with the growing season (May–July) index values, and ring width. The Palmer index was computed from monthly precipitation and temperature values for a single station, Columbia, Missouri. In order to compute the Palmer

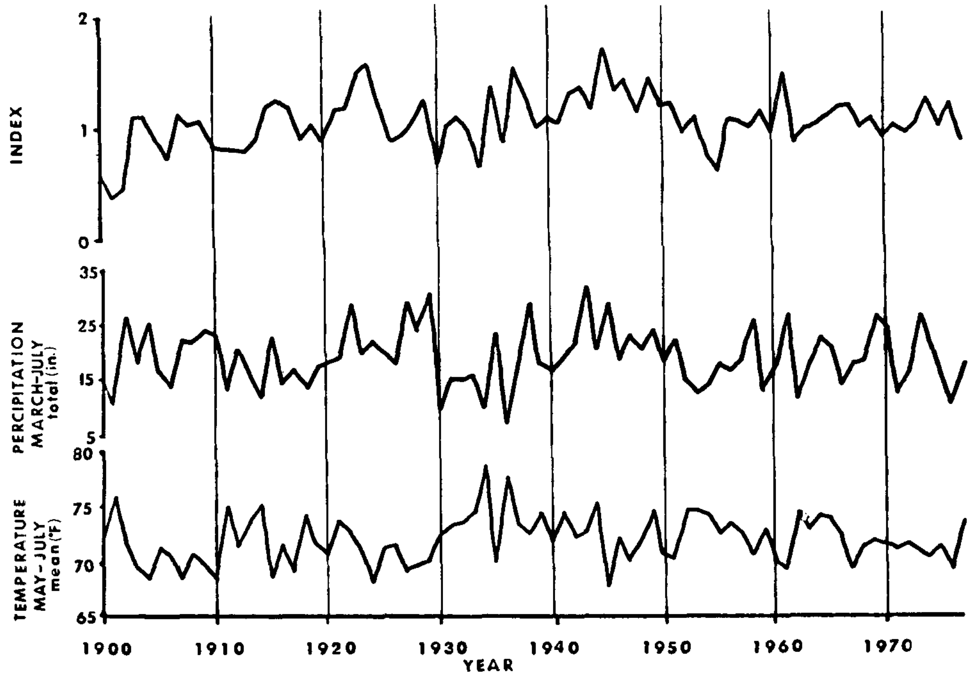

FIG. 6. Comparison of curves for ring-width index, precipitation, and temperature over the time period of available weather records.

index, a soil moisture holding capacity must be given to an upper and lower soil layer. The tree sites were estimated to have an upper layer capacity of 0.25 inches and a lower layer capacity of 1.5 inches. Because of the arbitrary (not based on actual measurement) estimation of the soils' moisture holding capacity and the use of only a single station's climatic records, the actual relationship between soil moisture and ring width may be stronger than indicated by the 0.6 correlation. Figure 7 compares the Palmer drought index and the ring-width index, and additional statistics are shown in Table 1 as indicated previously.

A model was developed using stepwise multiple regression analysis to explain ring-width variance due to climate factors. Equation 1 describes this model.

$$\text{Ring-width Index} = \text{Intercept} + \underset{\text{Temperature}}{\overset{\text{Mean May–July}}{}} + \underset{\text{Precipitation}}{\overset{\text{Total March–July}}{}} + \underset{\text{Temperature}}{\overset{\text{Mean Nov.–Feb.}}{}}$$

$$y = 1.683 + (-0.036 \times \text{F5-F7}) + (0.016 \times \text{RAINSUM}) + (0.033 \times \text{FW})$$

Ridge regression (Rogers and Hildebrand 1978) was used to test the model for each ten-year period from 1900 to 1970 because the intercorrelation between climatic variables can inflate explained variance in standard multiple regression. Tests for each ten-year period varied from a high of 81% of ring-width variance

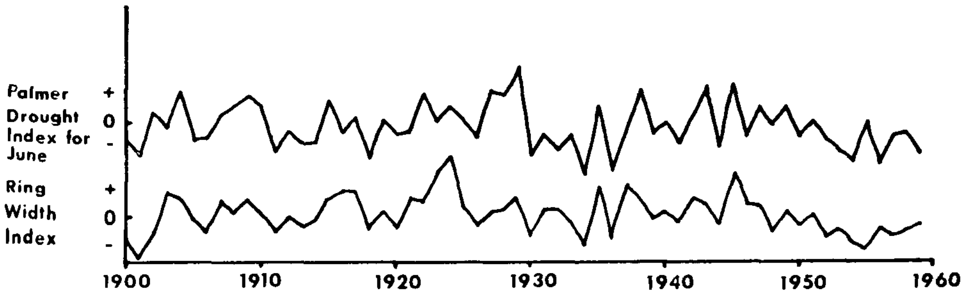

FIG. 7. Comparison of Palmer drought index and ring-width index.

explained by climate (precipitation and temperature) to a low of 12%. The mean explained variance for all seven periods was 50%.

The differences in the degree of climatic factors explained by ring width in succeeding decades is probably due to many factors. For instance, it was found that the standard error of the ring widths for the index increased directly with precipitation—that is, the wetter the climate, the less the predictive value of the index. Site disturbances also could be a factor influencing index reliability, especially since the area in this study was small.

Verification of the master index with independently derived chronologies is one check for the validity of a tree-ring index (Fritts 1976). The index of *Juniperus virginiana* from Boone County is comparable to other midwest chronologies. Indices of shortleaf pine from Arkansas (Schulman 1942), southern Missouri (Estes 1969), and the central Mississippi drainage (Hawley 1941) show agreement of narrow rings in key years such as 1951–1954; 1936, 1934; 1914, 1913, 1911; 1901; 1881; 1879. Chronologies of oak from Columbia, Missouri (Robbins 1921); Dent County, Missouri (Stockton[1]); and southern Missouri (Estes 1969) agree in most if not all of those years. Good agreement was found with a published chronology of eastern redcedar from Jefferson County, Missouri, done by R. Bell, F. Magre and D. Senter (Dewitt and Ames 1978), (Cole 1951).

Spectral analysis

Spectral analysis is a statistical technique that uses trigonometric functions to fit sinusoidal curves of different frequencies by the least squares method to a

[1] Personal communication, 1973. C. W. Stockton.

TABLE 1. *Correlation between ring-width and climatic variables. All values are significant at the 0.01 level. Significance levels have been adjusted for persistence in the ring-width series. The ring-width index had a lag 1 autocorrelation of 0.27.*

	Climatic variable		
	Precipitation total (March–July)	Temperature mean (May–July)	Palmer drought index (June)
Ring-width index	0.48	−0.54	0.60

time series such as tree-ring widths (Raymer 1971). In dendrochronology it is used to find possible periodic characteristics of tree-ring series. A spectral analysis (see Acknowledgments) of the Boone County index by Sharon LeDue and Buddy Jeun of the Environmental Assessment Service (NDAA) indicated two frequencies at which ring-width variance was periodic beyond that which would be expected from a purely random process.

In the 257-year series analyzed (1720–1977), a 51.6- to 64.5-year periodic cycle was detected. The significance of this cycle should be viewed with caution since its calculation is based on only four or five observations at this frequency. This cycle of ring-width variance has not been linked to a generating process such as climate.

The second frequency at which ring-width variance changed regularly was a two-year period, that is, one year being a narrow ring and the next being a wide ring. This period was present not only in the master ring-width index, but in individual cores as well. This period may be linked to reproduction or climate or both. Reproduction in eastern redcedar is on an alternate year basis, with one year having a heavy seed crop and the next year a light seed crop (Fowells 1965). The senior author also has observed this in the male trees and their production of pollen cores. Formation of wood on the bole may be concurrently reduced because of the stress of reproduction (Fritts 1976). The problem of attributing the two-year period found in the master index to reproduction is the necessary assumption that most of the trees sampled had their heavy seed crops in phase, that is during the same years. If the two-year period found in eastern redcedar is caused by reproduction stress, then two possibilities present themselves as hypotheses to explain the group of trees being in phase. First, it is possible that in certain sections of the tree-ring chronology the trees are in phase only by chance; second, reproduction could be linked to climatic cycle or events (drought) or to other factors such as fire.

A spectral analysis was performed on May–July mean temperature (1900–1977) and March–July precipitation (1900–1977) and no two-year cycles were found in either. However, Lansberg (1962) has reported a common biennial (2- to 2.3-year cycle) in temperature, barometeric pressure and precipitation in many areas. The two-year cycle in ring width may correspond to a two-year cycle of drought during certain periods. For instance, in the Boone County index, the periods 1933–1937, 1822–1828, 1777–1784, and 1644–1650 reflect this cycle. Further research will be needed to clearly define these relationships.

Some possible interpretations of the ring-width index

1945–1955	The early fifties were very dry and hot in Boone County. This is one of the few places in the index with a downward trend in ring width for ten years.
1930, 34, 36	These were "signature" years, that is, years that show up narrow in almost every core and were very helpful in dating. When these years do not crossdate, it is a good indication the core cannot be used. These were the dry years of the dust bowl. Some trees showed injury in 1930—probably from fire or fence post cutting.

1917–1919	Two trees a half mile apart show wounding response in their bole. This could be due to logging or fire.
1898–1902	An extended period of low index values, distinctive because of its duration. Record summer highs in Missouri and record low precipitation in Columbia, Missouri, in 1901.
1879, 81	Signature years, these years show up over much of southern Missouri, Illinois, and Arkansas as narrow rings indicating widespread drought. Cold winters also were reported for these years.
1860	An individual year of drought that shows well because of the wide rings before and after it.
1855, 56	These narrow rings also show up in a *Juniperus virginiana* chronology of Jefferson County, Missouri.
1836, 41, 43	Tree-ring indices narrow in Boone, Jefferson, and Shannon counties. Dry years.
1784	Many samples from Boone County show a drop from their mean ring width this year. It is ten years before the index returns to the pre-1784 mean. This could indicate structural damage to the crowns of many trees. This may have been due to the severe winters of 1783–84, 1784–85, 1785–86 which occurred over much of the world. These severe winters were caused by a lack of radiation reaching the earth because of high quantities of dust that were thrown into the atmosphere by the eruption of the volcanoes Asama (Japan 1783), Skaptar, Jokul (Iceland 1783), and Vesuvius (Italy 1783). Benjamin Franklin writes, "the winter of 1783–84 was more severe than any that had happened for many years," (Sparks 1906).
1778–84	Signature years. A very strong 2-year cycle from 1778 to 1784 preceded by a short period of extraordinarily good growth. This pattern appears in Jefferson County and in oaks *Quercus alba* in southern Missouri—probably a period of alternating drought years.
1767–68	Dry years in Jefferson and Boone counties.
1742	Wounding response in one tree, also a low point in index. Fire is a possibility.
1690–1720	Period of missing rings in several samples. If any period in the index had fire or drought, this period is the most likely. Also a period of extreme climatic variance in Northern Hemisphere.

Potential

There is a potential for reconstructing Missouri climate from eastern redcedar. Correlations between ring width and climate show this. The Ozark area, as well as some of the river valleys in northern Missouri, have many bluffs with old junipers. If Boone County is representative, then a climate history of the past 400–500 years is feasible for the state. With more extensive sampling chronology error will be reduced by allowing the selection of only the most reliable and climatically sensitive ring-width series. The window that eastern redcedar provides to our past climate is a valuable one. Through it we can view the climate of the most economically sensitive season, the growing season.

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