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VARIATIONS BETWEEN RING CHRONOLOGIES IN AND NEAR THE COLORADO RIVER DRAINAGE AREA

By Edmund Schulman

All the groups noted herein are in the form of increment borings obtained from selected living trees by the writer during 1939-1942. The area represented lies between the eastern limits of the Rocky Mountains and about 113° W. Longitude, and from the Mexican border to northern Wyoming. Each site within this region was carefully studied for its chronology possibilities before any tree samples were taken, and in general only those trees were bored whose physiographic and biotic environment indicated a maximum susceptibility to fluctuations in seasonal precipitation. Factors, especially in the generally dry southern Rockies, favoring such sensitivity are: thin and porous soil and visible bedrock (limestone and sandstone are most favorable), steep rocky slope, minimum of downhill seepage of water, dry exposure, lower forest or forest outlier elevations, particular species (Douglas fir is most consistent; ponderosa pine, pinyon pine, and scopulorum juniper are also good), sparse surrounding vegetation, and minimum of injury to tree.

THE SKELETON CHRONOLOGY MAP AND ITS LIMITATIONS

Since the thin rings are somewhat more consistent features for cross-dating ring chronologies in dry areas like the Southwest than are the thick rings, use of the former as the main dating criteria is emphasized by Douglass.[1] In a skeleton plot of a series, then, only relatively thin rings are noted in general and the thinner the ring the higher the skeleton lines. The range of emphasis in the plots of the map runs on a scale of about 1 to 8 with the shortest lines denoting a ring only just noticeable as a minimum in relation to its neighbors and the tallest lines representing microscopic or locally-absent rings. The date of any line may be read from the chart by joining corresponding marginal divisions with a ruler.

Since all the ring series in these collections have been measured and mean growth curves derived, the skeleton plots were obtained by direct reading of these mean group curves.

In considering the chronology in any sub-region within the domain of the chronology map it is desirable to base judgments on more than one group.

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[1] Climatic Cycles and Tree Growth, I. Carnegie Inst. Wash. Pub. 289, 1919, p. 55.

TABLE I. DATA ON TREE GROUPS IN AND NEAR THE COLORADO RIVER DRAINAGE AREA.

No.	Group	Species[1]	No. Trees[2]	Location[3]	Site	Approx. Elev., ft.	Quality[4]
1	SRH	DF	6:3	35—S—Tucson, Ar.	Summit Ridge	8500	A
2	SRL	DF	5:2	30—S—Tucson, Ar.	Canyon Slope	6000	A
3	SCH	DF	6:5	15—NNE—Tucson, Ar.	Mtn. Top	8500	B
4	SCL	DF	5:2	15—NE—Tucson, Ar.	Canyon Slope	6000	A
5	PYO	DF	3:1	80—NE—Tucson, Ar.	Ridge Top	9000	B
6	PYO	PP	3:2	80—NE—Tucson, Ar.	Ridge Top	9000	B
7	CHH	DF	3:1	100—ESE—Tucson, Ar.	Summit Ridge	8500	B
8	CHM	DF	2:2	100—ESE—Tucson, Ar.	Saddle Top	7500	B
9	BUR	PP	7:2	15—SW—Silver C., N.M.	Upper Slope	7500	C
10	GUA	DF	8:2	35—SW—Carlsbad, N.M.	Canyon Slope	6500	B
11	SFEe	DF	3:3	40—NE—Santa Fe, N.M.	Upper Slope	9000	B
12	SFEs	DF	4:4	35—SE—Santa Fe, N.M.	Mesa Edge	7500	AA
13	SFEs	PNN	1:1	35—SE—Santa Fe, N.M.	Mesa Top	7500	B
14	ZUN	DF	4:1	15—SSE—Gallup, N.M.	Footh'l Ridge	7000	B
15	ZUN	PP	2:1	15—SSE—Gallup, N.M.	Footh'l Ridge	7000	C
16	ZUN	JSC	1:1	15—SSE—Gallup, N.M.	Footh'l Ridge	7000	C
17	GCF	DF	6:2	35—N—Silver C., N.M.	Mesa Top	6000	B
18	GCF	PP	5:1	35—N—Silver C., N.M.	Mesa Top	6000	B
19	MGH	DF	3:1	30—NW—G. Cf. Dw., N.M.	Summit Ridge	9200	B
20	MGH	PP	2:2	30—NW—G. Cf. Dw., N.M.	Summit Ridge	9200	B
21	MGL	DF	4:1	35—WNW—G. Cf. Dw., N.M.	Footh'l Ridge	7000	A
22	MGL	PP	2:1	35—WNW—G. Cf. Dw., N.M.	Footh'l Ridge	7000	B
23	MGN	DF	1:1	50—NW—G. Cf. Dw., N.M.	Ridge Top	7500	B
24	MGN	PP	4:2	50—NW—G. Cf. Dw., N.M.	Ridge Top	7500	B
25	BRL	PP	2:2	65—WNW—G. Cf. Dw., N.M.	Divide Top	7000	C
26	ROZ	PP	4:2	65—WNW—G. Cf. Dw., N.M.	Upper Slope	8500	C
27	CFN	PP	2:2	14—N—Clifton, Ar.	Steep Wash	5500	C
28	CFN	PNN	3:2	13—N—Clifton, Ar.	Steep Wash	5500	C
29	HTP	PP	6:2	30—NE—Globe, Ar.	Upland Slope	6000	A
30	FOR	PP	5:3	7—S—Showlow, Ar.	Footh'l Ridge	6500	A
31	OAK	DF	3:1	15—SSW—Flagstaff, Ar.	Lower Can. Sl.	5300	B
32	KBH	DF	4:3	10—E—KBL	Plateau Top	8500	B
33	KBL	DF	2:2	120—NNW—Flagstaff, Ar.	Footh'l Slope	5700	A
34	ZIO	WF	1:1	35—S—Cedar C., Ut.	Lower Can. Sl.	4500	C
35	BRYh	DF	2:1	50—E—Cedar C., Ut.	Mesa Top	8000	C
36	BRYh	PP	2:2	50—E—Cedar C., Ut.	Mesa Top	8000	C
37	BRYh	FXP	1:1	50—E—Cedar C., Ut.	Mesa Top	8000	C
38	BRYl	DF	5:5	45—E—Cedar C., Ut.	Canyon Slope	7500	A
39	BRYl	LBP	1:1	45—E—Cedar C., Ut.	Canyon Slope	7500	C
40	CED	DF	2:2	4—E—Cedar C., Ut.	Steep Wash	6500	A
41	CED	PNN	2:2	4—E—Cedar C., Ut.	Steep Wash	6500	A
42	MOAs	PP	2:2	10—SSW—Blanding, Ut.	Footh'l Slope	6000	A
43	MOAs	PNN	1:1	8—SSW—Blanding, Ut.	Footh'l Slope	6000	B
44	DOL	DF	5:5	40—WNW—Durango, C.	Footh'l Slope	7500	A
45	DOL	PP	2:1	40—WNW—Durango, C.	Footh'l Slope	7500	B
46	DOL	PNN	1:1	40—WNW—Durango, C.	Footh'l Slope	7500	B
47	DOL	JSC	2:1	40—WNW—Durango, C.	Footh'l Slope	7500	B
48	MVR	DF	7:7	35—W—Durango, C.	Canyon Slope	6800	A
49	DURl	DF	3:1	7—N—Durango, C.	Footh'l Slope	7000	A
50	DURh	DF	4:1	7—N—Durango, C.	Upper Slope	9000	B
51	NDU	DF	3:3	30—N—Durango, C.	Canyon Slope	9200	B
52	WWG	DF	5:5	65—NE—Durango, Co.	Footh'l Slope	9000	B
53	WWG	CBS	1:1	65—NE—Durango, Co.	Footh'l Slope	9000	B
54	GUNh	DF	4:2	25—W—Gunnison, C.	Lower Slope	8000	C
55	GUNl	DF	3:3	20—W—Gunnison, C.	River Wall Top	7200	A
56	SAL I	DF	6:6	6—SE—Salida, C.	Footh'l Slope	7000	A
57	SAL II	DF	2:2	6—SE—Salida, C.	Footh'l Slope	7000	AA
58	PIKh	ES	4:6	12—W—Col. Springs, C.	Upp. Timberline	12000	D
59	PIKw	DF	4:4	30—WNW—Col. Springs, C.	Ridge Top	9000	AA
60	SOP	DF	2:2	17—SSE—Glenwood Spr., C.	Footh'l Slope	7000	A
61	SOP	PNN	2:1	17—SSE—Glenwood Spr., C.	Footh'l Slope	7000	C
62	STM	DF	5:4	20—N—Steamboat Spr., C.	Footh'l Ridge	8300	C
63	VER	DF	4:1	20—N—Vernal, U.	Footh'l Slope	8400	C
64	VER	PP	4:4	20—N—Vernal, U.	Footh'l Slope	7700	C
65	VER	JSC	2:1	20—N—Vernal, U.	Footh'l Slope	7700	C
66	LOGe	DF	3:2	15—ENE—Logan, U.	Lower Can. Sl.	7500	C
67	LOGh	DF	3:1	12—ENE—Logan, U.	Upper Can. Sl.	8500	C
68	BGP	DF	5:4	20—W—Big Piney, Wy.	Footh'l Slope	8500	B
69	WND	DF	6:3	5—NE—Pinedale, Wy.	Footh'l Ridge	8500	C
70	WND	LBP	1:1	5—NE—Pinedale, Wy.	Footh'l Ridge	8500	C
71	LAN	DF	6:4	5—W—Lander, Wy.	Footh'l Slope	8000	B
72	TETs	DF	2:1	12—SSE—Jackson, Wy.	Canyon Slope	6500	C
73	TETs	JSC	2:1	12—SSE—Jackson, Wy.	Canyon Slope	6500	C
74	TETw	DF	4:1	15—W—Jackson, Wy.	Footh'l Ridge	7500	B
75	TETe	DF	5:1	35—NE—Jackson, Wy.	Footh'l Ridge	7000	C

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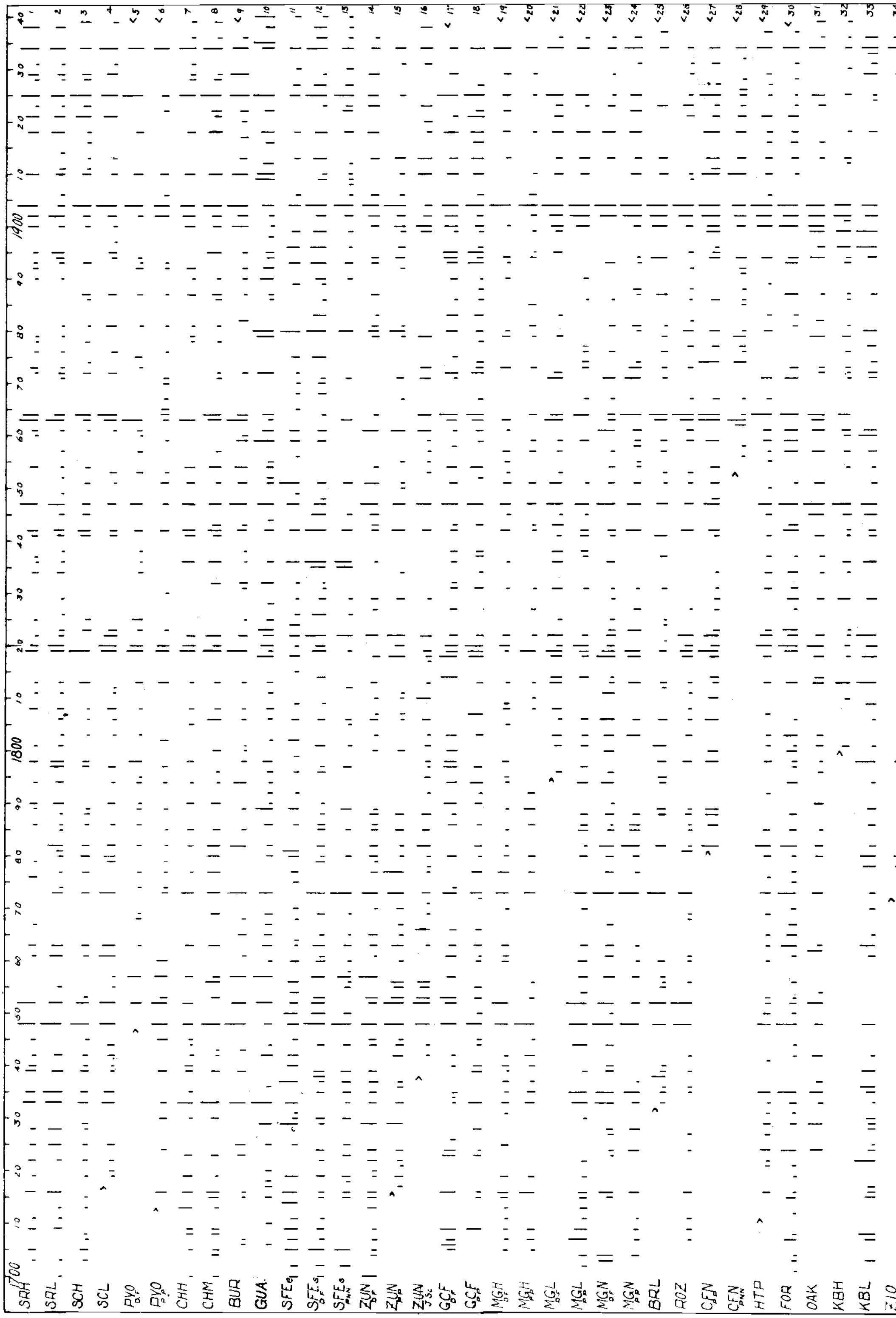
[1] DF=Douglas fir; PP=ponderosa pine; PNN=pinyon pine; JSC=Scopulorum juniper; WF=white fir; FXP=foxtail pine; LBP=limber pine; CBS=Colorado blue spruce; ES=Engelmann spruce.

[2] The first figure shows the number of trees entering the late part of the record; the second figure shows the minimum number of trees in the early portion of the record following 1700.

[3] For the first entry read: 35 miles south~~east~~ of Tucson, Arizona; for No. 19, 30 miles northwest of Gila Cliff Dwellings (GCF), New Mexico.

[4] This column shows an estimate of the sensitivity and quality of crossdating within the group: AA=extraordinarily good; A=excellent; B=good; C=fair; D=poor.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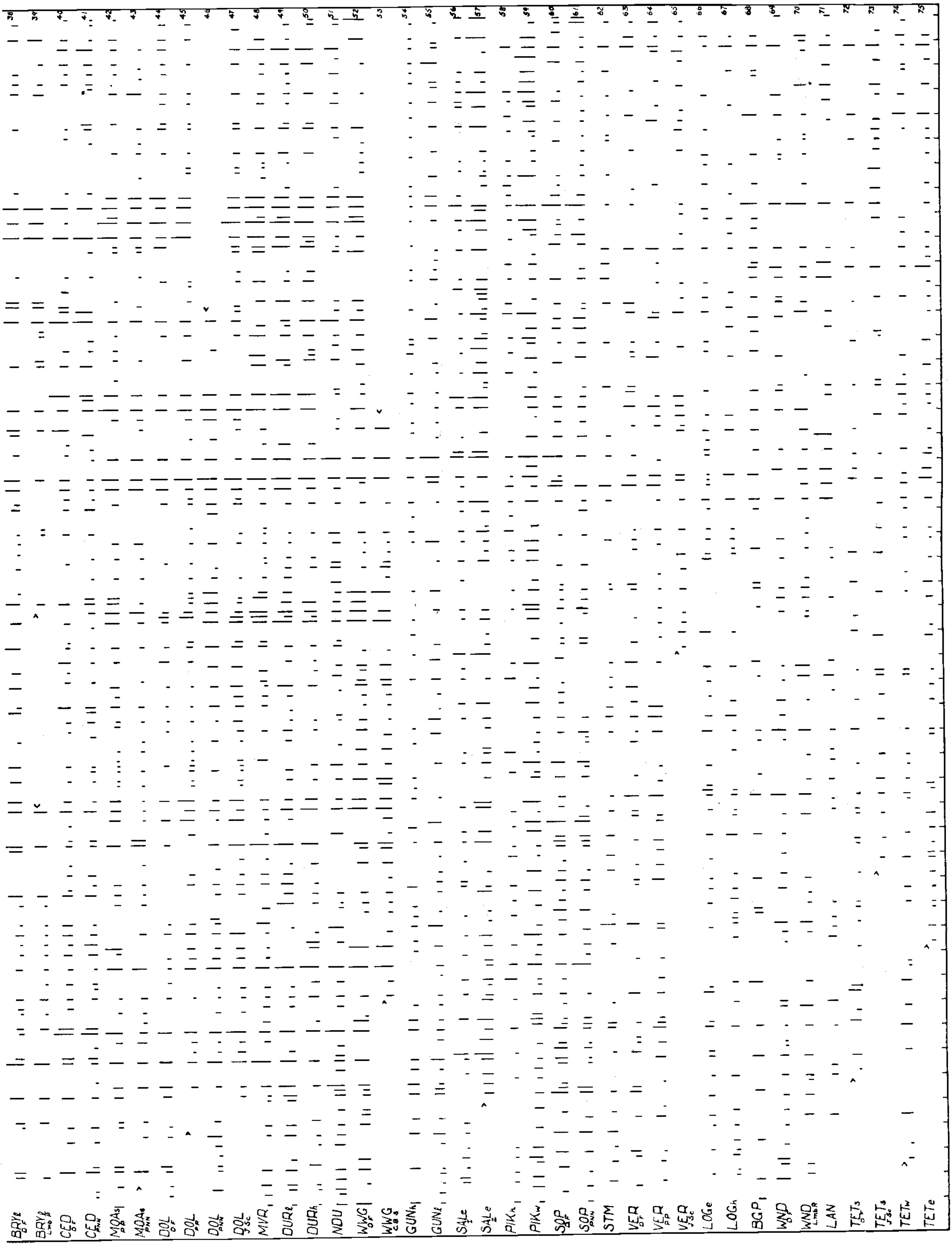
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In many cases the number of specimens is too few to give more than an approximation to the true chronology for the site and species. Secondary local differences with site are often real, as reference to the actual seasonal precipitation records of two neighboring meteorological stations will often show. Local variations with species owe their importance largely to slightly differing optimum requirements; it has been found, for example, that dry-site Douglas fir will agree in chronology with dry-site ponderosa pine across 400 miles of the Southwest climatic unit, that the growth curves from highly sensitive pinyon and neighboring Douglas fir are nearly identical for almost 500 years of record, but that moist-site ponderosa pine can show utterly no agreement in chronology with dry-type Douglas fir of its own stand.

BOUNDARIES OF A HOMOGENEOUS DENDROCHRONOLOGIC AREA

It is obvious from the chronology map that there is a strong tendency to persistence in chronology within large areas, but in other regions there is a rapid change in chronology with small change in distance; the latter character would thus appear to denote the borders of dendroclimatic units. Within a generally homogeneous area real local differences appear, as in the fading out of 1904 as a diagnostic thin ring in south-central Utah. Entirely variant records such as the cold-timberline record of PIKh, and perhaps the Wyoming chronologies, are probably representative to a greater or less degree of fluctuations in temperature in place of or in addition to precipitation changes. A quantitative method for delimitation of such climatic areas has recently been suggested by the writer.[2]

LONG-LIVED TREES

Eighteen of the series in the map extend back into the 1500's and some into the 1300's and even earlier. These are: 1, 12, 33, 36, 38, 39, 40, 41, 44, 48, 51, 55, 56, 58, 59, 60, and 71. Skeleton plots of these are available at the Tree-Ring Laboratory.

FLUCTUATING AREAS OF DROUGHT IN DIFFERENT YEARS

The chronology map shows a remarkable tendency in the area affected by drought for varying extent from one year to the next. For some years most of the Colorado drainage area was subject to drought, 1735, 1748, 1773, 1782, 1847, 1902, 1904, and 1934 among others. In some years (e.g., 1900) only the southerly portions of this area were generally affected; in other years (e.g., 1899) the northerly portions. Local bays or islands of more normal or even moist conditions in sub-regions during a year of general drought are not infrequent, e.g., 1904 in south-central Utah.

SUPERSENSITIVE CHRONOLOGIES

Three of the groups given in the map represent what may be called supersensitive chronologies; these are SFEs, SALe II, PIKw.

SFEs, a Douglas fir group from a small canyon in Glorieta Mesa southeast of Santa Fe, New Mexico, represents a site in that locality far below the normal range for fir. Changes of ring-width from zero (locally-absent) to more than a millimeter in successive rings in these specimens are common; the number of locally-absent rings is extraordinarily large. The cross-dating character of the specimens is so true however, that identification of the rings is in all cases unique.

The SALe group, Douglas fir from a very dry slope above the Arkansas River at the eastern limit of the range for the species, is perhaps the most remarkable group of all. Sub-group I, from an exposed gravel slope almost

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[2] To be published in Bull. Amer. Meteorological Society, April-May, 1942.

bare of vegetation, represents spike-topped trees averaging 12 feet high, 10-12 inches in diameter at the base, and about 500 years in age. A dozen of these were found. The records are perfectly datable, but very complacent, with *no absent rings*. Sub-group II, however, from a wind-protected cove only a few yards from the first site but supporting somewhat more vegetation, exceeds in sensitivity even the SFEs firs, and has many locally-absent rings. These trees, while also slow-growing, have much better crowns than the others. Table II shows the extraordinary range in number of absent rings in the two sub-groups.

PIKw is a group of Douglas firs from a ridge just north of Lake George, Colorado, at an elevation of 9000 feet. It shows unexpectedly high sensitivity for so far north and high a site. This may be related to the fact that it is an outlier site, a dry ridge top which borders a tree-less valley. Although in these specimens one notes relatively few locally-absent rings, the crossdating quality of the ring sequences is equal to that of the other two groups.

Table II summarizes some representative characters in the above groups. The extraordinary number of locally-missing and microscopic rings in such specimens as 838 is further emphasized by the fact that these are sprinkled among the thick rings and are not merely a continuous series of thin rings.

The mean sensitivity (M.S.), given in the last column of Table II, has been used by Douglass[3] as an index of fluctuation. This coefficient is the average percentage change of the year-to-year ring-widths in terms of the mean growth. It may be expressed as

$$\text{M.S.} = \frac{2}{n-1}\sum_{i=1}^{n-1}\frac{|X_i - X_{i+1}|}{X_i + X_{i+1}}$$ where $X_i + X_{i+1} > 0$ and the X_i are the ring-widths.

When there is little age curve in the series of ring widths it may be easily computed to a close approximation from the measurements simply by adding the first differences (disregarding sign) and dividing by the sum of the ring-widths. The formula then becomes

$$\text{M.S.} = \frac{\overline{|\Delta X|}}{M}$$ where $\overline{\Delta X}$ is the average first difference of the ring-widths and M is the mean ring-width.

This method has been used in deriving the values in Table II.

Normally-sensitive specimens in the Southwest tend to have an M.S. of about 35%. Thus the large coefficients in the table, applying to an interval of 221 years, take on a special significance. While the low values for specimens 835 and 853 are about the same and indicate great complacency, they represent two series fundamentally different in character, for the former shows superb crossdating with its neighbors while the latter, a timberline

TABLE II. CHARACTERISTICS OF RINGS IN SELECTED SPECIMENS, 1720-1941.

Specimen		Species	Ave. Width, mm.	Number Absent	Number 0.01-0.10 mm.	Mean Sens., %
SFEs	789	DF	0.63	2	13	55
	791	DF	0.46	10	16	62
	792	DF	0.38	14	19	64
SAL I	828	DF	0.37	0	1	29
	835	DF	0.22	0	14	19
SAL II	837	DF	0.48	4	10	57
	838	DF	0.27	19	29	80
PIKw	861	DF	0.36	1	10	53
	865	DF	0.47	1	15	64
	866	DF	0.66	0	5	56
PIKh	853	ES	0.25	0	4	17
MOAs	946	PP	0.96	0	1	41

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[3] Ecology, *1*, 29, 1920.

spruce from Pikes Peak, shows only a faint though definite agreement in chronology within its group. For comparative purposes, an unusually sensitive ponderosa pine from southeastern Utah is also given in Table II.

THE LIMITATIONS OF A SKELETON PLOT FOR DATING OLD WOOD

The method of dating an unknown series by memory of the characteristic ring sequence of the region, aided if necessary by direct reference to comparative specimens showing this sequence most brilliantly, is the most precise of all methods of dating and the only one which offers an absolute certainty of date in many cases.

The skeleton plot as used by Douglass and his co-workers in the Southwest is a weighted plot against time of the outstanding thin rings and other diagnostic features of any given ring series. Skeleton plots of all dated specimens for any homogeneous region may be merged to form a master plot which represents the characteristic ring chronology for the region. Any unknown series of rings may be matched against this master chart and a dating of its skeleton plot *suggested* at one or more points of apparent similarity. Unless the match is nearly perfect, ring for ring (as it sometimes is) it will be necessary to directly compare the specimen in question with various dated specimens covering the same interval in time. Only then can one become satisfied with the validity of the suggested date.

Since the skeleton plot is merely a tool in dating ring sequences, it cannot in general completely describe and substantiate the dates assigned to the rings in such specimens as building timbers from prehistoric Indian dwellings. A complete description of such dates should perhaps include:

a. A skeleton plot matched against a master chart.

b. A comparison of the outstanding diagnostic features of both master chronology and specimen. This will include false rings, unusual characters in latewood, etc.

c. A discussion of the ring differences between the master chronology and the specimen. This should include a discussion of the variations found for such rings in the master chronology itself, and a realization that in short series especially only a small number of rings need vary from the master chronology in order to fix a number of apparent but spurious regions of fit for the specimen plot.

d. A growth curve, or plot of ring measurements against time, matched against the master growth curve for the region.

Since the growth curve contains an objective statement of ring widths it is obviously a more valuable record of the tree's annual growth fluctuations than is the skeleton plot. At the same time, it cannot be used with safety as a conclusive criterion for determining dates by matching with a dated curve. Often in the first matching of curves many places of almost equal apparent agreement will be found; thus this is an ambiguous correlation method which when unsupported yields only blind *probabilities* of accuracy. Indeed, the skeleton plot when properly constructed is a more rigorous tool, and yet as already pointed out it may be only a preliminary step in dating. Only by considerations of the detailed facts, ring for ring, supporting the assigned dates, can one arrive at an outside date for the specimen which is certain.

It is thus seen that statistical devices such as correlations based on growth curves or on skeleton plots introduce an apparent objectivity into the problem of dating ring series which has only a fictitious advantage. Such methods may yield results on the very rare specimen carrying a long and essentially perfect chronology; on all others, which comprise by far the bulk of prehistoric records, they can yield only doubtful success or complete failure.