DENDROCLIMATIC CHANGES IN SEMIARID REGIONS

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RECORDS IN LIVING TREES

How faithful are selected tree-rings as annual indices of rainfall? What is the geographical distribution and the length of those indices which are reliable? What may be deduced from those indices about climatic changes? The last of these three questions is the primary concern of this brief evaluation of the present status of arid-zone dendroclimatology.

For the western United States and adjacent areas, fairly complete answers to the first two questions are now possible. In all major drainage basins, trees on semiarid sites have been found which exceed 500 years in age and provide annual indices showing correlation coefficients with twelve-month rainfall of +0.70 to +0.85 or more; a few localities furnish ring sequences of 1,500 years or more in length. During the last 15 years, about one-third of a million rings from these trees have been reduced to growth series; the results illuminate and extend the vast amount of pioneer analysis of earlier decades on less sensitive trees and species such as *Sequoia gigantea.*

Certainly, the dendroclimatic data now available provide much valuable information on the details of climatic fluctuations in some areas during the past millenium. It has been known for 25 years, for example, that a great drought occurred in the Southwest in the late 1200's. Recently derived chronologies for the Colorado River basin now suggest that this was merely the final phase of a long drought, of sometimes phenomenal intensity, from A.D. 1215 to 1299, which was followed for about a century by phenomenally wet years and intervals. But it is not enough to make tentative estimates of the probable order of magnitude of such departures. It would, obviously, represent a major advance in our understanding of and practical allowances for climatic changes to place these and numerous other dendroclimatic fluctuations on a secure quantitative basis. Why has this not yet been satisfactorily done?

It is the opinion of the writer, after twenty years of intensive field and laboratory work on drought conifers, that only now have we the prospect of accumulating enough tree-ring series of sufficiently great fidelity and length to fully justify quantitative estimates of climatic changes from the growth rings of trees. It is noted once again in this journal, but only in passing, that certain exacting requirements must be fulfilled in order to yield a *significant* solution of the sometimes subtle problems of dendroclimatology, requirements which are shared with many another research area of apparently easy access. The long delay in attaining truly quantitative chronologies is directly related, however, to two simple statistical requirements in the derived regional series.

The crux of the matter is the *relative* rather than the *absolute* nature of the thickness of the annual ring in terms of rainfall. This thickness depends on the age of the tree, the location of the measured radius in the stem, the species, environment, and many other factors, not the least of which is the magnitude of the "random" term in radial growth.

Since it is necessary to work only with annual departures from the tree's individual and systematically changing mean growth rate, so-called trend or age curves need to be fitted to each series of measured ring-widths in the process of reduction to growth indices. It has long been recognized that even series several hundred years long cannot provide an absolute trend line, for any pronounced departure for some decades preceding or following the series could substantially modify the position of the fitted age curve. Thus, only minor refinements in fitting approximate trend lines to the series from drought conifers have been introduced in recent years. Obviously, such computations as the cumulative departure for given intervals in indices derived in this way can have only a very restricted meaning.

Another defect of almost all published tree-ring series is lack of homogeneity, which is an inevitable deficiency in an average growth curve based on trees of different ages; the use of individually standardized tree series at best corrects this deficiency only in part. Of the various conditions which lead to heterogeneity one may specially note the following: in most collections of tree samples, the use of only the longest series in any locality may result in too weak a statistical base; injuries or other effects during the life of an old tree often make part of its ring record unusable; in different localities which provide ring data for a regional mean, different maximum ages are found. Errors both in individual trend lines and in the averaging-out of random fluctuations are hidden in the resultant mean indices.

The finding during the past two years of forest stands of rainfall-sensitive pine trees in the phenomenal age class of 1500-1700 years (*Science* 119:396, 1954) now appears to justify analysis of tree-ring data in the western United States to a degree of precision not previously useful. Trend lines fitted by objective, precise techniques to a homogeneous and widely based 1500-year mean growth curve should permit a fairly secure placement of precisely fitted trends to an entire family of shorter, individually homogeneous curves in the same general climatic region. A limited application of this procedure to the Colorado River basin was responsible, among other results, for the recognition of the two-century fluctuation already noted.

Thus, it would appear that statistically homogeneous rainfall indices 1500 years or more in length may now be derived from trees in the upper Snake River basin and in central California; the Colorado River basin and the upper Missouri River basin may soon be added to this list. It should be noted that even in these long series neither width nor sensitivity of tree-rings can reveal any steady underlying change in climate over the entire period, if the total change is small. Nevertheless, it appears possible now to construct tree-ring indices for the listed regions from which significant rainfall parameters may be derived for at least the past millenium.

CLIMATIC-ARCHAEOLOGIC CHRONOLOGIES IN THE COLORADO RIVER BASIN

It seems appropriate in this final number of volume 20 of the BULLETIN to take an over-all look at the quantitative chronologies which have thus far been reported in beams from Indian ruins of the Southwest.

In the Colorado River basin, extensive, measured chronologies have now been derived for three main Pueblo areas: the Northern Periphery (Nine Mile Canyon, Hill Canyon, and Dinosaur National Monument), the San Juan basin (Durango, Mesa Verde, Northeast Arizona, and Navajo National Monument), and Flagstaff. A series of papers beginning in volume 12 of this BULLETIN contains the details of construction of each of the local master chronologies in these areas.

In similar form are the archaeological chronology for the Rio Grande, which is based largely on ponderosa pine, and a living-tree index for the same basin derived principally from Douglas-fir. Other related areas for which centuries-long indices of growth are available are Bryce Canyon, Grand Canyon North Rim, and Big Bend National Park.

The principal sub-region of the Colorado River basin for which no important archaeological extension of the living-tree chronologies is yet available is the Gila River basin of central and southern Arizona and New Mexico; however, the possible efficiency for dating beams from this and other such sub-regions by means of established master chronologies from nearby areas is surprisingly high, as shown by a skeleton-plot map based on living trees (*TRB* 8:28).

Unfortunately, an optimistic forecast may no longer be made for adjacent areas in northern Mexico. The results of an analysis of living trees in the state of Durango and especially a recent and as yet unpublished analysis of living-tree chronologies and nearby archaeological beams in Chihuahua suggest that direct tree-ring dating of ruins in those areas will be definitively done only in very few localities, if at all. It appears that localities favorable for tree-ring dating are rare, because the most suitable species, Douglas-fir, is of very limited distribution, and because low-latitude characteristics such as marked local variations in chronology, incidence of false and erratic growth, and tendency to short length of sequence are all very pronounced.

The far more objective nature of the evidence for reliability of the dates of ancient beams and the more significant information about past climate which measured and properly reduced tree-ring sequences may provide was perhaps recognized by most early workers in dendro-archaeology, but the labor required to put tree-ring dates on such a secure foundation can be very great when properly done, and time often seemed to permit only the use of reconnaissance methods, such as the unsupported skeleton-plot techniques, for the rapid analysis of the early flood of excavated wood. However, most of the beams of critical importance in Southwestern archaeology have since been analyzed in more quantitative form.

Edmund Schulman, *Tree-Ring Bulletin*, 20(3/4), 1954

MASTER GROWTH INDICES FOR ARCHAEOLOGICAL AREAS OF THE COLORADO RIVER BASIN

This chart is published at the standard horizontal scale of 2 mm per year to permit its direct use in beam-dating work. For the major areas, data from A.D. 1300 to 1900+ may be found in the references below.

The horizontal line on each curve is that of zero departure; in all curves an index departure of 100% is represented by one division at the left or right margin. Zeros below the curves indicate assumed locally absent rings in all component specimens. Plots of measured ring-widths of component specimens in each index and, in most cases, tables of mean growth departures, are published as follows in this BULLETIN:

Dinosaur	PNN	16(3), 1950.
Durango	DF	15(4), 1949; 16(2), 1949; 18(4), 1952.
Durango	PNN	16(2), 1949.
Durango	PP	15(4), 1949; 16(2), 1949; 18(4), 1952.
Flagstaff	PP+	14(2), 1947.
Hill	DF	15(1/2), 1948.
Mesa Verde	DF	12(3), 1946; 14(1), 1947.
Mesa Verde	PNN	12(3), 1946.
Navajo	DF	14(3), 1948.
N. E. Arizona	DF	15(4), 1949; 18(4), 1952.
N. E. Arizona	PNN	15(4), 1949.
Nine Mile	DF	15(1/2), 1948; 16(2), 1949; 17(4), 1951.

(Note: The curve here published includes a revision of the 1948 table for the interval A.D. 826-1200 on the basis of later collections.)

See also:
- Bryce Canyon area, Utah . . . TRB 17(1/2), 1950.
- Colorado basin, supplementary . . . TRB 20:30, 1954 (list of references).
- Rio Grande basin, DF . . . TRB 19(3/4), 1953.
- Rio Grande basin, PP+ . . . *Univ. Arizona Bull.* 24(3), 1953.

DF Douglas-fir, *Pseudotsuga taxifolia*
PNN Pinyon pine, *Pinus edulis*
PP Ponderosa pine, *Pinus ponderosa*

A general summary of the various climatic-archaeological chronologies in the Colorado River basin published in this journal are presented herewith in a master figure.* Of the local measured chronologies which are compared in this figure, four major ones—Mesa Verde Douglas-fir, Nine Mile Douglas-fir, Navajo Monument Douglas-fir, and Flagstaff ponderosa pine—were all derived as essentially independent composites with the dating anchored in local living trees. In another, the Mesa Verde pinyon pine, living-tree records measured but not plotted here strongly overlap the archaeological data from 1090 to 1270, so that this chronology also may be considered essentially independent. The general consistency in chronology from area to area and species to species, evident in the figure, thus takes on added significance.

This diagram includes some 32,000 measured rings, which document the interval preceding A.D. 1300. Data for later centuries in the four major chronologies just noted may be found in the detailed earlier surveys in this BULLETIN.

Not included in the figure are some miscellaneous growth curves for the localities within the Colorado River basin, principally representing single specimens, published in this BULLETIN as follows (species, A.D. interval, volume, and page):

Hill Canyon	DF	927-1042	17:30
S.E. Utah	DF	450- 674	16:21
S.E. Utah	PNN	1140-1250	16:21
Durango	DF	124- 196	17:30
Mesa Verde	DF	675- 700	Ms
Mesa Verde	DF	821- 896	13:31
Mesa Verde	PNN	463- 625	16:22
Mesa Verde	PNN	547- 665	16:23
Mesa Verde	PNN	710- 769	16:23
Mesa Verde	PNN	923-1076	16:23
Mesa Verde	PNN	1016-1074	17:30
Mesa Verde	PNN	1142-1213	13:31
Flagstaff	PP	1047-1132	16:21
Flagstaff	CBS	1072-1255	16:21
Forestdale	PP; PNN	967-1115	16:23
Point of Pines	PP	1155-1293	15:20

Dated archaeological beams of the Southwest necessarily represent, on the whole, the more sensitive types of chronology, and thus the climatic interpretation of the ring records in living trees applies to some extent to the archaeological chronologies also. However, the two limitations already noted in the discussion of records in living trees are specially severe in these chronologies.

First, the number of available specimens differs greatly from area to area and, in general, from decade to decade. Thus the various sequences in the figure have differing and changing weights. This defect is somewhat alleviated by the high fidelity of individual series and the tendency for the means of even two or three trees to represent well the details of short-term fluctuations.

Second, the average number of rings in the archaeological beams is relatively small, usually less than 100. Thus, the trend lines fitted to each specimen curve lead to standardized values in which long-term departures in growth, of the order of 50 years or more, are very largely eliminated. The archaeological series thus are indices of short-term variations only.

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