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DEFINITIVE DENDROCHRONOLOGIES: A PROGRESS REPORT

Edmund Schulman

Basic to all chronology use of ring data are the discovery, sampling, and reduction of groups of trees whose records tend towards a maximum in length, fidelity to a single climatic element, and areal representativeness. The maximizing of these desirable properties is possible by means of the repeated, fundamental refining of the indices through more selective and extensive sampling—a powerful and in some respects unique operation on historical data.

In the summer of 1939 the writer undertook a program of basic investigations along the line just sketched. The collection and analysis by 1950 of some 300 selected groups of specimens throughout the western United States and adjacent areas of Canada and Mexico (hereafter denoted the West) resulted in a set of indices showing fair, and in some cases high, fidelity to gage records, and served to extend such records—in many cases perhaps only in a qualitative way—for many centuries into the past.[1]

In April, 1950, an intensified three-year program was begun,* pointing towards the further refinement and lengthening of western dendrochronologies in order, first, to develop more secure interpretations of the ring records in terms of absolute values of past rainfall and river flow and, second, to permit a quantitative, comparative examination of the fluctuations in these variables in all major drainage basins of the West.

In this review of the results of this accelerated program, just past the half-way mark, consideration of the long-period climatic characters in the newly derived tree-ring histories is postponed; of primary concern during this phase of the program has been the production of highly sensitive tree-ring data for all major streams of the West. Chronologies for almost all areas previously studied have been amplified. Also now undergoing analysis are continuous series 500 years or more in length from sensitive living trees in the Rio Grande, Arkansas, North Platte, and Snake basins and in the central Sierra Nevada.

Perhaps the most important of the selected topics noted below is the extension to July-June of the estimated general ring-rain relationship in conifers of the West, so long considered to be the October-June interval, a reinterpretation having a fundamental bearing on climatic and other research in tree-rings.

*Under contract between the Office of Naval Research, Department of the Navy, and the University of Arizona (NR-089-020).

[1]Tree-Ring Hydrology of the Colorado River Basin, Univ. Arizona Bull. 16(4), 1945; Tree-Ring Hydrology in Southern California, Univ. Arizona Bull. 18(3), 1947; Tree-Ring Hydrology of the Missouri River Basin, American Philosophical Society Yearbook for 1949, p. 177; Tree-Ring Bulletin, 1945-1950; Tree-Ring Indices of Rainfall, Temperature, and River Flow, in Compendium of Meteorology, Amer. Meteorol. Soc., pp. 1024-1029, 1951.

REVISED PROCEDURE IN CLIMATIC DENDROCHRONOLOGY

In order to interpret ring indices to obtain absolute values of past rainfall it has seemed desirable to modify slightly the classical procedures.[2] Almost everyone who has had to meet the problem of combining short sequences of data of varying length into a single long index has recognized that even at best a small degree of inhomogeneity may remain in that index.

Since, apart from the sequoias, a large majority of the trees or stumps sampled during the interval 1904-1939 in the West by Douglass and coworkers carried records 300 years or less in length, much attention had been given to the problem of extending these by the few longer tree records and by archaeological data. The age-trend line, which had to be fitted to each sequence in order to combine best all series, was necessarily controlled in position by the data themselves. Thus, the resultant ring-width departures, expressed as percentages, could be compared more readily from series to series but were obviously not absolute values; for example, extending any sequence might raise or lower much or all of the fitted trend line (the so-called end effect), whether the fitting was done by eye or by the least squares method.

The discovery during recent years of a large number of trees in the West with sensitive chronologies 500 or more years in length makes it possible largely to eliminate the standardizing process in much of the analysis. To repeat a recent statement:[3] "In any area, the individual series of growth measurements are subdivided into two or more sets, e.g., young, mature, and over-age trees, and the original ring measures averaged with the earliest common year as beginning date; no change is made in the raw data other than the application of a simple factor, as x2 or x½, to *all* values in some occasional series showing particularly fast or slow growth. Unstandardized mean curves from various localities are then similarly averaged into regional means. In this way, unmodified indices of various lengths become available from which conclusions representing a consensus of climatic indications may be derived. Standardized values of such unmodified indices, which may be necessary for certain comparative studies, may easily be interpreted in terms of the original ring measurements."

Given a homogeneous, representative body of sensitive ring sequences for any region, the foregoing procedure when further modified, so that *all* possible sequences enter the sub-group means, will yield a set of curves whose fluctuations tend to approach a limiting form, the best climatic index which trees can provide under the known field selection criteria. This index may be called the *optimum dendrochronology,* to which the rapidity and regularity of approach of the sub-group indexes will be greater, the greater the freedom in the component sequences from "random" fluctuations —fluctuations not directly related to the dominant climatic element.

A COEFFICIENT OF CROSSDATING QUALITY

The extreme emphasis which Douglass has given to crossdating in dendrochronology[4] is an expression, of course, of the cross-checking processes so essential in field-and-laboratory sciences. With the increasing attention to quantitative aspects of dendroclimatology, it seems useful to consider the numerical representation of the degree of crossdating in a set of ring series.

The computation of correlation coefficients, each series *vs* the others and *vs* the group mean, is an obvious procedure, more laborious but more reliable

[2]A. E. Douglass, Climatic Cycles and Tree Growth, Carnegie Inst. Washington Pub. 289, v. I, 1919, pp. 54-64; v. III, 1936, pp. 17-28.

[3]Tree-Ring Bulletin, v. 17, 1950, p. 11.

[4]Douglass, *op. cit.*, 1919, pp. 16-17; Univ. Arizona Bull. 17(3), 1946.

than trend coefficients.[5] Since, however, the qualities of crossdating and sensitivity are so closely allied in this research, it seems desirable to set up a coefficient of crossdating based on the long used coefficient of mean sensitivity.[6]

Such a sensitivity coefficient of crossdating has, in fact, already been outlined by the writer.[7] The mean sensitivity, that is, the average year-to-year change in ring-width in per cent of the mean growth (standardized if the actual growth contains a strong age trend) is obtained for each sequence in a set of ring series. The mean sensitivity of the index representing the group as a whole is divided by the average of the specimen mean sensitivities. The greater the parallelism in chronology among the members of the set, the greater will be the group mean sensitivity coefficient and hence, also, the sensitivity coefficient of crossdating, here called R.

R is computed in Table 1 for the 250-ring group in the Big Bend collections and for several representative, comparative series.

Table 1. Mean Sensitivity of Selected Records

Locality[1]	Species[2]	No. Trees	Interval	Tree M.S.	Aver. Tree M.S.	Group M.S.	R
Kings Canyon, Calif.	GS	4	1800-1900	.19, .15, .23, .23	.20	.15	.75
San Jacinto Mts., Calif.	BCS	5	1850-1942	.27, .42, .43, .39, .53	.41	.39	.96
San Jacinto Mts., Calif.	PP	5	1850-1942	.20, .19, .31, .22, .28	.24	.13	.54
Mesa Verde, Colo.	DF	7	1800-1900	.44, .40, .47, .40, .43, .43, .45	.43	.38	.88
Ft. Garland, Colo.	PNN	10	1850-1950	.38, .40, .40, .48, .36, .41, .34, .35, .29, .37	.38	.34	.88
Sangre de Cristo Mts., N. Mex.	DF	4	1850-1941	.34, .32, .36, .31	.33	.29	.87
Pecos,[3] N. Mex.	DF	4	1500-1600	.51, .56, .50, .58	.54	.51	.96
" " "	"	4	1600-1700	.67, .70, .55, .57	.62	.57	.91
" " "	"	4	1700-1800	.61, .72, .54, .70	.64	.60	.93
" " "	"	4	1800-1900	.67, .68, .61, .64	.65	.63	.96
Big Bend, Tex.	DF	5	1850-1945	.82, .83, .81, .83, .86	.83	.80	.96

[1]Specimen numbers are:
Kings Canyon—D 1, 2, 3, 4
San Jacinto BCS—JAC 1270, 1272, 1273, 1274, 1275
San Jacinto PP—JAC 1276, 1277, 1278, 1279, 1283
Mesa Verde—MV 625, 627, 635, 636, 637, 642, 643
Ft. Garland—FTG 3834, 3835, 3838, 3840, 3842, 3843, 3845, 3846, 3847, 3855
Sangre de Cristo—TAOh 797, 798, 799, 800
Pecos—PEC 2208, 3911, 3912, 3921
Big Bend—BBN 2119, 2123, 2124, 2126, 2127

[2]PNN—pinyon pine; PP—ponderosa pine; DF—Douglas-fir; GS—giant sequoia; BCS—bigcone spruce.

[3]The mean ring-width in this group is as follows: 1500-1600, 0.47 mm.; 1600-1700, 0.62 mm.; 1700-1800, 0.64 mm.; 1800-1900, 0.35 mm.

The most striking feature of Table 1 is the extremely high mean sensitivity and crossdating quality of the Big Bend Douglas-firs. The highest single-tree coefficient heretofore observed for any extended series of rings was 0.80, for a Douglas-fir near Salida, Colorado; a neighboring tree in that group showed 0.57. The Mesa Verde series, with coefficients for the individuals consistently near the mean group coefficient of 0.38, is more typical of the better dendrochronologic records. That all five Big Bend trees run above 0.80, with so little spread in the individual values, is evidence for a degree of

[5]Tree-Ring Bulletin, v. 17, 1950, p. 9.
[6]Douglass, Ecology, v. 1, 1920, p. 29; Schulman, Tree-Ring Bulletin, v. 8, 1942, p. 31.
[7]Tree-Ring Bulletin, v. 13, 1947, pp. 14-15.

sensitivity observed nowhere else as yet; the crossdating coefficient R of 0.96 is near the theoretical maximum of 1.00 for perfect parallelism.

The Pecos set of coefficients indicates a small but systematic increase in ring sensitivity with increasing age. This would seem to be related to the greater incidence of microscopic and locally absent rings in older trees of high sensitivity; decreasing mean ring-width might also be expected to permit greater percentual growth fluctuation, though the century means of growth for the Pecos group noted in the table do not provide as strong evidence for this as do the 20-year data discussed below. No test was made of these trees in the sapling stage (each of the four trees was over 50 years old in A.D. 1500, the first date used in Table 1). The crossdating coefficient R seems to be independent of ring-width.

Short-term coefficients like those in Table 1 were derived for every 20 years from 1500 to 1940 for the Pecos trees; the resulting 132 coefficients show the following characteristics:

Table 2. The Range of 20-Year Coefficients of Mean Sensitivity in Douglas-firs near Pecos, New Mexico

Tree No.	Min. M.S.	Mean Ring-Width, mm.	Max M.S.	Mean Ring-Width, mm.	Median M.S.
2208	.42	.62	.83	.39	.58
3911	.46	.56	1.22	.16	.65
3912	.27	.54	.78*	.28*	.54
3921	.43	.28	1.02	.20	.57
Average	.42	—	.89	—	.59
Group Index	.37	.42	.87	.32	.57

*Another interval of this sensitivity has a mean ring-width of 0.46 mm.

The crossdating coefficient R ranges from 0.85 to 1.00 with the median at 0.94.

Although the median sensitivity for such a short interval as 20 years is fairly stable and compares well with that for 100 years, it is evident from the foregoing tabulation that individual coefficients must be based on relatively long series to be representative. The maximum observed coefficient, signifying an average year-to-year change in ring-width of 122% of the mean annual growth during a 20-year interval, is based on a mean growth decidedly less than the overall average for the tree of 0.40 mm. In fact, as might be expected, there is a marked inverse relation of mean sensitivity to average ring-width in any single sequence.

Although computations of mean sensitivity have thus far been made for only a few dozen trees and less than a score of areas, one may judge the order of such coefficients to a first approximation by the quality of the ring records observed on dating them. Of the several hundred groups of specimens collected and dated by the writer in western North America during the past thirteen years, it may be safely estimated that at least half would show group mean sensitivities between 0.25 and 0.40 for 100-year intervals.

The low individual mean sensitivities associated with low R in the San Jacinto pine group[8] would appear to be typical of ring series which, as sources of climatic history, show at best what have been called "obscure chronologies" in the cited reference.

Four groups of specimens among those tested show mean sensitivities substantially exceeding those at Mesa Verde. It is an important guide to certain phases of dendroclimatic research that *all four* are groups in the general boundary zone between montane forest and prairie: near Salida, Colorado, in the upper South Platte basin, Colorado, near Pecos, New Mexico, and at Big Bend National Park, Texas.

[8]Tree-Ring Hydrology in Southern California, Univ. Arizona Bull. v. 18, n. 3, 1947, p. 14.

SINGLE-CORE INDEXES OF REGIONAL RUNOFF

The most sensitive of the Douglas-fir trees of the West and to a lesser extent the best trees of the other dendrochronologic species of that region often present along a single radius remarkably faithful records of rainfall and runoff, despite the numerous factors tending to disturb single-core correlations. The outer rings of four such Douglas-firs, sampled near October 1, 1951, are compared in Figure 1 with the water-year runoff of nearby drainage basins.

The Mesa Verde trees are in the upper San Juan basin and some 100 miles southwest of the upper Rio Grande basin but may be studied in terms of runoff in the latter area since the two basins show very similar fluctuations in yearly flow, despite outstanding differences for occasional individual storms. The Pecos trees grow within the upper Pecos basin, only some 12 miles from the weighted center of rainfall in that basin above the tree site.

Since radial growth in these trees is complete by the end of August, since it is dependent on the rainfall of the entire preceding year, and since the water-year, which ends September 30, represents on the average a somewhat earlier rainfall year, the two variables, rings and runoff, are closely comparable. As the photographed records are all from mature or over-age trees there is very little age trend in growth.

To make convenient a direct view of the cumulative accretions in tree-growth and runoff, the scale for the photographs has been so chosen that each pair of trees has, as nearly as possible, the same linear spread as the appropriate runoff record plotted in the form of a ring series.

Pertinent data on the specimens:

No. 3929. Upper slope near Spruce Tree House, Mesa Verde Nat. Park, Colorado; over 300 years old; average ring-width, 1890-1951, 0.35 mm.

No. 3932. Near 3929; about 500 years old; average ring-width, 1890-1951, 0.31 mm.; 1899, 1902, and 1904 very small but well differentiated under the microscope.

No. 3916. Near Glorieta Pass, about 5 miles s.s.w. of Pecos, New Mexico; about 225 years old; average ring-width, 1905-1951, 0.47 mm.; pronounced false rings at 1911 and 1913 easily identified under microscope by diffuse boundary and by continuation of dark color beyond false late wood, apart from crossdating criteria; crack in core at 1931; 1925 locally absent, 1934 very small but completely differentiated under the microscope.

No. 3921. Near 3916; over 600 years old; average ring-width, 1905-1951, 0.34 mm.; 1899 very small, 1904 locally absent, 1925 very small, crack in core at 1927.

Coefficients of correlation with the compared runoff are: no. 3929, +0.68; no 3932, +0.65; no. 3916, +0.78; no 3921, +0.49.

The coefficient *vs* runoff for the average growth of the two Mesa Verde trees is +0.72 and for the Pecos trees also +0.72.

The group coefficients closely approach the correlations of runoff with the master indexes of mean growth. No great weight is to be attached to the fact that the youngest tree in the photographed set yields the highest coefficient. These specimens are indeed highly selected; however, it is estimated that at least 20% of the trees under analysis have this order of fidelity to the appropriate rainfall and runoff series.

REVISION OF THE ESTIMATED RING-RAIN RELATIONSHIP

Tree-ring literature of the past four or five decades will show, even for the limited region of the West, substantial differences in the rainfall interval selected or empirically deduced as most closely related to ring growth by different investigators, or by the same student at different times or for different groups of specimens.

In recent years the tendency has been to interpret the longer ring chonologies, based on mature and old trees, in terms of winter rainfall only, the summer rains being taken to have some influence only in the production of

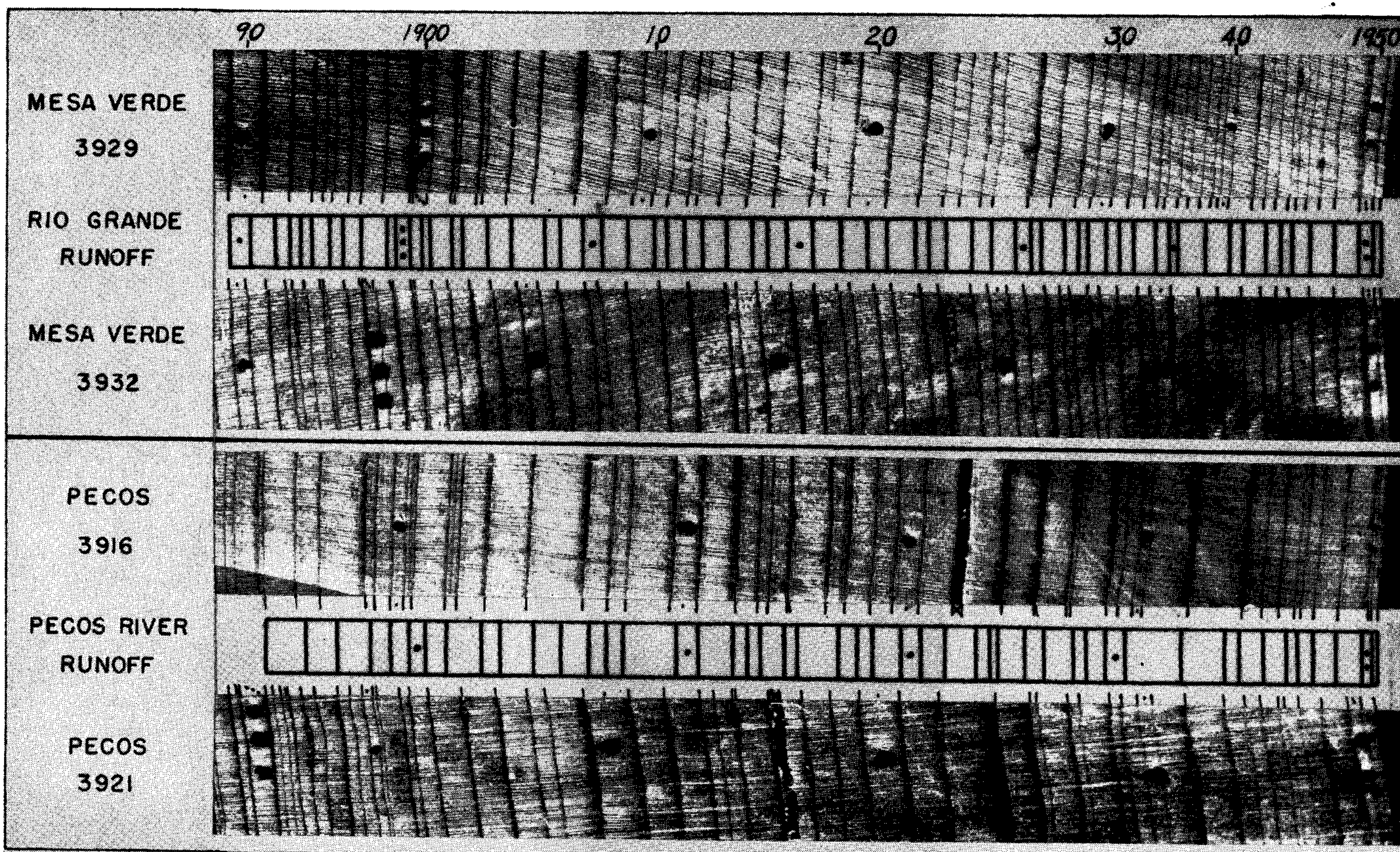

Figure 1. The measured water-year runoffs of the Rio Grande at Del Norte, Colorado, and of the Pecos River at Pecos, New Mexico, are plotted in the form of tree-ring series and compared with the growth in sensitive, regional Douglas-firs sampled near October 1, 1951. Guide lines along the photograph edge help in identifying false and locally absent rings and cracks in the wood. The dark areas at the right of each ring photo represent bark. Magnification: 3929, x7.5; 3932, x8.7; 3916, x7.2; 3921, x10.0.

false rings and thus being of importance mainly in the growth of young trees. In the west coast states, with little or no summer rainfall, the choice of ring-rainfall interval is, of course, much more restricted than in such regions of two-maxima rain regimes as the Rocky Mountains.

Beclouding the true mean relation between rainfall and measured growth are factors such as variation in the distribution of storms within the year, changes from year to year in the frequency of specially intense or of long-lasting storms, differences in rainfall at the tree from that at the rain-gage, special spottiness of summer rains, carry-over effects of excessive or deficient rainfall of earlier years, associated effects of temperature, and errors of observation in the rain-gage record. With respect to the ring series itself, incomplete elimination of irregular effects, ecologic and otherwise, can easily lead to an apparent rain-ring relation quite different from that which would be found in the optimum dendrochronology.

During 1951 a systematic correlation analysis was made of ring growth in relation to rainfall.* The best local and areal ring sequences in the Rocky Mountains and adjacent areas, representing various tree stations from Jasper, Alberta (lat. 53° N), to the Guadalupe Mountains of southern New Mexico (lat. 32° N), were compared with the longest and best rainfall series near each station or within each area. Sixteen rainfall intervals, from three months to two years, were chosen, and a total of over 22,000 rainfall sums of the published monthly values computed and checked.

In all, 693 linear correlation coefficients were derived and checked. Since the paired series ranged from 31 to 60 years in length, with a median near 45, and since trends in the ring series were either nonexistent or too small to affect the coefficients, it is believed that the results as a whole are fairly general. The data were classified according to three regions: Montana-Southwest Canada, Colorado-Utah, and Arizona-New Mexico.

Only a general note on the results can be given here. Although the interval showing the maximum coefficient differed in general from series to series, the regional average coefficients showed remarkable consistency. Shortening the classical October-June interval yielded consistently lower coefficients than those for that interval. Ponderosa or limber pine and to some slight extent pinyon pine showed higher coefficients when October-July was used; the coefficients for Douglas-fir decreased slightly. Of special significance is the fact that adding the July-September rainfall *of the previous summer* to the standard October-June interval resulted in maximum coefficients for Douglas-fir; the pines showed little or no improvement over October-July when this July-June interval was used. The coefficient for Douglas-fir remained high and the pines recorded slightly higher coefficients on a July-July or August-July interval. Use of a two-year rainfall interval resulted in occasional slightly higher coefficients for ponderosa pine but decidedly lower ones for Douglas-fir.

The fact that fluctuations in rainfall for the entire year are recorded in the rings of Douglas-fir, the major dendrochronologic species in the West, permits us to consider the climatic chronologies in this species as continuous in time; the other important chronology conifers may, in light of the preceding discussion, be similarly interpreted. Since, at most of the stations, the summer rainfall approaches half of the annual total, a substantial increase in climatic significance of the tree-ring indices can result from this reinterpretation, if these indices represent a sufficiently wide area. At the same time, the established dominance of the winter rainfall in the ring growth

*The rainfall computations were carried out by Charles W. Ferguson, Estella B. Leopold, and Don K. Cox, and the correlation work by Margaret A. Spencer.

of chronologic trees of the West makes possible an index of year-to-year changes in the cyclonic storms typical of that season.

It remains to be seen whether the ring-rain relations noted in the preceding paragraphs are of general significance for temperate zone conifers on well drained sites. The results of a thorough quantitative analysis of a Swiss stand[9] provide at least one important piece of evidence for this possibility.

Of interest particularly to archaeologists, in this connection, is the interpretation of population declines in terms of prehistoric droughts. It has been argued, for instance, that the drought of A.D. 1276-1299 in the Colorado Plateau area may not have been connected with the exodus or dying-out of the Pueblo peoples during that interval, since their crops depended not on the winter rainfall supposedly recorded in the trees but on the rains of spring and summer. It is evident, apart from various climatic phases of the matter which cannot be considered here and also without reference to non-climatic and perhaps more cogent reasons which have been proposed to explain the Puebloan decline, that the argument above noted is no longer tenable.

THE RECENT CLIMATIC FLUCTUATION

The persistent warming-up of much of the world's climate during recent decades—a phase possibly now generally ended—and other spectacular climatic phenomena such as the droughts of the 1930's in much of the United States are perhaps in good measure responsible for the recent extension of research in long-range forecasting.[10]

Curiously enough, the interpretation of western dendrochronologies in terms of absolute rainfall values is particularly difficult for the last century, since the direct and indirect effects of increasing human population are noticeable in most forest stands of the West. Liberation of growth because of cutting is common. Overgrazing, almost universal in the marginal areas where the best ring chronologies are found, seems in many areas, though not everywhere, to result in *increased* tree growth—perhaps an effect of the reduction or elimination of competing vegetation on very dry sites. Related changes in the soil microorganisms cannot be overlooked as a factor in the special modification of the normal age trend of tree growth. Only by the most careful selection of stands and widespread sampling may the hidden errors of this type be in good part controlled.

In terms of the mean indices for the last five to ten centuries, as indicated by selected groups of over-age trees throughout the West, it now seems evident that the recorded average rainfall and river flow (corrected for depletions) of the past half-century is everywhere of the order of magnitude of the estimated long-time means. A number of regions, however, have experienced unusually deficient rainfall and runoff during much of the past two or three decades; among the notable exceptions to this are the rainfall maxima in southern California in the decade beginning in 1935 and in some areas

[9] F. X. Schumacher and H. A. Meyer, Effect of Climate on Timber-Growth Fluctuations. Journ. Agric. Research 54:79-107, 1937.

[10] H. W. Ahlmann, The Present Climatic Fluctuation, Geographical J. 112:165-195, 1948.

I. Hustich, On the Correlation between Growth and the Recent Climatic Fluctuation, Geografiska Annaler, 1949, pp. 90-105.

J. B. Kincer, Our Changing Climate, Trans. Amer. Geophysical Union 27:342-347, 1946; see also Monthly Weather Review, Sept., 1933.

L. Lysgaard, Recent Climatic Fluctuations, Danish Meteorological Institute, 1949.

H. C. Willett, Temperature Trends of the Past Century, Proc. Royal Meteorological Soc., 1950, pp. 195-206.

H. C. Willett, Extrapolation of Sunspot-Climate Relationships, J. Meteorology, 8:1-6, 1951.

of the northern Rockies in recent years. Particularly hard-hit by low rainfall were some sub-areas in Arizona and New Mexico which have suffered drought with only an occasional wet year since 1920. Since the growth records suggest no strong secular trend in climate during the past millenium, the conclusion is inescapable that a series of generally wet years, as in the past, will again occur in such areas. Though the statistical chance of early occurrence is high, it will be obvious that in the absence of a physical explanation for such fluctuations no precise forecast is possible. It is perhaps widely realized, too, that even at best a wet interval can only result in temporary alleviation of the increasingly critical problem of water shortage in these regions of rapidly growing population.

DENDROCHRONOLOGY IN BIG BEND NATIONAL PARK, TEXAS

EDMUND SCHULMAN

Rocky Mountain Douglas-fir *(Pseudotsuga taxifolia)*, an excellent source of climatic chronology throughout its great range southward from middle British Columbia and Jasper National Park in Alberta, is represented by only a few scattered trees in the Chisos Mountains of southwestern Texas. Nevertheless, these trees provide a significant base for estimating the march of winter rainfall and of river flow during the last three hundred years in the Big Bend region of the Rio Grande. Ring analysis suggests also that here is one of the more remarkable boundary complexes in coniferous growth, whose study might well cast new light on certain problems in plant physiology.

COLLECTIONS

Park headquarters at Chisos Basin, 29° 16′ N, 103° 18′ W, elev. 5,100 feet, is reached by road south from Marathon, Texas. In late November, 1945, a horseback trip was made to the Boot Spring-Channing Rock area a few miles south of the headquarters in order to sample the groves there.* The sparse stand of Douglas-firs, stunted, slow-growing, and seldom reaching 20 inches in stem diameter, which has developed on the Tertiary lavas in this locality, is truly of an outlier character, some 200 miles s.s.w. of the general limit for this species in the Lincoln National Forest near the New Mexico border. Apparently, the Chisos Mountains, maximum elevation 7,835 feet, reach just high enough to provide the minimum moisture-temperature conditions for the presence of Douglas-fir. It is curious that Arizona cypress *(Cupressus arizonica)*, usually found on lower, drier sites than Douglas-fir everywhere else within their joint range in the Southwest, here grows interspersed with the latter. "A few canyons of the Chisos Mountains are phenomenal in that they harbor trees which are nonexistent in other canyons of the area."[1]

*The fine cooperation in the field work of Dr. Ross A. Maxwell, Superintendent, and Mr. Harry Linder, guide, is gratefully acknowledged. Study of the collections beyond the dating stage had to be postponed for some years. Measurement and analysis have now been completed as part of a project in the tree-ring hydrology of the Rio Grande, under contract between the Office of Naval Research, Navy Department, and the University of Arizona (NR089-020).

[1]O. E. Sperry and B. H. Warnock, Plants of Brewster County, Texas, Sul Ross State Teachers College Bulletin, v. 22, no. 1, 1941, p. 21. Alpine, Texas.