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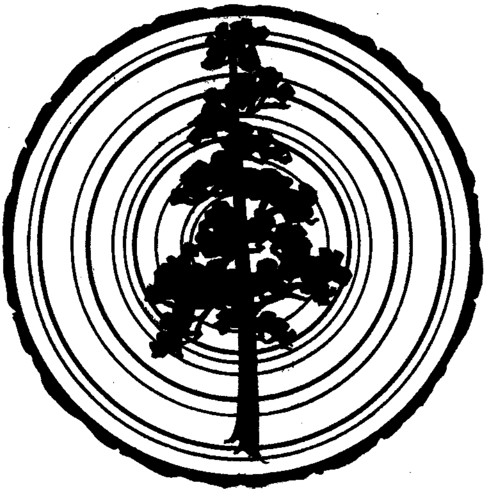

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DENDROCHRONOLOGIES IN SOUTHWESTERN CANADA[1]

EDMUND SCHULMAN

The semi-arid character of many localities in southwestern Canada[2] might be expected to favor the existence there, as in the Colorado River Basin, of significant, centuries-long rainfall chronologies in dry-site conifers. The value of such great extensions of the short gage records of rainfall and runoff needs no emphasis. Furthermore, if such ring records could be found, in spite of the high latitude and attendant cold climate and short growing season, a substantial addition could be made to the potential source areas of drought dendrochronologies in various regions of the world.

Preliminary field sampling by the writer in 1943 had yielded fairly sensitive ring series in ponderosa pine *(Pinus ponderosa)* and Douglas fir *(Pseudotsuga taxifolia)* of north-central Washington and one promising, though short, series near Penticton in southern British Columbia[3]. Though none of the Washington records approached in quality that at Mesa Verde or other similar districts, they gave a first approximation to an index of winter rainfall for the semi-arid Okanogan Valley.

During September, 1944, a number of dry-type forest stands in British Columbia and at Banff National Park were sampled and are here reported. Ring records were found in both Douglas fir and ponderosa pine which, in quality of crossdating and sensitivity, approximated that of the better series from the Colorado Basin.

COLLECTIONS IN BRITISH COLUMBIA

In the interior plateau of British Columbia rain-shadow effects are superposed on the transitional maritime climate to produce the "Dry Belt," over 100 miles wide, which is specially pronounced from the International Boundary northwestward some 300 miles to the Quesnel district. At typical valley stations in this south-central area the average annual precipitation is

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[1] It is a great pleasure to express appreciation to members of the Canadian Government Services, who suggested possible sites and provided field transportation and other aid: P. J. Jennings, Superintendent of Banff National Park; G. R. Hopping and H. B. Leech, Vernon Entomological Laboratory; H. B. Forse, Kamloops Forest Office; Bill Adamson, Ranger at Quesnel; and Floyd Nelson, Ranger at Williams Lake. Climatic data were provided by the Meteorological Division of Air Services, Ottawa. I am indebted to A. E. Douglass, who made special research funds available for the field expenses. Preliminary studies were sponsored by the American Geographical Society.

[2] H. N. Whitford and R. D. Craig. Forests of British Columbia. Comm. of Conservation, Ottawa, 1918. 409 pp., 28 pl., 26 maps.

[3] Geographical Review 35: 59-73, 1945.

15 to 20 inches, the mean January temperature is near 15°-20° F. and the July temperature near 65°F.; wide fluctuations from year to year in both elements are characteristic. The middle portion of the Fraser River system drains much of this area. In light of the well-established tendency for ring sensitivity to increase at the forest border, it may be emphasized that the northern limit is reached in central British Columbia in both Douglas fir (about 55°N.) and ponderosa pine (about 51°30′ N.); these are the two most desirable species for dendrochronologic work in the southern Rocky Mountains.

One increment boring was obtained from each selected tree.

Quesnel. 53°01′ N., 122°31′ W., about 1800 feet; about 4 miles north of Quesnel along Cariboo Highway and some 300 feet above Fraser R.; glacial moraine; moderate slopes, west exposure; Douglas fir and a good stand of mixed hardwoods; trees fairly tall, considerable underbrush; no old trees found; 5 cores of Douglas fir.

Williams Lake. 52°10′ N., 122°13′ W., about 1900 feet; about 5 miles north of Williams Lake along Cariboo Highway; schist; steep, rocky slopes east of Fraser R.; Douglas fir, an occasional *Juniperus scopulorum,* and open brush of mixed hardwoods; stunted trees; 6 cores of Douglas fir.

Alkali Lake. 51°48′ N., 122°14′ W., about 2000 feet; just north and west of dry lake; chlorite schist; moderate slopes bordering valley; very open stand of Douglas fir; trees of medium height, little brush, dwarfed cactus like prickly pear *(Opuntia)* in Arizona but only a few inches in height; 7 cores of Douglas fir.

Tranquille. 50°42′ N., 120°31′ W., about 2500 feet; 4-5 miles by winding road WNW of Tranquille Sanatorium; basaltic lava; rolling knolls, south exposure mainly; thin rocky soil; mixed Douglas fir and ponderosa pine, many very old; moderate height growth; open stand, little brush; both pines and Douglas firs apparently injured by pests[4]; 14 cores of Douglas fir, 14 of pine along a strip one mile in length.

Vernon. 50°13′ N., 119°11′ W., about 1500 feet; 2-3 miles SW of Vernon; granite; hilltop; Douglas fir and ponderosa pine; moderate height growth, very open stand, probably much reduced by fire; 4 cores of Douglas fir, 3 of ponderosa pine.

Penticton. 49°38′ N., 119°37′ W., about 1300 feet; about 10 miles N.; granite; rocky, west-facing slopes above Okanagan Lake; ponderosa pine and scattered Douglas fir, open stand, little brush, some evidence of past fires; 1 core of Douglas fir, 4 of ponderosa pine.

COLLECTIONS IN BANFF NATIONAL PARK, ALBERTA

Banff is near the eastern limits for Douglas fir. Annual rainfall averages about 19 inches, almost one-half of which occurs during June to September,

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[4] See G. R. Hopping, Insect-Injury to British Columbia Forests During the Past Decade. Chap. VII. of F. D. Mulholland, The Forest Resources of British Columbia, B. C. Forest Service, Victoria, 1937.

mean January temperature is 13°F. and mean July temperature 58°F.; thus the climate is very similar to that in many Douglas fir stands in central British Columbia.

51°10′ N., 115°33′ W., about 4500 feet; foothill ridge of Tunnel Mountain just southeast along Bow River to Bow Falls; quartzite; mixed open stand containing some lodgepole pine *(P. contorta)* and some hardwoods; considerable disturbance of natural conditions in this popular resort area during the last few decades; wind distortion evident in tree form; 10 cores of Douglas fir, 1 of lodgepole pine. For comparison purposes, a few cores of eastern white spruce *(Picea canadensis)* and Douglas fir from more moist sites nearby were obtained.

PROBLEMS OF RING ANALYSIS

Locally-Absent Rings. As a result of the excellent crossdating quality in the Douglas fir and ponderosa pine ring records which were obtained, the cases of rings locally-missing in the cores could be identified with sureness. All such rings have been listed in Table 1. The data there support the conclusions of studies in the Colorado River Basin which indicate that the frequency of rings locally-absent because of climatic stress is dependent on tree age, species, environment, and on climatic anomalies and their relation to growth.

The observed frequencies, for all trees in Table 1, are: for ages 200-299 years, twenty-two cases of rings locally-absent on the cores, or one per 218 rings; 300-399 years, ten cases, one per 159 rings; 400-499 years, five cases, one per 97 rings. At the site which shows the best combination of stress and age of trees, at Tranquille, eight old trees (435 to 525 years) showed a total of nineteen locally-absent rings; one pine showed eight such rings, one ring in the first century of growth. Young trees on relatively moist sites, as at Quesnel, showed no locally-absent rings.

False Annual Rings and other Growth Anomalies. As one would expect in relatively high latitudes, supernumerary rings are not common in these records of Douglas fir and ponderosa pine of southwestern Canada, though an occasional specimen showed a rather surprising number of such rings. None was found which provided any serious difficulty in identification. Growth anomalies are discussed separately for those localities where they were found.

Williams and Alkali Lakes: Only three cases of false rings, all weak; no frost rings; occasional rings of traumatic resin ducts in mid-season; more pronounced latewood than in Douglas fir of the Colorado River Basin.

Tranquille Douglas fir: False rings rare and unmistakable; no frost rings; pest effects are perhaps responsible for the extraordinarily reduced growth in some specimens near A.D. 1630 and in the early 1930's; extremely common pseudo-rings of traumatic resin ducts, usually among the first earlywood cells, occasionally in mid-season and in the latewood, and common in the outer rings of the older trees; latewood rather heavy, especially in the wide rings, forming about one-third of the total growth on the average, and tending to show fairly abrupt transition from the earlywood.

TABLE 1. LOCALLY-ABSENT RINGS.

Tree No.[1]	Species[2]	Approx. Pith Date, A.D.	Absent Rings, A.D.
	QUESNEL		
1518	DF	1785	no
1519	DF	1750?	no
1520	DF	1700?	no
1521	DF	1750	no
1522	DF	1750?	no
	WILLIAMS LAKE		
1523	DF	1650	no
1525	DF	1689	no
1528	DF	1690	no
1529	DF	1650?	no
1530	DF	1600	1869, 1931
1531	DF	1685	no
	ALKALI LAKE		
1533	DF	1650	1800, 1886, 1905
1534	DF	1625	1886
1536	DF	1650	1931
1538	DF	1640	no
1539	DF	1650	no
1540	DF	1600	no
1542	DF	1630	no
	VERNON		
1482	DF	1770	no
1484	DF	1630	no
1486	DF	1650	no
1488	DF	1800	no
	BANFF		
1543	DF	1580	no
1544	DF	1600	no
1545	DF	1600?	no
1546	DF	1600?	1843
1547	DF	1680	no
1548	LgP	1835	no
1549	DF	1670	no
1550	DF	1600	1831, 1939
1551	DF	1570	1843
1552	DF	1560	no
1553	DF	1600?	no
1554	DF	1620	no
1556	EWS	1850	no
1557	EWS	1815	no
1558	EWS	1830	no
	PENTICTON		
1341	PP	1710	1929, 1931
1342	PP	1700?	no
1343	PP	1750	no
1344	PP	1720	1843, 1869, 1875
1345	DF	1700	no
	TRANQUILLE		
1489	DF	1500?	1869, 1931
1490	DF	1500	1869
1491	DF	1700?	1932, 1933
1492	PP	1460	1843, 1869
1493	PP	1475	no
1494	PP	1420	1501, 1623, 1636, 1773, 1800, 1869, 1891, 1926
1495	PP	1650?	1891, 1932
1496	PP	1650	no
1497	PP	1751	no
1498	PP	1650?	no
1499	DF	1630	1891, 1905
1500	DF	1680	no
1501	DF	1490	1777, 1869
1502	DF	1685	no
1503	DF	1700	no
1504	PP	1700?	1891, 1922
1505	PP	1680	1869
1506	PP	1700	no
1507	PP	1680	1869, 1891
1508	DF	1600	no
1510	PP	1600?	1869
1511	DF	1680	no
1512	DF	1510	1869
1513	DF	1700?	no
1514	DF	1600	no
1515	DF	1650?	1843
1516	PP	1490	1515, 1843, 1941
1517	PP	1625	no

[1] Missing numbers in any group sequence represent discarded cores, from trees which proved to be very young or rotten-centered.

[2] DF-Douglas fir; PP-ponderosa pine; LgP-lodgepole pine; EWS-eastern white spruce.

Tranquille ponderosa pine: About 2% of the rings are double, but in almost all cases are easily identifiable by the criterion of hazy outside, apart from the check in crossdating; no frost rings; somewhat heavier latewood than is characteristic of the Colorado Basin.

Vernon: Very few false rings except in one young Douglas fir; rather poor crossdating quality; no frost rings.

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[5] Douglass, Carnegie Inst. of Washington Pub. 289, II, 1928, pp. 94-96.

Penticton: About 2% of the pine rings are double; occasionally identification can be assured only by crossdating with other specimens; no frost rings.

Banff Douglas fir: No false rings; no frost rings; pest effects possible but not striking; occasional lines of traumatic resin ducts, usually in mid-ring, sometimes in latewood; latewood much like that in the Colorado Basin; excessive growth in late 1820's may be a release effect; diminution in growth in recent decades may be related to human disturbance of natural conditions.

Mean Sensitivity. Douglass has shown that, in the drought areas of Arizona and elsewhere, the significance of tree-ring width as an index of total seasonal rainfall is closely related to non-erratic ring sensitivity. He has suggested, as a coefficient of mean sensitivity, "the difference between each two successive rings divided by their mean[6]", or a modification, "the average difference for every set of ten rings divided by the mean ring-width of the set."[7]

For practical purposes, the coefficient of mean sensitivity may be defined as the average change from year to year, disregarding sign, in the per cent departures of growth; that is,

$$\text{M.S.} = \frac{1}{n-1} \sum_{i=1}^{n-1} \left| x_{i+1} - x_i \right|$$ where the x_i are the standardized ring-widths or growth departures.

It is desirable that the coefficient be based on at least 100 rings.

To obtain the coefficient it is not usually necessary to remove the age-trend, if, as is often the case, the ring series is expressed as a table of growth measurements. For, if there is only a fairly shallow, closely linear age-trend in growth, this coefficient may be readily computed from such raw data, to a very close approximation, by averaging the differences in successive ring-width and dividing by the average annual growth of the entire series. As a test of this, the mean sensitivity, A.D. 1800-1900, was computed for two of the most sensitive series in these collections as based on (a) mean measured ring-widths and (b) standardized ring-widths, the respective coefficients being: Tranquille Douglas fir, .322 and .319; Williams Lake, .414 and .400 (the ring measures and the estimated trend lines are plotted in Figure 2 below).

Applied to one tree the coefficient is a measure of sensitivity only.

Applied to the mean index of growth of a group of trees from one locality the coefficient is a measure of both sensitivity and of the degree of crossdating. For a precise measure, the mean sensitivity of the individual trees in the group and their number must be considered. A growth index based on a number of ring series which are random and which therefore do not crossdate will rapidly flatten out as the number of series increases, roughly in proportion to the square root of the number. On the other hand,

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[6] Ecology, v. 1, 1920, p. 29.

[7] Carnegie Inst. of Washington Pub. 289, II, 1928, p. 30.

in tree-ring series which crossdate well the random variations of the individual tree represent only a small part of the growth fluctuations and are largely cancelled out in a mean of three to ten trees (depending on the quality of crossdating); thus a growth index based on such trees should show a mean sensitivity not substantially smaller than that of the individual trees. For example, in Table 2, the mean sensitivity of the Mesa Verde group mean compares favorably with those of its seven component trees.

Applied to a regional mean of a number of tree groups the coefficient is a clear measure of sensitivity and crossdating only when the year-to-year fluctuations in the dominant climatic element are essentially the same throughout the region. Such a homogeneous region will of course vary in size in different parts of the world.

TABLE 2. COEFFICIENTS OF MEAN SENSITIVITY, A.D. 1800-1900.

Station	**Species**[1]	**No. of Trees**	**Standardized**	**Mean Sensitivity**
Quesnel, B. C.	DF	3- 5	no	.22
Williams Lake, B.C.	DF	6	yes	.40
Alkali Lake, B.C.	DF	7	no	.35
Tranquille, B. C.	DF	13-14	yes	.32
Tranquille, B.C.	PP	13-14	no	.27
Vernon, B.C.	DF	3- 4	no	.27
Penticton, B.C.	PP	4	no	.29
Banff, Alberta	DF	9	no	.26
No. Pennsylvania[2]	EH	10	yes	.14
White Mountains, Alaska[3]	Sp	10	no	.18
Hunt River, Alaska[3]	Sp	6	no	.16
Kuovhonvuopio, Sweden[4]	PS	23	yes	.15
Hilmo, Norway[5]	PA	7	yes	.25
Selbu Area, Norway[5]	PA	64-75	yes	.20
Mesa Verde, Colorado[6]				
no. 625	DF	1	no	.44
no. 627	DF	1	no	.40
no. 635	DF	1	no	.47
no. 636	DF	1	no	.40
no. 637	DF	1	no	.43
no. 642	DF	1	no	.43
no. 643	DF	1	no	.45
group mean	DF	7	yes	.38
San Juan R. Basin, Colorado[7]	DF	19-21	yes	.33
Grand Canyon, Arizona[8]	PP	7	no	.36
Sequoia Forest, California[9]	GS	4	no	.15

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[1] DF-Douglas fir; PP-ponderosa pine; Sp-spruce,*Picea canadensis, P. mariana;* EH-eastern hemlock, *Tsuga canadensis; PS*-Scotch pine, *P. sylvestris; PA, spruce, Picea abies;* GS-giant sequoia, *Sequoia gigantea.*

[2] Meyer, Tree-Ring Bull. v.7, 1941, p.23.

[3] Giddings, Univ. Ariz. Bull. v.12, n.4: Univ. Alaska Pub. 4, 1941, pp.92,97.

[4] Erlandsson, Stockholms Högskolas Geokron. Inst. Data 23, 1936.

[5] Eidem, Nytt Mag. f. Naturvid., v.83, 1942, pp.180,184.

[6] Schulman, Bull. Amer. Met. Soc., v.23, 1942, pp.153,155.

[7] Schulman, Univ. Ariz. Bull., v.16, n.4, 1945, pl.III.

[8] Douglass, Carnegie Inst. Wash. Pub. 289, II, 1928, p.141.

[9] Douglass, Tree-Ring Bull., v.11, 1945, pp.28-29.

Table 2 indicates that some localities of southwestern Canada provide ring chronologies whose sensitivity and crossdating is of fine drought-chronology type. For comparison, the mean sensitivity in a number of type series from various areas were computed for this table. Some earlier computations[8] for single tree records may be cited: complacent Engelmann spruce at upper timberline, .17; the most sensitive drought-type Douglas fir, .53 to .80. The relatively low coefficients of the arctic groups in Table 2 are a resultant, in good part at least, of the characteristically complacent ring series of the individual trees in temperature-dominated growth; the quantitative degree of crossdating in such groups could easily be obtained by analysis such as that of the Mesa Verde group above.

Site and Chronology. As in the warm-dry areas of the southern Colorado Basin, ring chronologies in the cold-dry areas of southwestern Canada seem to be closely related to local site conditions.

At Alkali Lake the sampled range of sites was not great; one tree from a flattish area showed a decided tendency to complacent growth as compared with the slope and ridge specimens (Figure 1-C).

At Banff the phenomenon of relatively fast growth on optimum sites, resulting in large Douglas firs which proved to be much younger than small individuals on difficult sites, is very pronounced. The largest tree, about 45 inches in stem diameter, at a flat site—the "Animal Paddocks" two miles north-east of Banff—where the trees apparently tap a good supply of underground water, proved to be about 350 years of age. Its record, plotted in Figure 1-A (No. 1545), is very complacent, though it shows most of the minimal growth years recorded in the sensitive specimens from the Bow Falls foothill ridge. Trees from a long slope at Stoney Squaw Mountain, a mile and a half north-west of Banff and a few hundred yards above it, show only slightly faster growth and essentially the same chronology as the Bow Falls trees.

Species and Chronology. In the Colorado Basin, drought-sensitive Douglas fir, ponderosa pine, and pinyon pine have shown extraordinarily similar chronologies, though systematic differences with species in occasional years seem well established.

Analogous results may now be presented for British Columbia. At the Tranquille site, ponderosa pine and Douglas fir in an old-growth, mixed stand were sampled essentially at random. In Figure 1-D, the mean growth curve of the first seven sampled pines is compared with that for the last seven; the Douglas firs are similarly treated. The agreement in chronology between the two species is strikingly evident in almost all major and most minor maxima and minima. Random fluctuations are probably almost entirely cancelled out in a mean curve based on seven sensitive trees such as these.

Yet some apparently systematic differences exist, especially in the degree of emphasis of the more favorable growth-years. Whether detailed differences, as the more pronounced minimum at 1931 in Douglas fir as compared with that of ponderosa pine, may be traced to pest or other factors re-

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[8] Schulman, Tree-Ring Bull., v.8, 1942, p.31.

mains to be seen; if this instance proves to be a pest effect—there seems to have been a strong infestation of Douglas fir tussock moth in the early 1930's—its influence on the growth of survivors, as differentiated from general climatic stress, seems surprisingly small.

As in other areas of the Rocky Mountains, lodgepole pine at Banff proves to have a very erratic chronology (Figure 1-A); white spruce seems to be fast growing and very complacent, but no sites where this species is under stress were visited.

THE TREE-RING INDICES

The growth of eight groups of crossdatable trees in southwestern Canada, representing over 15,000 measured rings, has been plotted in Figure 2. By omitting the fast early growth in some trees a representative direct average of the ring-widths, without first removing the age trend, could be made in these trees. The estimated age trend has been drawn on each curve for the interval since A. D. 1800.

It is apparent from the figure that there is in general a strong tendency to persistence in ring chronology along the entire dry belt of south-central British Columbia; this is especially pronounced in the region from Tranquille to Williams Lake. The chronology at Banff is substantially different from, though it is perhaps not entirely unrelated to, that in central British Columbia.

A quickly derivable parameter which presents these comparisons in somewhat more quantitative form is the well-known trend coefficient. As applied to any two series of ring-widths, this is simply the per cent of agreement in sign of the respective year-to-year changes, the amplitude of the changes being disregarded. Standardized (trend-free) series are desirable. The coefficient has obvious limitations, but as a reconnaissance tool possesses the great advantages of simplicity and rapidity.[9] It is perhaps obvious that this and similar coefficients are properly applicable only to correctly dated ring series.[10]

The trend coefficients of various series with respect to the Tranquille index in Douglas fir are given in Table 3. Reference to the curves plotted in Figure 2 will show that most of the disagreements in trend, for the central British Columbia series, are to be found in the minor fluctuations in growth.

A mean index for central British Columbia was obtained by averaging the records from Williams Lake, Alkali Lake, Tranquille Douglas fir and Tranquille ponderosa pine. The standardized index is tabulated in Table 4.

The standardized index for Banff Douglas fir is tabulated in Table 5.

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[9] For a fine use of this tool see Per Eidem, Über Schwankungen im Dickenwachstum der Fichte *(Picea abies)* in Selbu, Norwegen, Nytt Mag. f. Naturvid. 83: 145-189, 1942.

[10] See Douglass, Crossdating in Dendrochronology, Journal Forestry 39: 825-31, 1941, for a discussion of absolute as differentiated from probable dating. Also, Douglass, Precision of Ring Dating in Tree-Ring Chronologies, Univ. Arizona Bull. 17 (3), 1946.

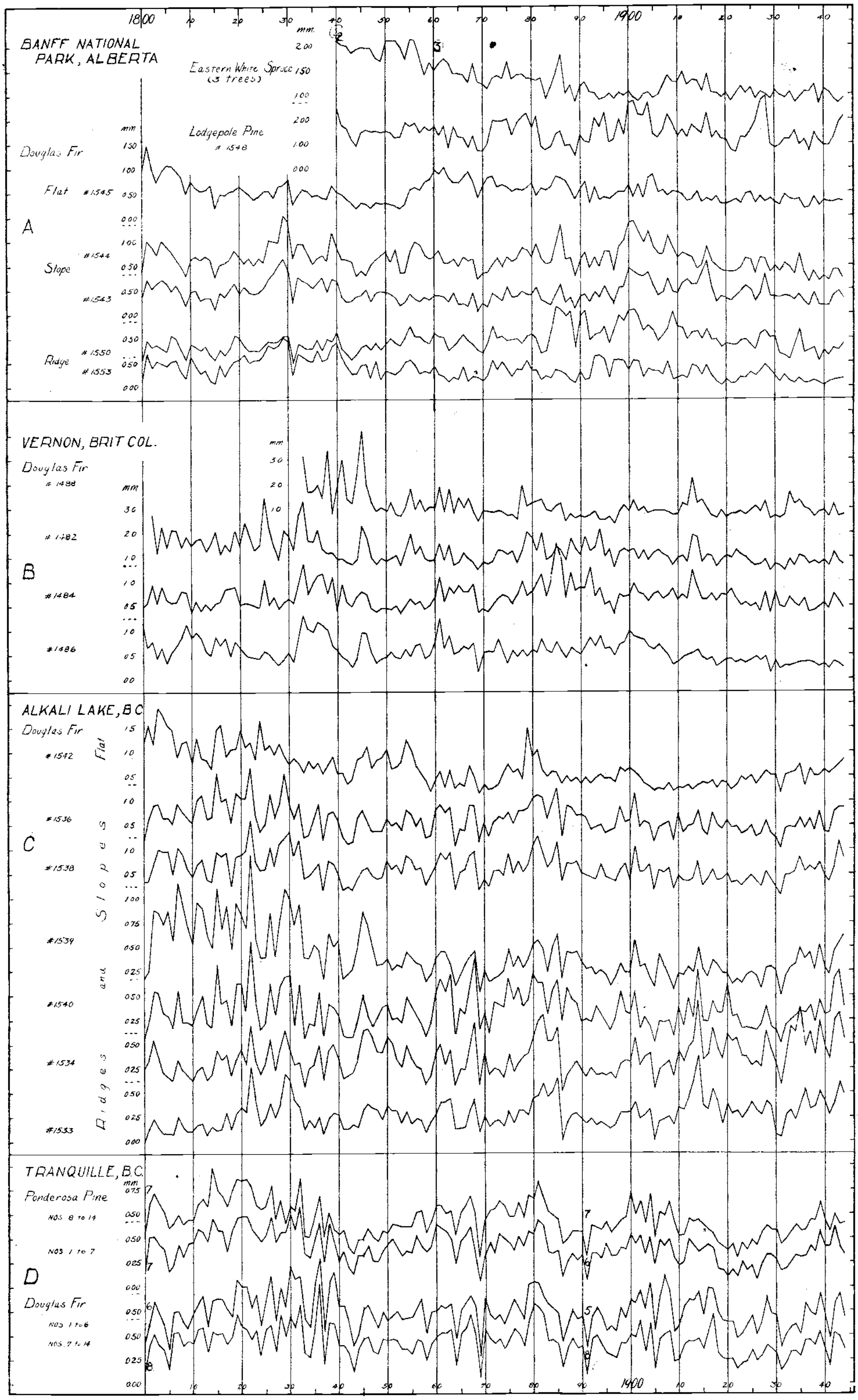

Figure 1. Site and species in relation to crossdating between growth records. Figures along the group curves give the number of trees on which such curves are based.

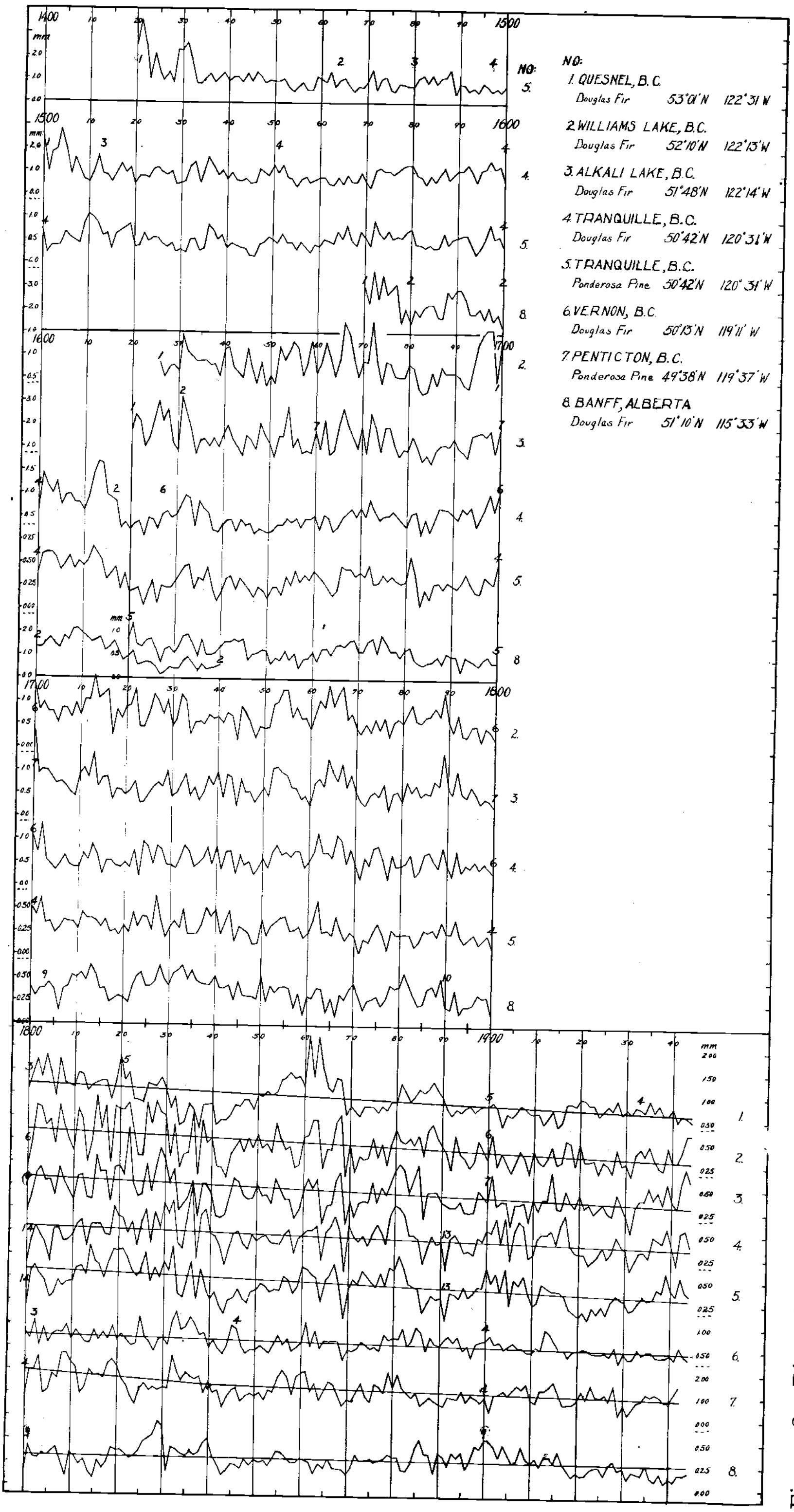

Figure 2. Ring chronologies in selected areas. These are plots of the averaged ring-widths before removal of trend. Figures along the curves give the number of trees on which each curve is based. Trend or standardizing lines are fitted to the measured ring-widths since A.D. 1800.

TABLE 3. PROPORTION OF GROWTH-CHANGES AGREEING IN TREND WITH TRANQUILLE DOUGLAS FIR, A.D. 1800-1942.

Quesnel	58%	Vernon	60%
Williams Lake	68%	Penticton	58%
Alkali Lake	66%	Banff	52%
Tranquille (pine)	77%		

TABLE 4. TREE-RING INDICES FOR CENTRAL BRITISH COLUMBIA IN PER CENT OF THE GENERAL TREND IN GROWTH.

A. D.	0	1	2	3	4	5	6	7	8	9
1420	116	174	130	54	112	67	48	133	50	138
1430	140	166	121	59	59	78	93	69	90	110
1440	89	94	103	85	123	87	132	120	89	107
1450	107	106	112	71	56	82	98	65	60	126
1460	119	105	154	82	116	124	85	56	83	75
1470	115	174	64	130	140	73	66	103	99	91
1480	98	135	152	119	155	107	142	151	189	55
1490	109	108	75	86	64	117	103	78	89	72
1500	146	50	88	100	137	127	76	98	78	91
1510	104	116	142	86	88	46	97	118	104	125
1520	51	72	98	78	103	108	88	78	107	49
1530	62	61	120	131	59	97	175	142	100	120
1540	66	96	75	66	70	44	50	103	100	101
1550	121	95	135	88	86	53	86	79	55	77
1560	81	95	78	73	114	81	134	82	76	130
1570	90	59	154	131	114	131	107	118	125	142
1580	146	90	85	62	87	67	93	134	81	106
1590	122	125	137	98	55	100	123	171	120	134
1600	75	136	125	117	125	83	99	111	87	96
1610	81	104	142	153	141	82	88	95	36	64
1620	32	43	51	10	52	67	24	68	71	66
1630	82	167	156	140	75	114	108	107	83	54
1640	99	123	99	71	77	105	83	48	99	65
1650	62	53	105	89	140	102	120	69	95	107
1660	110	89	134	87	59	99	171	152	125	89
1670	126	95	183	117	74	119	114	96	75	75
1680	89	120	86	26	59	50	72	101	92	93
1690	93	78	83	78	111	107	123	146	158	80
1700	164	116	170	111	104	77	98	108	84	93
1710	96	138	120	174	117	108	128	62	89	77
1720	93	90	139	58	97	111	106	147	110	110
1730	75	87	119	143	72	77	71	89	133	102
1740	136	72	123	131	41	121	91	84	41	63
1750	97	71	136	147	150	150	102	115	98	78
1760	69	123	168	114	160	122	164	169	87	124
1770	77	39	77	67	108	105	105	27	101	90
1780	78	110	116	74	76	108	110	124	99	184
1790	96	68	149	69	69	89	94	52	80	75
1800	36	83	119	112	91	75	75	115	88	81
1810	73	119	118	67	104	138	114	114	82	144
1820	138	136	151	108	72	90	150	93	144	135
1830	150	104	151	54	63	95	154	41	126	110
1840	87	62	46	27	69	93	101	74	77	85
1850	100	90	92	75	110	93	95	99	53	73
1860	116	127	127	134	43	96	104	150	138	18
1870	101	76	88	100	91	120	99	122	87	140
1880	164	168	150	113	118	130	51	105	119	104
1890	94	54	79	108	90	82	67	73	119	106
1900	118	143	115	98	124	47	108	121	121	59
1910	88	86	110	110	142	91	91	139	96	69
1920	91	72	61	67	59	82	61	67	114	88
1930	77	35	75	98	96	107	104	110	93	150
1940	102	77	142	154	130					

The number of localities and trees on which these data are based, for various dates, are as follows (date-localities-specimens): 1420-1-1; 1450-1-1; 1500-1-3; 1550-1-8; 1600-1-8; 1650-3-13; 1700-3-23; 1750-3-23; 1800-3-41; 1850-3-41; 1900-3-39; 1944-3-39.

TABLE 5. TREE-RING INDICES FOR BANFF IN PER CENT OF THE GENERAL TREND IN GROWTH.

A. D.	0	1	2	3	4	5	6	7	8	9
1570	108	81	133	89	129	100	110	119	61	81
1580	58	83	73	88	95	95	77	74	129	118
1590	135	140	122	92	91	107	85	114	86	103
1600	69	69	75	93	85	80	110	103	138	142
1610	134	122	111	121	133	93	106	132	100	69
1620	83	108	68	66	87	92	70	39	74	85
1630	73	92	122	128	103	65	117	70	71	79
1640	97	114	115	121	116	126	65	82	86	94
1650	91	54	68	64	96	65	86	39	69	77
1660	95	63	105	110	87	122	130	123	146	152
1670	107	108	146	160	102	177	149	112	117	95
1680	123	137	84	68	63	77	82	103	81	118
1690	111	110	38	108	95	85	72	108	121	89
1700	92	68	91	93	110	92	35	92	97	130
1710	122	137	116	159	134	89	97	58	68	77
1720	72	59	106	135	145	107	107	125	167	125
1730	110	146	156	169	126	153	129	120	116	120
1740	140	104	104	112	72	128	88	85	85	79
1750	143	68	113	96	113	114	109	50	95	31
1760	88	85	112	108	38	86	29	94	80	112
1770	131	96	49	80	83	92	62	84	132	120
1780	132	173	131	95	67	74	120	133	102	157
1790	65	59	122	44	65	67	77	108	99	102
1800	35	137	96	92	108	102	115	128	77	32
1810	111	96	73	86	48	26	87	58	81	130
1820	122	122	108	98	105	124	157	167	177	226
1830	213	50	141	134	116	93	141	113	120	157
1840	172	108	81	41	57	81	78	64	99	79
1850	95	89	89	79	99	130	122	105	89	89
1860	107	100	90	48	87	69	104	69	65	62
1870	45	70	123	98	102	106	95	99	106	123
1880	114	114	66	62	91	153	181	129	125	52
1890	134	119	81	134	112	134	70	109	162	151
1900	183	183	164	121	168	136	100	107	164	118
1910	106	120	91	128	123	102	149	100	78	52
1920	67	56	58	82	89	89	59	100	116	83
1930	91	46	75	68	64	102	49	39	69	31
1940	50	39	70	70	74					

The number of trees on which these data are based, for various dates, may be read on Figure 2.

CLIMATIC CORRELATIONS

The apparent similarity in growth reactions of the trees here reported to those in drought conifers of the Colorado Basin suggests rainfall as a controlling element in growth. To test the influence of various rainfall intervals, trend coefficients were computed for several critical areas[11] and are presented in Table 6. The average of five pairs of growth-rainfall comparisons indicates that the June or July rainfall alone shows no correlation with ring growth, the March-May interval shows a positive agreement, the January-May interval is slightly better, and the still longer October-May interval much better still. The October-June interval, extensively used in publications on Colorado Basin chronologies, is apparently somewhat less good as an effective interval for growth.

At Banff the March-May interval is slightly better than the longer periods. It is possible that the greater proportion of spring rainfall at Banff as compared with central British Columbia may introduce a difference in the respective rainfall intervals effective on growth, but only a study of a number of sensitive tree groups in the Banff area will decide this.

Comparison of Tranquille tree-growth with June-July mean temperature at nearby Kamloops shows no correlation.

TABLE 6. PROPORTION OF YEARS AGREEING IN TREND, TREES *vs.* RAINFALL

Trees	**Quesnel**		**Quesnel**		**Tranquille**		**Tranquille**		**Banff**		
Rainfall	**Quesnel**		**Barkerville**		**Tranquille**		**Kamloops**		**Banff**		**Mean**
Interval	Yrs.	%	Yrs.	%	Yrs.	%	Yrs.	%	Yrs.	%	%
June	35	54	54	41	28	54	48	50	49	57	51.2
July	34	47	52	42	25	56	45	60	43	47	50.4
Mar.-May	35	60	53	57	28	61	49	73	49	69	64.0
Jan.-May	35	66	53	70	28	63	49	76	49	65	68.0
Oct.-May	35	80	53	68	28	79	48	75	49	65	73.2
Oct.-June	35	74	53	62	28	79	48	69	49	63	69.4

In Figure 3 the reliability of these ring indices as records of past climate may be examined in detail. Although, as indicated in Table 6, the October-May rainfall season would show slightly better relations to growth than the October-June interval plotted in the figure, the longer interval is retained here for the time being, to permit comparisons with other published data. It is obvious that many of the larger and some of the smaller variations in growth may be interpreted in terms of winter-season rainfall. Yet there are a number of inconsistencies. Incomplete cancellation of random error in the tree curves, the errors in single-station gage records, irregularities in rainfall distribution through the year, and other factors distorting the growth-rainfall relationship may be left to later

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[11] Occasional short breaks in the sequence of monthly climatic data for some stations were closed by interpolation from neighboring stations.

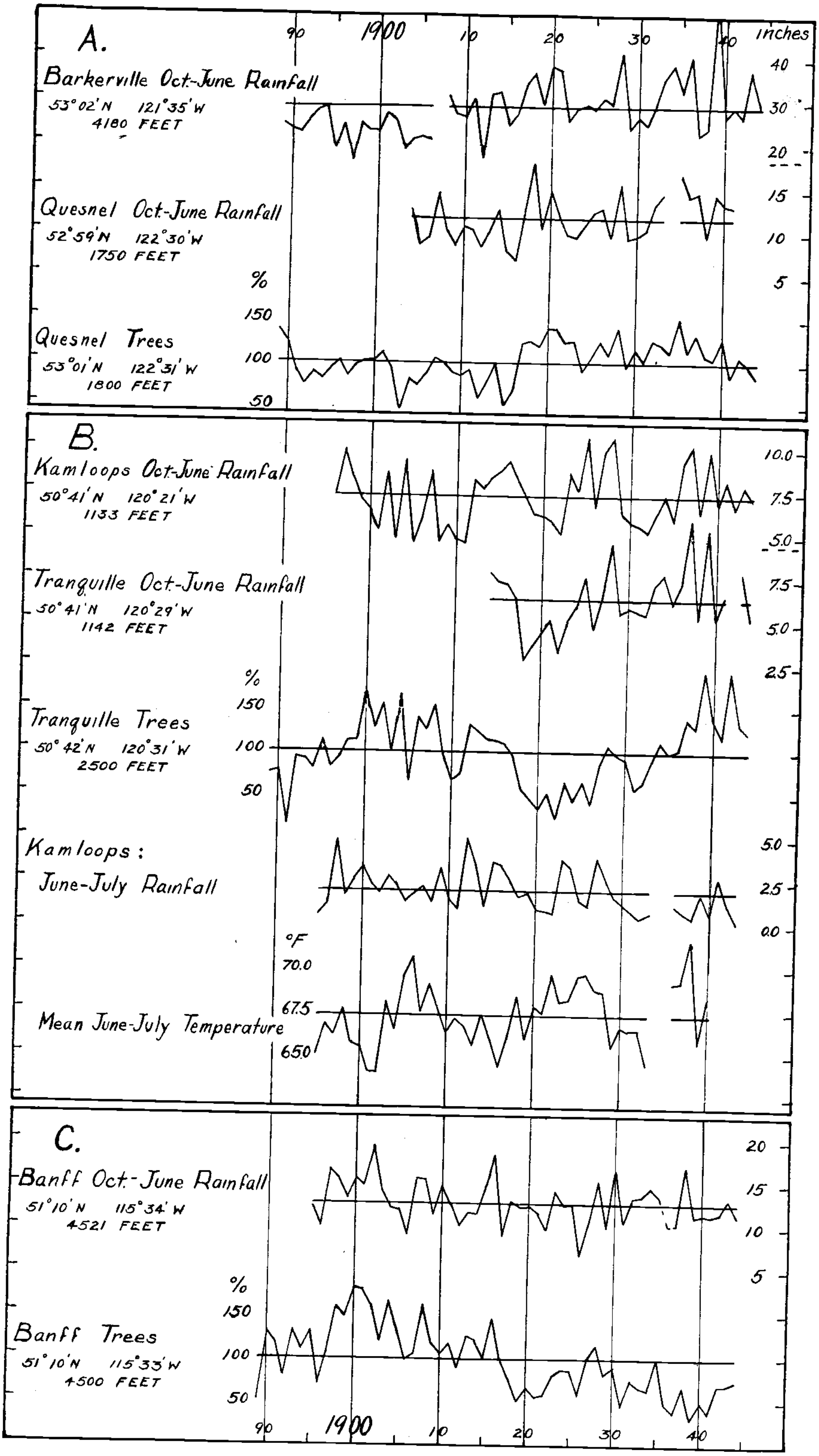

Figure 3. Tree growth as an index of rainfall and temperature.

analysis of more complete data. In view of the encouraging results in the limited data here analysed it appears possible that, with a sufficient number of ring series, regional climatic indices approaching in fidelity those of the Colorado River Basin may be derived.

Analysis with the cycloscope[12] shows that there exist in the British Columbia index tendencies to recurrence of wavelengths near 7, 13½, and 31 years. In the Banff index the wavelengths strong enough to suggest possible reality are of the order of 11½, 23½-24, and 31-33 years. More detailed cycle analysis has been postponed to the time when more extensive data will have been developed.

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[12] Douglass, Tree-Ring Bull. 10:10-16, 1943.