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DENDROCHRONOLOGY AT NAVAJO NATIONAL MONUMENT*

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In continuation of the development of quantitative master chronologies for selected localities in the Southwest, which has now extended to Mesa Verde[1] and Flagstaff,[2] this report presents a climatic-archaeological tree-ring index, continuous since A.D. 698, for the Tsegi Canyon region of the Navajo Reservation, roughly 120 miles airline northeast of Flagstaff.

THE CHRONOLOGY IN LIVING TREES

Like Mesa Verde and other regions of the Colorado Plateau of generally comparable physiographic character, the Tsegi Canyon area supports a sparse forest cover — pinyon pine and juniper on the mesa tops and, within the canyons, coexistent with oak brush and other stunted hardwoods, small groves or strings of Douglas fir on shaded talus slopes. The only other conifer noted was an occasional scopulorum juniper; ponderosa pine is said to grow in some bottom sites, and one archaeological specimen from Keet Seel was identified in the laboratory as *Abies* spp., probably white fir.

Increment borings obtained in April and June, 1947 show that Douglas fir trees of age and sensitivity comparable with that at Mesa Verde may be found here. With respect to the latter quality, however, it was noted that many firs, though very slow growing, were rather complacent; the firs in one prosperous grove, at Spruce Springs some miles west of Betatakin, proved to be so insensitive as to be almost undatable. The generally more complacent chronology as compared with Mesa Verde seems traceable to the relation of the tree sites to the massive beds of pervious Navajo sandstone; seepage along a less pervious stratum below this sandstone provides springs and seeps of a type "least liable to fluctuation"[3] and thus results in an almost constant, if minimal, water supply to trees tapping such sources.

Time permitted only a partial survey of the living trees in the region. The most sensitive firs in the collections were found in Betatakin Canyon (36° 41′ N, 110° 32′ W), along the top of the steep, north-facing talus slope above which towers the almost vertical canyon wall. The ring series were found to be notable for the almost complete absence of false rings; many long and sensitive series were entirely free of missing rings as well. Several trees over 600 years old were located. The oldest, a Douglas fir which had been truncated in mid-stem near the 40-foot level centuries ago by a rock or tree fall (a neighboring fir had long since grown above and around its present head) showed a pith date at A.D. 1272 one foot above the ground; it appears to be quite vigorous at present. This tree thus provides an overlap, tho a short one, with the regional archaeological chronology, which ends in A.D. 1283.

No long weather data are available for the Tsegi area, but the relation of the ring chronology to that in neighboring areas, discussed below, indicates that the derived tree-ring index gives a good first approximation to

*I am indebted to A. E. Douglass and H. S. Colton for making archaeological specimens available, to Custodian J. W. Brewer, Jr. for aid in the field work, and to Marion C. Young for laboratory assistance.

[1]Schulman, Tree-Ring Bulletin 12(3), 1946 and 14(1), 1947.
[2]Douglass, Tree-Ring Bulletin 14(2), 1947.
[3]H. E. Gregory, The Navajo Country, U.S.G.S. Water-Supply Paper 380, 1916, p. 137.

the winter rainfall. Since the living-tree sequence is derived from one site only, some improvement in the chronology as a rainfall index may be expected in a more inclusive regional mean.

THE CHRONOLOGY IN ANCIENT TREES

To construct the climatic index based on the archaeological specimens from the Tsegi area, the longest and most sensitive ring records were selected from two collections of specimens, the Douglass series obtained in 1927 and dated in 1929[4] and the series obtained by L. L. Hargrave in 1933[5] and dated by J. C. McGregor in 1934 and later.[6]

Ring dates in all sequences were independently identified and measured by the writer, the Mesa Verde specimens being used for comparisons.

Specimen KS-16 is of special interest. During his 1927 visit to Keet Seel Douglass found a three-foot length of stem shell, whose ring record proved to be extremely compressed and of little immediate value. Called to the writer's attention by Douglass, this specimen was dated in part and gives a first, though probably weak, approximation to the climatic chronology of this area in the 700's and 800's. The outer 14 mm, including a thin zone of sapwood, represent an undatable interval in which some 150 rings may be counted—many more must be missing, and the original bark date may have reached to A.D. 1250 or later. Some four inches of inner radius are gone; extrapolation of the growth curve indicates a center date probably not later than A.D. 450. This unusually old Douglas fir may have been a hollow snag at the time it was felled, and perhaps was intended for firewood rather than building material.

The measured ring-widths of the archaeological specimens listed in Table 1, selected for length and sensitivity, are plotted in the upper two panels of Figure 1; the standardized mean growth for Tsegi Douglas fir over the entire analysed range is plotted in the lower panels of this figure and is tabulated in Table 2. In deriving the latter table the juniper specimens BK-25 and F-3161 were omitted; these provide excellent data supplementary to the chronology given by the Douglas firs.

Ring photographs of the following specimens plotted in Figure 1 are available on microfilm[7] (the photographed range follows the specimen number): BK-25 (1076-1265), BK-2 (1081-1219), BK-20 (1182-1272), BK-18 (1214-1275), and KS-13 (1225-1284). KS-13, originally thought to be juniper, identifies with high probability as white fir (*Abies* spp.) and suggests the presence of this species among living trees of the locality. In ring character this specimen is like the concurrent Douglas fir records and is included in the growth table for that species.

TABLE 1. MEASURED SPECIMENS FROM RUINS IN TSEGI CANYON

Spec.No.	House	Form	Species[1]	Mean ring width, mm.	Inner ring A.D.[2]	Heartwood ends, A.D.	Outer ring A.D.[3]		Record quality
KS-16[4]	Keet Seel	shell	DF	0.25	698	1175±	1210+	vv	good
F-3194	N.A. 2630	v-cut	DF	0.81	898 p	1055	1124	v	exc.
F-3161	Keet Seel	block	JSC	0.53	940	no?	1109	vv	exc.
F-3193	N.A. 2630	.....	DF	0.63	956	1064	1129	c	exc.
BK-25	Betatakin	1/8 sec.	JSC	0.50	1064 p	1175	1266	v	exc.
BK-2	Betatakin	block	DF	0.47	1072 p	1210	1259	v	exc.
BK-20	Betatakin	core	DF	0.72	1177	1227	1273	c	exc.
F-3192	Keet Seel	1/2 sec.	DF	0.63	1195	1233	1272	c	exc.
BK-18	Betatakin	core	DF	1.50	1210 p	1246	1277	c	exc.
KS-13	NA 2630	core	WF	1.24	1225	1252	1284	c	exc.

[1] DF—Douglas fir; JSC—scopulorum juniper; WF—white fir (identification probable but not certain).
[2] p—pith ring present.
[3] c—outside ring constant along outer face of specimen—probably very few or no rings lost;
v—outside ring variable, possibly 5 or more rings lost;
vv—outside ring very variable, probably many rings lost;
+—outer rings very crowded, probably some absent.
[4] Mean ring-width represents measured interval A.D. 698-1068 only.

[4] National Geographic, vol. 56, 1929, p. 750. See also, Dating Pueblo Bonito, Nat. Geog. Soc. Tech Papers, P.B.S. 1, 1935, p. 53.
[5] Report on Archaeological Reconnaissance in the Rainbow Plateau Area, Univ. California Press, Berkeley, 1935.
[6] Tree-Ring Bulletin 1:6-8, 1934, and 2:37, 1936.
[7] Southwestern Photographic Ring Sequences, Amer. Documentation Inst. Doc. 1298, Washington, 1939.

TABLE 2. TREE-RING INDICES FOR DOUGLAS FIR AT NAVAJO NATIONAL MONUMENT (TSEGI): RING WIDTHS IN PER CENT OF THE GROWTH TREND*

A. D.	0	1	2	3	4	5	6	7	8	9
690	.....	.....	.....	.....	.....	.....	.....	.....	114	81
700	119	96	102	122	70	111	65	150	112	64
710	144	49	43	80	93	81	76	53	117	130
720	116	106	132	136	62	124	134	116	195	124
730	165	140	67	134	84	100	67	101	40	67
740	108	61	152	136	106	61	136	126	48	113
750	79	69	110	94	83	118	111	77	60	42
760	56	11	42	46	49	67	71	43	64	67
770	39	35	85	75	39	68	54	72	50	69
780	91	69	44	76	110	114	92	81	85	70
790	41	66	104	97	108	86	112	52	135	162
800	185	178	125	163	156	125	100	91	50	46
810	92	107	126	100	89	69	77	47	105	43
820	82	156	109	55	67	75	126	83	75	63
830	71	103	95	128	124	84	128	44	92	132
840	77	77	69	81	102	89	93	61	110	122
850	90	66	111	124	137	120	158	112	138	112
860	121	142	180	139	89	114	118	183	128	136
870	148	94	85	85	47	64	81	69	48	52
880	30	74	74	26	53	79	61	52	66	44
890	75	40	56	120	94	76	103	112	73	86
900	136	65	126	119	39	109	57	26	112	97
910	72	95	63	93	92	106	106	143	130	138
920	29	81	80	65	38	90	123	88	107	134
930	33	109	100	113	97	74	109	92	142	98
940	104	104	123	84	91	115	107	128	115	138
950	110	42	149	120	49	83	110	90	90	120
960	165	97	135	128	95	114	192	119	48	73
970	126	130	46	193	140	111	100	157	99	101
980	07	46	144	88	72	140	149	181	219	251
990	148	54	58	43	116	107	104	78	108	73
1000	110	62	87	63	101	51	102	131	127	72
1010	72	127	109	64	62	145	117	97	91	21
1020	121	121	74	79	115	131	101	90	104	97
1030	96	97	85	64	151	54	32	116	114	21
1040	73	60	80	47	50	80	43	110	57	102
1050	120	136	169	117	165	53	70	174	154	85
1060	114	140	110	189	189	206	240	12	61	97
1070	91	17	104	65	72	86	98	108	95	124
1080	184	56	189	133	187	20	67	169	125	121
1090	18	56	107	48	73	56	105	78	56	26
1100	68	43	117	111	102	140	101	37	66	77
1110	126	103	105	57	99	136	164	160	151	122
1120	154	69	260	105	219	72	42	123	187	209
1130	124	30	34	40	49	59	80	39	31	90
1140	53	52	78	65	·60	87	07	111	64	54
1150	00	40	75	43	45	65	43	125	33	93
1160	133	58	113	128	23	148	65	155	103	00
1170	73	80	58	58	50	20	83	50	153	99
1180	126	91	32	100	162	78	15	33	89	74
1190	85	18	49	44	106	110	113	178	72	69
1200	174	136	121	154	167	69	126	121	63	170
1210	165	181	169	139	84	52	15	43	54	98
1220	109	43	92	106	93	58	118	09	122	73
1230	91	75	105	20	118	92	58	93	155	158
1240	44	135	183	122	77	76	66	41	172	165
1250	114	42	72	144	16	121	129	171	26	206
1260	117	92	79	30	51	110	59	69	91	92
1270	54	91	112	104	58	154	36	34	29	62
1280	55	48	56	59	104	83	98	09	08	16
1290	98	53	61	36	94	47	82	11	107	00
1300	56	96	76	152	163	151	106	30	33	162
1310	140	77	167	195	135	43	12	61	69	118
1320	138	150	58	38	43	126	149	83	66	33
1330	160	167	158	104	114	19	166	185	108	57

*The number of trees on which these data are based, for any date preceding A. D. 1300, may be found in Figure 1. The more recent chronology is based on living trees with center dates as follows: 1273, 1304, 1358(2), 1440, 1446.

A. D.	0	1	2	3	4	5	6	7	8	9
1340	68	100	59	78	103	134	121	82	65	101
1350	28	44	60	157	121	81	113	156	162	157
1360	40	36	57	82	72	56	110	83	137	86
1370	142	103	84	113	151	103	54	68	112	107
1380	177	190	188	80	122	115	137	133	115	68
1390	34	49	76	41	68	57	38	89	46	32
1400	54	54	40	43	105	124	127	65	100	138
1410	103	97	127	51	181	83	138	138	86	127
1420	138	65	127	73	124	40	122	118	211	130
1430	146	168	176	146	111	49	108	76	46	57
1440	81	124	65	103	108	102	51	108	98	61
1450	35	110	97	142	118	22	118	54	155	104
1460	27	94	124	96	19	89	107	154	127	117
1470	70	24	38	50	85	78	126	148	123	99
1480	63	85	118	126	197	146	158	68	132	146
1490	137	162	156	126	140	10	81	81	110	140
1500	10	84	108	92	116	82	42	87	99	154
1510	70	152	155	158	155	128	107	47	70	100
1520	132	98	10	98	81	79	156	87	74	72
1530	102	90	10	93	85	105	105	110	18	88
1540	108	70	05	89	33	70	70	57	71	89
1550	118	108	158	134	132	82	148	148	119	116
1560	128	91	66	75	132	134	84	146	108	135
1570	99	73	95	59	48	95	79	93	90	68
1580	68	91	69	27	46	11	89	78	97	96
1590	67	44	41	52	122	84	84	81	90	104
1600	76	96	106	101	116	138	130	80	142	140
1610	171	137	92	63	98	166	190	193	173	208
1620	160	215	179	49	93	132	61	121	115	99
1630	97	117	33	129	124	112	86	62	78	156
1640	158	158	173	142	176	116	213	150	66	198
1650	136	160	99	151	22	112	91	110	110	110
1660	119	147	107	104	107	93	126	116	86	90
1670	46	87	98	129	136	121	68	124	112	72
1680	121	140	150	128	62	06	59	112	110	91
1690	88	107	129	124	60	121	83	73	106	90
1700	77	122	94	61	87	116	119	103	103	100
1710	126	82	104	118	124	95	85	92	102	125
1720	171	138	62	145	56	160	172	106	30	53
1730	73	84	81	50	100	33	118	78	118	61
1740	71	92	68	119	126	133	164	206	62	152
1750	100	110	118	73	94	70	81	45	108	116
1760	130	105	141	71	120	96	150	82	118	150
1770	68	144	86	33	79	104	98	80	33	98
1780	69	88	43	98	92	95	92	105	92	73
1790	33	102	92	113	80	113	109	116	126	113
1800	105	113	88	88	92	105	102	92	40	80
1810	47	66	109	30	95	102	128	128	36	43
1820	36	98	40	84	92	113	139	98	135	73
1830	139	146	105	135	117	135	105	128	152	167
1840	171	113	88	109	150	22	146	40	120	135
1850	135	88	139	88	95	139	124	67	109	109
1860	102	22	139	113	67	102	103	117	120	150
1870	98	92	51	69	92	105	95	117	139	105
1880	95	51	84	47	98	98	113	55	139	142
1890	128	120	122	102	73	95	43	131	120	19
1900	109	77	26	88	30	80	80	150	146	142
1910	128	142	167	139	142	175	135	142	77	157
1920	157	128	164	109	131	95	139	84	113	84
1930	66	120	117	62	62	66	40	62	80	58
1940	62	80	84	51	69	47	58			

CORRELATIONS WITH FLAGSTAFF AND MESA VERDE

The general similarity of chronologies in the Pueblo area and the presence of numerous local differences, mostly secondary but sometimes major, is well established. This is strikingly exemplified in the lower portion of Figure 1, in which the three long climatic-archaeological series recently constructed, each continuous for over 1200 years, are plotted in parallel.

Though these three series represent a small portion only of the potential data of this type for the Southwest, they will perhaps suffice for a prelim-

inary quantitative study of the implications of crossdating. The widely used Pearsonian correlation coefficient r will be the basis of this inquiry; the objections to its use as an indicator of physical relationship do not affect its importance as a simple measure of co-variation. To compute r requires considerably more labor than does the very simple trend coefficient which gives the proportion of agreements in sign of the year-to-year changes. However, for other than the type of reconnaissance work in which many sets are tested, the former has the advantage of much greater sensitivity; tests of a score of 50-term pairs showed cases of almost identical trend coefficients despite very great variation in the corresponding correlation coefficients.

The degree of crossdating. The correlation between individual ring records within any area can provide not only a measure of the "normal" or expected agreement in chronology but also a quantitative statement of the agreement with the regional chronology in dated archaeological specimens. (The latter property should not be confused with the dating process itself, which is a technique of *forecast and verification* leading to certain rather than blind correlation dating.)

The following coefficients apply to sensitive specimens in the groups of records selected for climatic study and are thus higher than one would expect to find in the *average* archaeological ring record. However, an attempt was made to correlate pairs from as widely separated localities as possible within the main area. The average specimen *vs* specimen correlations seem to be: Mesa Verde Douglas fir +.74 (three 50-year pairs tested); Mesa Verde pinyon pine +.58 (four 50-year pairs) Flagstaff ponderosa pine +.53 (four 50-year pairs). These average coefficients are, of course, based on too few trees to be definitive but probably give the right order of magnitude; for specific applications, more representative averages should be derived. Considerable variation in the coefficients was evident, not only from pair to pair but for the same pair from one interval to another; this variation is, no doubt, related not only to the random fluctuations in individual tree growth but also to differences from one interval to the next in the relative frequencies of various climatic departures from normal, especially those of large magnitude.

The specimen *vs* group mean correlations should be somewhat higher.

For Mesa Verde, the group *vs* group coefficients for Douglas fir *vs* pinyon pine are + .83 (1150-1199) and + .69 (1200-1249).

Interregional comparisons. The Mesa Verde, Tsegi, and Flagstaff tree-ring indices are correlated in Table 3, coefficients being computed for successive 50-year intervals. The successive coefficients are not strictly comparable, since a varying number of specimens support the indices at different dates, but apart from the low Flagstaff correlations in the 1400's and several comparisons preceding A.D. 900 the effect does not appear to be serious. Relatively low coefficients at those times may be traced directly to the approximations in indices based on only one or two trees.

The fluctuation in these coefficients in the last 500 years, during which all indices represent a number of individual tree sequences, is in part related to the already noted tendency to differences in crossdating quality in different time intervals. It would also appear that any so-called dendroclimatic region with given limits of chronology range must shrink and expand to some extent as a function of time.

Living tree vs archaeological chronologies. In view of the inherent approximations in removing the trend from many short archaeological growth records, in the averaging process, the degree of interregional correlation in the data preceding A.D. 1300 provides gratifying evidence of the climatic validity of the derived indices. As shown in Table 3, during the four centuries preceding this date the average correlation coefficients are of the same order of magnitude as those between living trees.

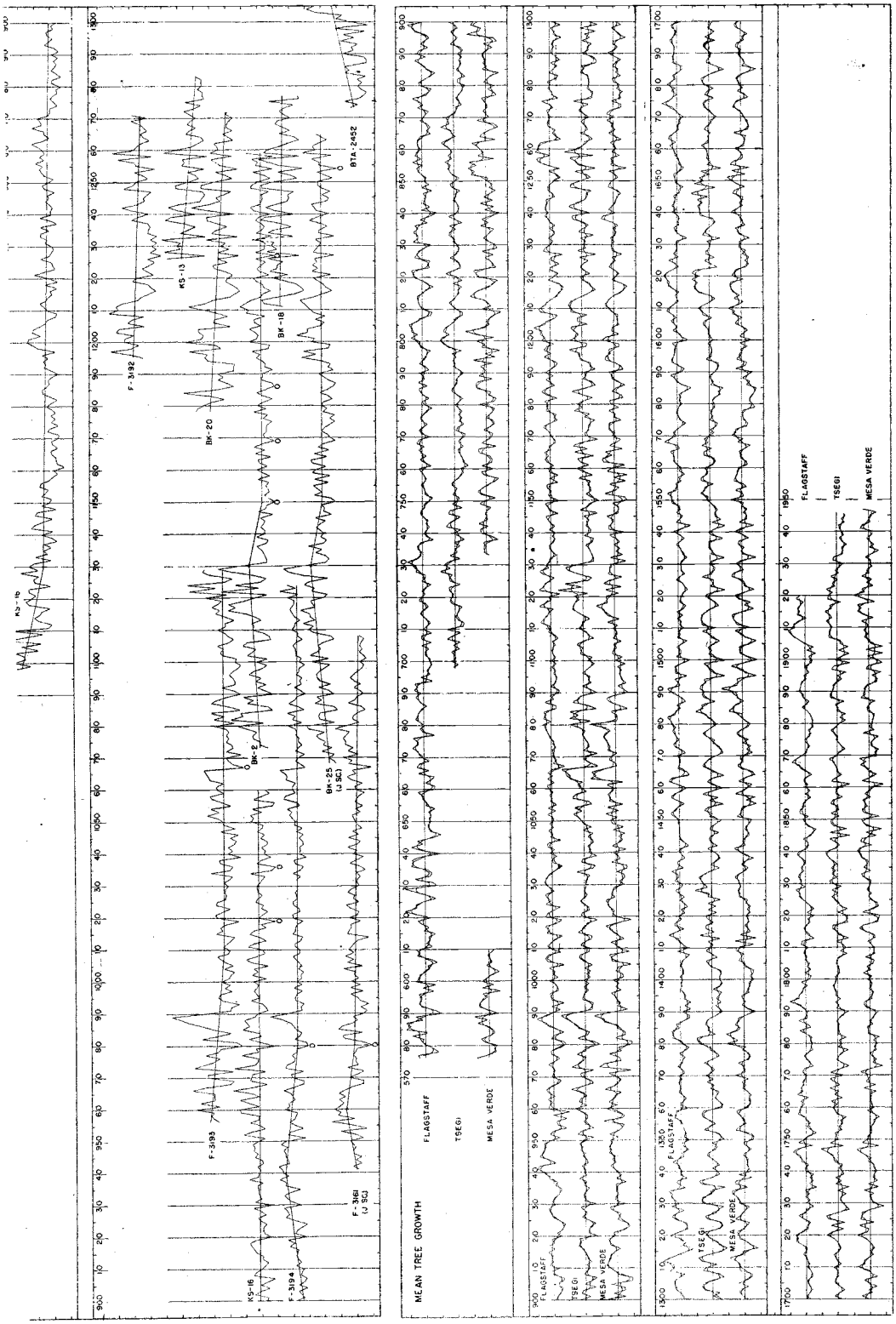

Figure 1. Upper: Ring records in the Tsegi Canyon area. The measures are plotted at various vertical scales to roughly equalize the spread of each curve, on which estimated trend lines have been drawn. Locally absent rings are indicated by zeros below the curves. The oldest known living tree in the area, BTA-2452, is plotted with these beam records; pending more data, the standardizing line must be considered as tentative. Lower: Comparison of the standardized indices for the Flagstaff, Tsegi, and Mesa Verde areas. Smoothed curves are superposed. The Mesa Verde series is started at A.D. 576, when the measured Flagstaff record begins.

TABLE 3. CORRELATION COEFFICIENTS BETWEEN SOUTHWESTERN INDICES

Interval A.D.	Mesa Verde vs. Tsegi	Mesa Verde vs. Flagstaff	Tsegi vs. Flagstaff
750- 799	+.33	+.29	+.27
800- 849	.43	.53	.64
850- 899	.35	.57	.25
900- 949	.58	.57	.58
950- 999	.83	.59	.72
1000-1049	.65	.55	.53
1050-1099	.68	.56	.71
1100-1149	.65	.52	.60
1150-1199	.65	.66	.64
1200-1249	.78	.56	.78
1250-1299	.60	.53	.68
1300-1349	.69	.64	.55
1350-1399	.77	.46	.50
1400-1449	.70	.17	.39
1450-1499	.83	.36	.41
1500-1549	.82	.54	.58
1550-1599	.56	.41	.51
1600-1649	.64	.52	.60
1650-1699	.61	.29	.48
1700-1749	.76	.62[1]	.72[2]
1750-1799	.68	.48	.48
1800-1849	.74	.53	.74
1850-1899	.76	.51	.55
1900-1946	.72		
Mean, 900-1299	.68	.57	.62
Mean, 1300-1899	.71	.46	.54

It may be noted in passing that such consistency of coefficients is possible only if the archaeological specimens are correctly dated!

Improvement in the fidelity of the index. The Mesa Verde-Flagstaff comparisons indicate that the archaeological portion of the Flagstaff index is closer to the "normal" local chronology than is the index based on the four photographed living-tree records. This is not totally unexpected, for the archaeological data are derived from a highly selected set of the best early records, whereas the sequence from A.D. 1309-1699 is based on four trees selected primarily for their longevity.

For the interval since A.D. 1700 a well based Flagstaff Area Mean (FAM) is available, representing eight groups of trees.[2] In Table 3 we note the average coefficient of this set against Mesa Verde to be +.54, as compared with + .39 for the Flagstaff photographed series.

Interregional rainfall vs tree growth. The correlation between records of observed rainfall in two areas gives a measure of the best correlation to be expected in corresponding rainfall-sensitive ring records. The Mesa Verde-Flagstaff correlation in October-June rainfall is +.72 for the short interval of record 1923-1945. The record at Durango, Colorado, some 35 miles east of Mesa Verde, shows a correlation with the Flagstaff record for the same interval of +.69; this decreases, however, to +.59 over the 48-year interval 1898-1945. This coefficient compares with an average 50-year coefficient of +.56 for the respective "archaeological" tree indices during the five centuries preceding A.D. 1300.

It will be interesting to observe the increase, if any, in the degree of correlation between the three regional indices treated herein as more specimens of high quality are included. More extensive analysis of the implications of such crossdating in terms of climatic and hydrologic phenomena should be specially valuable when comparable indices for additional areas are derived.

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[1]Mesa Verde vs. FAM, 1700-1899; coefficients for Mesa Verde vs. Flagstaff 4-tree group for this interval are +.50, +.35, +.31, and +.38.
[2]Tsegi vs. FAM, 1700-1899.