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THE DEVELOPMENT OF A MOISTURE-STRESSED TREE-RING CHRONOLOGY NETWORK FOR THE SOUTHERN CANADIAN CORDILLERA

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ABSTRACT

Fifty-three ring-width chronologies have been developed from open-grown, low-elevation stands of *Pseudotsuga menziesii* (Douglas-fir) and *Pinus ponderosa* (ponderosa pine) in the southern Canadian Cordillera. These chronologies will be used to develop precipitation reconstructions for the region. The sites are unevenly distributed across the interior valleys from east of the Coast Ranges to the Canadian Rockies and from the Canada-U.S. border to the northern limits of both species. The chronologies range from 123–691 years (mean = 383 years) and, on average, have a strong within-chronology common signal (Expressed Population Signal > 0.85) with as few as eight trees. A Rotated Principal Components Analysis (RPCA) identified three regions within which annual ring-width chronologies covary similarly. A preliminary assessment of regional chronologies and patterns of extreme narrow and wide marker rings demonstrates that common growth variations exist in the chronology network that are probably precipitation related. Both the RPCA and marker ring analyses suggest distinctive regional patterns of growth on both interannual and longer timescales that vary through time and are possibly linked to persistent large scale climatic anomalies.

Keywords: Douglas-fir, ponderosa pine, tree-ring chronology, network.

INTRODUCTION

Proxy climate records developed from tree rings are increasingly being used to explore climate variability and place existing instrumental climate records in an appropriate long-term context (Bradley 1999; Cook *et al.* 1992). The recent climate change debate has focused most scientific attention on developing proxy temperature records but there is probably a more urgent need for studies of precipitation variability because of its great economic and social impacts. Many dendroclimatic studies have estimated past precipitation from moisture-sensitive tree-ring chronologies growing in semi-arid areas in the United States (for reviews see Hughes and Graumlich 1996; Woodhouse and Overpeck 1998; Briffa 2000). Most of these studies have provided local or regional precipitation records that are the basis for more recent efforts to explore precipitation variability over much larger regions of the U.S. (Meko *et al.* 1993; Cook *et al.* 1996, 1999). In Canada, dendroclimatic studies at moisture-stressed sites have been limited to a few exploratory papers that generally develop one or two chronologies and provide local precipitation/lake level histories (Schulman 1947; Stockton and Fritts 1973; Robertson and Jozsa 1988; Case and MacDonald 1995; Szeicz and MacDonald 1996; Sauchyn and Beaudoin 1998). Larger chronology networks are necessary to evaluate the 'regional' representativeness of such records and to explore the spatial extent and nature of past precipitation variability. This paper presents the first results from a network of precipitation-sensitive sites in the southern Canadian cordillera. A discussion of the development of the chronology database is followed by an assessment of the common signal in (1) the individual chronologies (based on conventional signal strength statistics) and (2) the chronology network through the use of Principal Com-

Table 1(a). Location and characteristics of the chronologies in the moisture-stressed network.

Site Name	Species[1,2]	Latitude	Longitude	Approx. Elev. (m)	No. Cores	No. Trees	Start	End	Mean Length[3]
1: Pinchi Lake	DFa	54°41′N	124°31′W	1150	29	17	1638	1999	190
2: Coffeepot	DFa	54°27′N	122°42′W	750	30	20	1558	1999	313
3: Prince George—viewpoint	DFa	53°55′N	122°45′W	610	15	8	1876	1998	96
4: Dome Creek	DFa	53°43′N	121°00′W	760	27	12	1615	1998	255
5: Fort George	DFa	53°41′N	122°47′W	700	28	12	1780	1998	169
6: Maligne Canyon	DF	52°57′N	117°57′W	1200	26	21	1730	1996	172
7: Pyramid Lake	DF	52°56′N	118°05′W	1200	26	22	1630	1996	231
8: Lake Annette	DF	52°55′N	117°58′W	1150	16	9	1796	1996	159
9: Prairie de la Vache	DF	52°48′N	117°58′W	1150	29	17	1768	1996	183
10: Horsefly Lake	DFa	52°22′N	121°19′W	760	29	14	1656	1998	217
11: Bull Canyon	DFa	52°05′N	123°24′W	910	57	28	1574	1998	276
12: 2 O'Clock Creek	DF	52°04′N	116°25′W	1400	38	14	1464	1998	391
13: Deer Park	DFa	51°56′N	122°17′W	760–1070	40	18	1526	1998	243
14: Lac La Hache	DFa	51°46′N	121°23′W	910	36	14	1570	1998	235
15: Gang Ranch	DFa	51°40′N	122°24′W	820	38	19	1560	1998	282
16: Bridge Lake	DFa	51°27′N	120°45′W	1160	22	10	1686	1998	210
17: Churn Creek	DFa	51°25′N	122°17′W	910	47	20	1552	1998	236
18: Indian Meadows	DFa	51°24′N	121°57′W	1070	40	19	1592	1998	294
19: Clinton	DFa	51°13′N	121°29′W	1070	48	21	1537	1998	309
20: Clinton	PPa	51°13′N	121°29′W	1070	45	20	1633	1998	270
21: Powerhouse	DF	51°12′N	115°31′W	1430	53	25	1306	1996	303
22: Pavilion Lake	DFa	50°50′N	121°41′W	1160	54	28	1460	1997	269
23: Tranquille	DF	50°46′N	120°39′W	850	31	20	1472	1996	226
24: Tranquille	PP	50°46′N	120°39′W	850	12	8	1708	1996	171
25: Fritts	PP	50°46′N	120°36′W	700	38	21	1504	1996	275
26: Spatsum	DFa	50°34′N	121°17′W	370–430	32	13	1594	1997	218
27: Spatsum	PP	50°34′N	121°17′W	370–430	20	15	1639	1997	245
28: Westwold	DF	50°30′N	119°45′W	900	17	8	1614	1996	219
29: Westwold	PP	50°30′N	119°45′W	900	19	11	1571	1996	259
30: Lytton2 (Fraser)	DFa	50°20′N	121°38′W	460	42	16	1582	1998	212
31: Lytton2 (Fraser)	PPa	50°20′N	121°38′W	460	25	11	1625	1998	250
32: Lytton (N. Thompson)	DFa	50°15′N	121°28′W	610	37	17	1579	1998	210
33: Lytton (N. Thompson)	PPa	50°15′N	121°28′W	610	27	11	1468	1998	256
34: Patriot	DFa	50°09′N	120°49′W	700–760	44	17	1471	1997	267
35: Patriot	PP	50°09′N	120°49′W	700–760	20	15	1450	1997	342
36: Merritt	DFa	50°05′N	120°51′W	820	31	15	1510	1997	360
37: Merritt	PP	50°05′N	120°51′W	820	23	16	1650	1997	265
38: Bald Range	PPa	50°00′N	119°33′W	1070	31	16	1829	1998	138
39: Wasa Lake	DF	49°47′N	115°45′W	610	34	18	1762	1996	136
40: Naramata	DF	49°46′N	119°35′W	430	19	12	1703	1996	151
41: Naramata	PP	49°46′N	119°35′W	430	22	14	1463	1996	270
42: Perry Creek	DF	49°34′N	115°50′W	760	22	14	1745	1996	181
43: Shuttleworth Creek	PP	49°20′N	119°28′W	820	16	12	1806	1996	143
44: Keremeos	DFa	49°14′N	119°56′W	460–610	38	13	1573	1998	178
45: Kettle River	DFa	49°13′N	118°56′W	760	32	15	1790	1998	159
46: Kettle River	PPa	49°13′N	118°56′W	760	45	20	1584	1998	201
47: Ruby Ridge[4]	DF	49°05′N	113°59′W	1800	29	16	1787	1998	164
48: Crandell Mtn[4]	DF	49°04′N	113°54′W	1750	22	9	1450	1998	333
49: Golf Course[4]	DF	49°05′N	113°54′W	1800	49	23	1639	1998	206
50: Lost Horse Creek[4]	DF	49°08′N	114°00′W	1800	35	19	1605	1998	170
51: Chief Mtn.[4]	DF	49°05′N	113°48′W	1450	39	20	1673	1998	254
52: Skemeoskaunkin	DF	49°03′N	119°43′W	400	17	12	1517	1996	184
53: Osoyoos	DFa	49°02′N	119°33′W	610	30	13	1720	1998	180

Table 1(a). Continued.

	Site Name	Species	Latitude	Longitude	Approx. Elev. (m)	No. Cores	No. Trees	Start	End	Mean Length[3]
Mean										228
Minimum										96
Maximum										391
SD										61.9

[1] DF = Douglas-fir, PP = ponderosa pine.
[2] Chronology type: Sites designated DFa or PPa have earlywood, latewood and ringwidth chronologies.
[3] Mean segment length. For all sites the mean is 228 years (SD=61.9) ranging from 96–391 years.
[4] Chronology provided by Margaret Colenutt (Colenutt and Luckman 2000).

ponents Analysis (PCA) and an analysis of extreme years across the network. These analyses demonstrate complex and systematic variations of ring-width across the network that indicate a strong common control (which is probably precipitation related). Future analyses of the precise nature of the climate signal in these chronologies will form the basis for reconstructions of the precipitation history of this region.

DEVELOPMENT OF THE CHRONOLOGY NETWORK

Previous Work

Schulman (1947) first demonstrated the precipitation sensitivity of *Pseudotsuga menziesii* (Douglas-fir) and *Pinus ponderosa* (ponderosa pine) chronologies from a small number of semi-arid sites in the southern Canadian Cordillera. These and similar sites were later sampled in the mid-1960s and provided seven of the 65 chronologies in the Laboratory of Tree-Ring Research's (LTRR, University of Arizona) western North American network (Drew 1975; Fritts *et al.* 1979; Fritts 1976, 1991). Robertson and Jozsa (1988) developed the first Canadian precipitation reconstruction (1800–1980) from one of these sites at Banff. Watson (1998) resampled most of the LTRR sites in an examination of the dendroclimatic potential of 16 chronologies (11 Douglas-fir and 5 ponderosa pine) from semi-arid sites in the southern Canadian Cordillera. Annual (previous August–July or previous July–June) precipitation reconstructions, explaining 35–60% of the variance in the instrumental records used in calibration, were developed for Banff, Jasper, Cranbrook, Kamloops, Westwold and Penticton (Watson 1998; Watson and Luckman 2001). This study established the potential to develop an extensive network of sites for the reconstruction of precipitation variability throughout the southern Cordillera. Expanding the network of moisture-sensitive chronologies in this region is critical to document the spatial extent and patterns of historical drought across North America and may provide key insights into their underlying controls. A growing body of research has identified linkages between the climate of the southern Canadian Cordillera, North Pacific sea surface temperatures (SSTs) and associated atmospheric circulation anomalies (Bonsal *et al.* 1993; Moore and McKendry 1996).

The Chronology Network

Sampling carried out between 1997 and 2000 has updated five LTRR chronologies and developed chronologies from 38 previously unsampled sites in the southern Canadian Cordillera. In total, 40 Douglas-fir and 13 ponderosa pine chronologies have been developed from 43 low elevation sites (Table 1a; Figure 1). The sites sampled are irregularly spaced across southern interior British Columbia from the Coastal Mountains to the Rockies (*ca.* 550 km) and northwards from the US border to a site near Fort St. James (*ca.* 550 km). Precipitation in much of this area is limited by rain-shadow effects (Kendrew and Kerr 1955), with some areas receiving less than 300 mm of precipitation per year (*e.g.* Ashcroft). The majority of sites sampled in British Columbia are within the

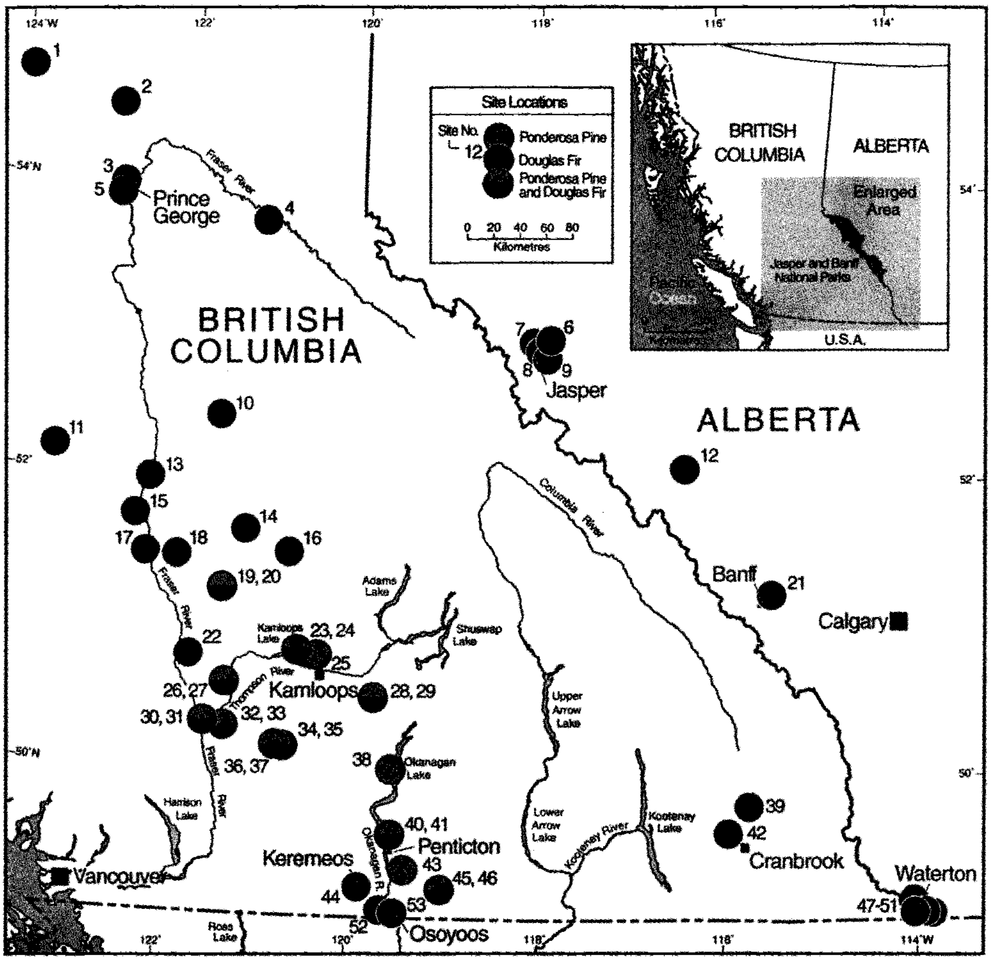

Figure 1. Location of the 53 tree-ring chronology sample sites and the meteorological stations in British Columbia and Alberta, Canada. Site numbers are identified in Table 1a.

Interior Douglas-fir or Interior ponderosa pine biogeoclimatic zones (British Columbia Ministry of Forests 1996, 1998). Winters in these zones are cool and short with limited snow cover. Summers are hot and dry. Maximum precipitation generally occurs in June though some stations exhibit a secondary December maximum. Minimum precipitation generally occurs in March or April. Precipitation in interior British Columbia tends to be most variable (*i.e.* exhibits higher monthly coefficient of variation values) in April or during the summer months of July and August whereas precipitation at many stations in southern Alberta is most variable in January. Tree-ring sites sampled in Alberta are in the montane ecoregion of Banff and Jasper National Parks (Holland and Coen 1982) and equivalent montane forests within Waterton Lakes National Park (Colenutt and Luckman 1999, 2000).

Open stands were targeted within the major valleys of southern interior British Columbia (Fraser, Thompson, Chilcotin, Okanagan, Similkameen and lower Kettle), the Rocky Mountain Trench and from sites near the northern limits of species range. Many of the more southern sites in British Columbia were mixed Douglas-fir and ponderosa pine stands, and cores were collected from both species. Ponderosa pine favors hotter, drier sites in the southern interior of British Columbia (particularly south-facing rocky outcrops; British Columbia Ministry of Forests, 1998) and reaches its northern limit between Clinton and Williams Lake in the Fraser Valley and around Barriere in the North Thompson River Valley. Only three sites yielded exclusively ponderosa pine chronologies (Bald Range, Shuttleworth Creek and Fritts ponderosa pine). Insufficient numbers of Douglas-fir were present for chronology development at the latter two sites. Douglas-fir extends northwards beyond Prince George where it is found in association with *Picea engelmannii* and *Abies lasiocarpa* (Engelmann spruce and subalpine fir).

Generally, the sites sampled were open grown with a grassy understory which often included *Artemesic tridentata* (big sagebrush) or *Chrysothamnus* sp. (rabbit-brush). In the southern Interior, the valleys are steep-sided and orientated north-south. North of the Kamloops area the valley sides are generally not as steep and the landscape, though still dry, consists of open, rolling grasslands, ideal for cattle grazing. Descriptions of individual sites and sample collection are given in Watson (1998); Watson and Luckman (1999, 2001), Watson *et al.* (2000) and Colenutt and Luckman (1999, 2000).

Chronology Development

The ring-width series from each site were cross-dated using standard techniques (Stokes and Smiley 1968), verified using the computer program COFECHA available in the Dendrochronology Program Library (DPL: Grissino-Mayer *et al.* 1996) and measured to the nearest 0.001 mm. Previous studies (*e.g.* Stahle *et al.* 1998; Stahle *et al.* 1999) have demonstrated that the earlywood (EW), latewood (LW) and total ring-width (RW) components of the annual ring in Douglas-fir contain different climatic signals related to the timing of cell formation. Therefore, three separate chronologies (EW, LW and RW) were developed for a subset of 23 Douglas-fir and five ponderosa pine chronologies (generally those sampled after 1997). Both Douglas-fir and ponderosa pine generally exhibit an abrupt color transition as well as a distinctive change in cell lumen size between earlywood and latewood cells. These changes were used to identify the boundary between EW and LW cells visually during measurement (M. Cleaveland, personal communication, Nov. 1998; for further detail refer to Stahle *et al.* 2000, pp. 294–295).

Following measurement, short (<100 years) and poorly correlated series were removed from each site collection to improve the strength of the overall chronology signal and to extend the mean segment length (Table 1a) used in each chronology. The computer program ARSTAN (Cook 1985) was used to standardize individual series by fitting either a modified negative exponential curve, a linear trend line of negative slope or a horizontal line through the mean of the raw ring-width series. The series were then divided by the value of the curve and averaged together to produce the mean indexed chronology for each site (Grissino-Mayer *et al.* 1996). These deterministic growth-trend models are considered to be conservative (Cook 1985; Meko *et al.* 1993) in that they permit the retention of as much of the low-frequency variance that is resolvable given the length of the individual tree-ring series (Cook *et al.* 1995). The mean chronology length is 383 years and 50% of the chronologies extend back beyond 1600 (Table 1a). The common period for all chronologies is the interval 1876–1996.

Chronology Quality: The Empirical Signal

Briffa (1995) defines the empirical signal in tree-ring series as the strength of the common signal in the tree-ring chronology. This is related to both signal strength and replication and has been described using a number of statistics (Fritts 1976; Wigley *et al.* 1984; Briffa and Jones 1990). Mean r_{mt}, r_{bt} and r_{wt} (mean, between and within-tree correlations of index series, respectively) values for the Douglas-fir and ponderosa pine chronologies are presented in Table 1b. The mean r_{bt} values serve as a preliminary and conservative estimate (they exclude within-tree correlations) of the common signal in the tree-ring index chronologies. Mean r_{bt} values are generally highest for the RW chronologies and lowest for the LW chronologies and are slightly higher for the Douglas-fir chronologies than the ponderosa pine chronologies (Table 2). This indicates that equivalently replicated LW chronologies have a weaker signal (more

Table 1(b). Chronology statistics. Species: DF = Douglas-fir, PP = ponderosa pine. Sens and Sdev are mean sensitivity (see Fritts, 1976 for details) and Standard Deviation values. r_{mt}, r_{wt}, and r_{bt} are the overall mean, within-tree and between-tree mean correlations. Underlined and italicized r_{bt} values are >1 standard deviation (SD) and <1 SD from the mean respectively. AC(1) is the lag 1 serial correlation coefficient. Expressed Population Signal (EPS) values for the chronologies collected in 1998–2000 were calculated over the optimum common period using r_{bt}. EPS values were calculated for the 1997 chronologies using r effective (r_{eff}) generated from correlations calculated over maximum-paired overlaps. The final two columns present the number of trees required to attain an EPS >0.85 and the year beyond which this threshold is met.

Site Name	Species	Sens	Sdev	AC(1)	Mean r_{mt}	Mean r_{wt}	Mean r_{bt}	No. Trees EPS 0.85	Year EPS >0.85
1: Pinchi Lake	DF	0.25	0.29	0.39	0.38	0.73	0.37	9.5	1779
2: Coffeepot	DF	0.16	0.28	0.76	0.28	0.63	*0.27*	15.5	1796
3: Prince George—viewpoint	DF	0.20	0.23	0.43	0.57	0.78	0.56	4.5	1905
4: Dome Creek	DF	0.17	0.18	0.37	0.29	0.69	*0.27*	15.5	NA
5: Fort George	DF	0.17	0.32	0.67	0.40	0.72	0.39	9.1	1792
6: Maligne Canyon	DF	0.28	0.35	0.52	0.43	0.73	0.42	7.8	1789
7: Pyramid Lake	DF	0.37	0.36	0.25	0.51	0.84	0.51	5.4	1716
8: Lake Annette	DF	0.26	0.28	0.38	0.47	0.50	0.46	6.7	1820
9: Prairie de la Vache	DF	0.28	0.32	0.44	0.51	0.72	0.49	5.9	1784
10: Horsefly Lake	DF	0.17	0.24	0.65	0.29	0.48	*0.27*	15.2	NA
11: Bull Canyon	DF	0.34	0.35	0.30	0.56	0.72	0.56	4.5	1629
12: 2 O'Clock Creek	DF	0.38	0.42	0.43	0.59	0.83	0.57	4.2	1476
13: Deer Park	DF	0.36	0.41	0.46	0.56	0.79	0.55	4.7	1651
14: Lac La Hache	DF	0.28	0.32	0.42	0.42	0.87	0.38	9.1	1704
15: Gang Ranch	DF	0.37	0.40	0.37	0.61	0.82	0.61	3.7	1598
16: Bridge Lake	DF	0.18	0.23	0.54	0.32	0.68	*0.28*	14.6	NA
17: Churn Creek	DF	0.33	0.38	0.40	0.42	0.73	0.41	8.2	1654
18: Indian Meadows	DF	0.32	0.37	0.42	0.53	0.74	0.53	5.1	1634
19: Clinton	DF	0.24	0.27	0.42	0.46	0.68	0.45	6.9	1599
20: Clinton	PP	0.19	0.27	0.63	0.42	0.75	0.41	8.1	1788
21: Powerhouse	DF	0.27	0.39	0.49	0.47	0.72	0.46	6.7	1470
22: Pavilion Lake	DF	0.30	0.30	0.28	0.49	0.73	0.48	6.0	1600
23: Tranquille	DF	0.42	0.44	0.32	0.57	0.76	0.56	4.5	1603
24: Tranquille	PP	0.27	0.36	0.59	0.50	0.84	0.48	6.1	1805
25: Fritts	PP	0.27	0.35	0.56	0.54	0.78	0.53	5.0	1545
26: Spatsum	DF	0.31	0.37	0.49	0.52	0.79	0.51	5.5	1660
27: Spatsum	PP	0.25	0.34	0.58	0.51	0.75	0.49	5.9	1733
28: Westwold	DF	0.20	0.25	0.48	0.45	0.70	0.44	7.2	1691
29: Westwold	PP	0.25	0.29	0.40	0.37	0.67	0.34	11.0	1683
30: Lytton2 (Fraser)	DF	0.22	0.24	0.32	0.20	0.69	*0.17*	27.3	NA
31: Lytton2 (Fraser)	PP	0.21	0.22	0.34	0.31	0.48	*0.29*	13.8	NA
32: Lytton (N. Thompson)	DF	0.27	0.30	0.47	0.35	0.80	*0.34*	11.2	1775
33: Lytton (N. Thompson)	PP	0.27	0.33	0.50	0.44	0.85	0.36	10.3	1835
34: Patriot	DF	0.29	0.37	0.56	0.49	0.68	0.49	6.0	1552
35: Patriot	PP	0.34	0.35	0.33	0.42	0.74	0.41	8.3	1720
36: Merritt	DF	0.28	0.30	0.41	0.46	0.80	0.44	7.2	1573
37: Merritt	PP	0.18	0.23	0.53	0.36	0.61	0.35	10.3	1798
38: Bald Range	PP	0.21	0.28	0.49	0.46	0.75	0.45	6.8	1839
39: Wasa Lake	DF	0.29	0.38	0.48	0.56	0.76	0.55	4.6	1844
40: Naramata	DF	0.24	0.35	0.62	0.42	0.67	0.41	8.2	1859
41: Naramata	PP	0.22	0.27	0.48	0.39	0.70	0.36	10.1	1721
42: Perry Creek	DF	0.23	0.28	0.46	0.38	0.61	0.37	9.6	1789
43: Shuttleworth Creek	PP	0.22	0.27	0.53	0.58	0.91	0.55	4.6	1828
44: Keremeos	DF	0.30	0.34	0.40	0.44	0.72	0.42	7.8	1722
45: Kettle River	DF	0.19	0.27	0.59	0.44	0.66	0.44	7.3	1812
46: Kettle River	PP	0.20	0.30	0.59	0.42	0.75	0.41	8.1	1788
47: Ruby Ridge	DF	0.25	0.35	0.55	0.50	0.68	0.49	5.9	1824

Table 1(b). Continued.

Site Name	Species	Sens	Sdev	AC(1)	Mean r_{mt}	Mean r_{wt}	Mean r_{bt}	No. Trees EPS 0.85	Year EPS >0.85
48: Crandell Mtn	DF	0.19	0.26	0.55	0.39	0.70	0.39	9.1	NA
49: Golf Course	DF	0.18	0.26	0.61	0.43	0.78	0.42	7.9	1711
50: Lost Horse Creek	DF	0.16	0.22	0.57	0.44	0.73	0.43	7.6	1734
51: Chief Mtn.	DF	0.17	0.25	0.58	0.41	0.71	*0.33*	11.6	1736
52: Skemeoskaunkin	DF	0.35	0.45	0.58	0.56	0.76	$\underline{0.54}$	4.8	1779
53: Osoyoos	DF	0.27	0.34	0.53	0.45	0.75	0.43	7.5	1756
Mean		0.26	0.31	0.48	0.45	0.72	0.43	8.3	
Minimum		0.16	0.18	0.25	0.20	0.48	0.17	3.7	
Maximum		0.42	0.45	0.76	0.61	0.91	0.61	27.3	
SD		0.06	0.06	0.11	0.09	0.08	0.09	4.0	

noise) than RW and EW counterparts from the same site.

The overall mean r_{bt} for the RW chronologies (0.43) indicates that, on average, eight trees are required to yield an Expressed Population Signal (EPS) value of 0.85 which has been "tentatively suggested as desirable" for climate reconstruction work (Briffa 1995; Wigley *et al.* 1984; Briffa and Jones 1990). Thirty-six of the 53 chronologies require less than nine trees to reach this threshold. Considerable variability in the r_{bt} values occurs (Table 1b), with a range from four (*e.g.* Gang Ranch Douglas-fir: $r_{bt} = 0.61$) to 27 trees (*e.g.* Lillooet Douglas-fir: $r_{bt} = 0.17$) required to reach the 0.85 EPS threshold. Although there is not a significant trend ($p > 0.05$) in the r_{bt} values related to latitude (or longitude), four of the more northwesterly chronologies (Table 1a) display mean r_{bt} coefficients more than one standard deviation below the mean. A similar observation is seen for the mean sensitivity statistics (mean 0.26). Again, there is no clear spatial pattern of variation, but many of the least sensitive sites (<0.20) are Douglas-fir growing at its more northerly (Prince George area, British Columbia) or higher elevation (Waterton area, SW Alberta) limits. The weaker common signal in these chronologies may reflect differences in climate or more localized site conditions.

Table 2 presents mean summary statistics for the standard chronology network by ring-width parameter (EW, LW or RW) and by species. Overall, the RW chronologies sampled in 1998–2000 display similar characteristics to the 16 sampled in 1997 (high mean sensitivity and standard deviation values and low autocorrelation). This suggests that the strong precipitation-ring width relationships demonstrated for the 16 original chronologies (Watson 1998; Watson and Luckman 2001) are likely to be replicated across the network. The average summary statistics for the two species are very similar, despite the difference in number of chronologies (13:40). The greatest differences are between the EW chronologies but they are not statistically significant ($p > 0.05$). On average, the ponderosa pine EW chronologies exhibit lower standard deviation, mean sensitivity and mean correlation statistics and higher first order autocorrelation (AC(1)) than the Douglas-fir chronologies. These differences are not related to mean segment length because the values are very similar (223 for ponderosa pine, $n = 5$; 234 for Douglas-fir, $n = 23$)

Statistics for the EW and RW chronologies are very similar (EW, on average, is 75–80% of RW) but mean statistics for the LW chronologies are different. The LW chronologies for both species exhibit much higher year-to-year variability, mean sensitivity and standard deviations and lower autocorrelation values than the EW and RW chronologies (Table 2). This might be anticipated given that the latewood component of an annual ring is narrow and difficult to measure accurately.

EVALUATING THE COMMON SIGNAL IN THE NETWORK

A key element in determining the dendroclimatic utility of a tree-ring chronology network is

Table 2. Average summary characteristics of the chronology network by ring parameter (EW = earlywood, LW latewood and RW total ring-width) and by species (DF = Douglas-fir and PP = Ponderosa pine). The summary statistics presented are based on the standard chronologies. Note that the standard deviation values are directly comparable as the chronologies are standardized to a mean of one. AC(1) is the lag 1 serial correlation coefficient. Mean r_{mt}, r_{bt} and r_{wt} represent average correlations between all series in the chronology, between all cores from different trees and between all series extracted from the same tree.

		Number of Sites	Mean Ring Width	Mean Sensitivity	AC(1)	Standard Deviation	Mean r_{mt}	Mean r_{bt}	Mean r_{wt}
Douglas-fir									
DF	EW	23	0.70	0.25	0.44	0.30	0.43	0.42	0.72
DF	LW	23	0.23	0.33	0.38	0.38	0.34	0.33	0.60
DF	RW	40	0.94	0.26	0.47	0.32	0.45	0.44	0.72
Ponderosa Pine									
PP	EW	5	0.89	0.21	0.51	0.26	0.39	0.37	0.69
PP	LW	5	0.21	0.30	0.39	0.34	0.33	0.30	0.62
PP	RW	13	0.94	0.24	0.50	0.30	0.44	0.42	0.74
Ponderosa Pine and Douglas-fir									
PP+DF	EW	28	0.73	0.25	0.46	0.29	0.42	0.41	0.71
PP+DF	LW	28	0.23	0.32	0.38	0.37	0.34	0.32	0.60
PP+DF	RW	53	0.94	0.26	0.48	0.31	0.45	0.43	0.72

the degree to which its constituent chronologies exhibit common growth variability. If the chronologies in a network are dissimilar it indicates that either tree growth is not related to a common factor or that the common factor is highly variable between sites. In either case, the ability of the network to capture coherent large-scale spatial patterns of climatic variability is limited and the chronologies will be most useful for exploring localized climatic conditions.

Principal Components Analysis (PCA) can be used as a data reduction technique, to explore interrelationships between variables or to identify the principal mode of variance within a dataset (Legates 1991). In this study, PCA is used to explore the relationships between chronologies and provide an important indication of the regional extent of coherent patterns of tree growth. Through an assessment of component loadings, it may also permit the identification of chronologies which exhibit unique (local) variance. Of the six modes of decomposition that can be used in principal components analysis (see Richman (1986) and Yarnal (1993) for details) S and T are used in this study. S-mode decomposition is the most commonly used in dendroclimatic research. The original dispersion matrix in an S-mode decomposition consists of correlations between the chronologies over their common period; the resulting components represent subgroups of chronologies which covary similarly. In a T-mode PCA, the original dispersion matrix consists of correlations between each year of record (121 years in this case) through space (*i.e.* the 53 chronologies), not the chronologies through time. Identified components (*i.e.* component scores) therefore represent spatial patterns of tree-growth and loadings indicate which years are most strongly identified with a particular pattern (*i.e.* component).

Principal Component Analyses

An S-mode PCA was conducted for the 53 standard ring-width chronologies over the common interval (1876–1996) to explore the interrelationships of chronologies within the network. Three components, explaining just over 50% of the variance in the original dataset, were retained (based on the 'scree' test) and subjected to a varimax rotation. Note that components (*i.e.* regions) identified using varimax rotation are constrained to be orthogonal—this expectation may be physically unrealistic (Cook *et al.* 1999; Meko *et al.* 1993). Very similar results were obtained from two additional principal component analyses us-

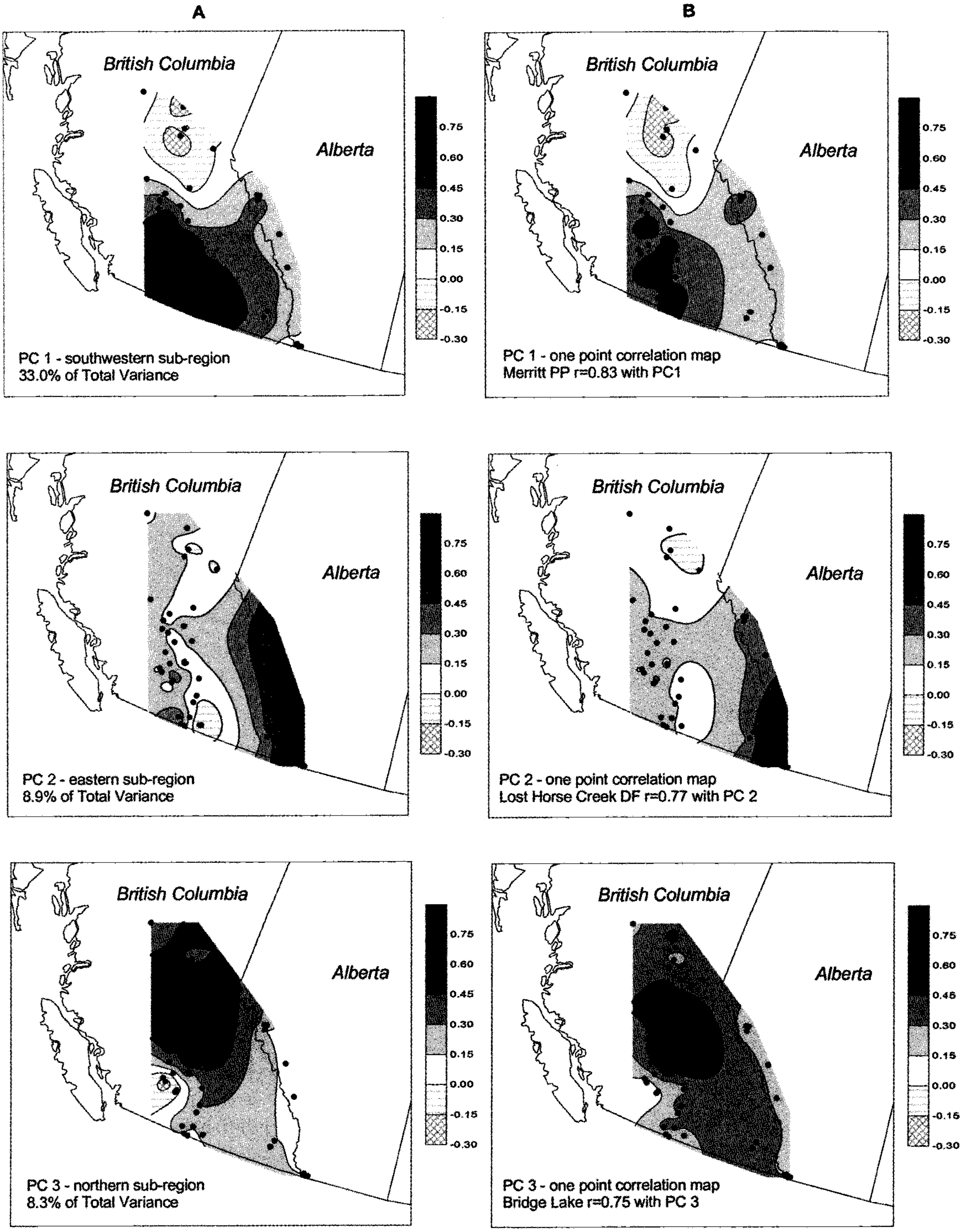

Figure 2. (A) Contoured loadings of the 53 RW chronologies on each of the three varimax rotated components extracted from the full 53 chronology network. The bold line is the 0.45 loading isoline and bounds the three sub-regions defined in this paper. (B) One point correlation maps calculated for the first three PCs retained from the RPCA of the full 53 chronology network. The thick line is the 0.45 correlation isoline. The chronology most highly correlated with each PC is listed along with the respective chronology-PC r value.

Table 3. Chronology loadings on the first three components retained from the RPCA conducted on the full 53 standard RW chronology dataset.

	PC 1	PC 2	PC 3
Merritt PP	0.83	0.08	−0.03
Shuttleworth Creek DF	0.82	0.11	0.16
Kettle River PP	0.79	−0.17	0.18
Fritts PP	0.76	0.09	0.28
Osoyoos DF	0.71	0.21	0.07
Naramata DF	0.67	0.25	0.18
Spatsum PP	0.67	0.42	0.07
Lytton DF	0.67	0.20	−0.22
Merritt DF	0.66	0.20	−0.04
Patriot DF	0.65	0.48	−0.08
Kettle River DF	0.62	0.06	0.36
Tranquille Df	0.61	0.02	0.56
Naramata PP	0.61	0.03	0.27
Tranquille PP	0.60	−0.08	0.45
Clinton PP	0.59	0.04	0.43
Bald Range PP	0.59	0.03	0.32
Skemeoskaunkin DF	0.59	0.29	0.09
Westwold PP	0.58	0.09	0.35
Patriot PP	0.57	0.51	0.06
Pavilion DF	0.57	0.28	0.38
Spatsum DF	0.54	0.31	0.28
Lillooet PP	0.53	0.13	−0.07
Lytton DF	0.47	0.38	−0.09
Keremeos DF	0.46	0.42	0.30
Westwold DF	0.46	0.11	0.29
Lillooet DF	0.45	0.41	−0.12
Perry Creek DF	0.43	0.34	0.23
Lost Horse Creek DF	0.11	0.77	0.03
Mt. Crandell	−0.05	0.76	−0.01
Golf Course	0.06	0.74	−0.03
Powerhouse	0.27	0.68	0.09
Two O'clock Creek	0.17	0.68	0.12
Ruby Ridge	−0.10	0.67	0.29
Chief Mt.	−0.03	0.66	0.22
Maligne Canyon	0.28	0.58	0.19
Lake Annette	0.16	0.56	0.23
Prairie de la Vache	0.38	0.55	0.16
Wasa Lake	0.33	0.55	0.16
Pyramid Lake	0.24	0.49	0.28
Bridge Lake DF	0.21	0.24	0.75
Deer Park	0.26	0.11	0.72
Lac la Hache	0.28	0.24	0.71
Gang Ranch	0.37	0.14	0.64
Horsefly Lake	−0.05	0.07	0.64
Indian Meadows	0.47	0.14	0.63
Bull Canyon	0.15	0.29	0.62
Clinton DF	0.56	0.18	0.58
Fort George	−0.31	0.20	0.54
Churn Creek	0.39	0.21	0.54
Coffeepot	−0.27	0.24	0.52
Dome Creek	0.00	−0.02	0.51
Prince George	0.04	−0.09	0.38
Pinchi Lake	0.13	0.13	0.32

ing (1) a promax rotation (k = 2) (an oblique rotation which permits intercorrelations between the rotated components (Richman 1986)), and (2) the prewhitened (*i.e.* residual) chronologies (results not shown). The loadings of the individual chronologies on the three components are mapped in Figure 2a and listed in Table 3; regional boundaries are represented by the bold 0.45 loading isoline. The subdivision of the chronologies essentially identifies an 'eastern sub-region' (Jasper, Banff, Cranbrook and Waterton chronologies; Principal Component (PC) 2); a 'northern sub-region' composed of the most northerly chronologies plus the majority of the chronologies sampled along the Fraser and Chilcotin Rivers north of Clinton (PC 3); and the remaining more southerly chronologies (PC 1—'southwestern sub-region'). This grouping broadly corresponds to sub-regional differences in site conditions, climate and topography across the area. The first two components from a T-mode Rotated Principal Components Analysis (RPCA) conducted on the full 53 chronology dataset represent an east-west and north-south pattern respectively and roughly correspond to the 'regions' identified in the S-mode analysis (Figure 4).

The component scores for the three sub-regional PCs are presented in Figure 3a. All three records show considerable evidence of low frequency trends indicating that, region by region, there are extended periods with growth above or below average. This low frequency variability is sometimes synchronous between regions but is often not. For example, both the eastern and southwestern series show long periods of increased or reduced growth which are in phase during the 1920s and out-of-phase during the 1990s. The northern sub-region appears to show greater interannual variability than the other two series. In the last 50 years, ringwidth has generally been increasing in the eastern and decreasing in the southern regions of the network (Figure 3a).

Evaluating the Regions Identified in the RPCA

Four tests were conducted to evaluate the regionalization of sites from the RPCA analysis.

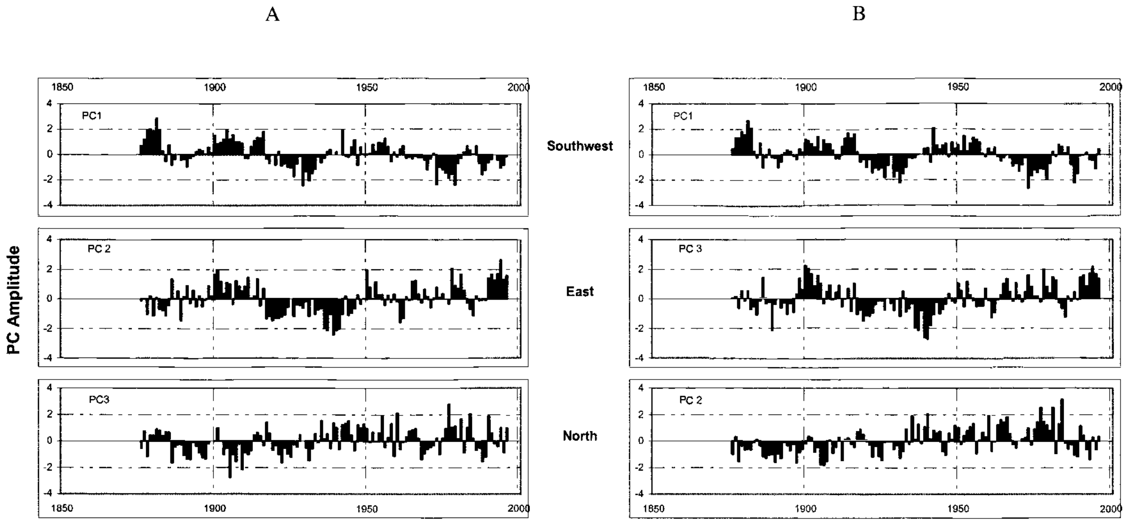

Figure 3. (A) Principal component scores (1876–1996) for the first three components retained from the RPCA performed on the full 53 RW chronology dataset. (B) Component scores for the first 3 PCs from an RPCA conducted on a reduced RW chronology dataset.

Correlation Fields

Point-to-point chronology correlation fields (or teleconnection patterns; Richman and Lamb 1985; Richman 1986) were developed by correlating the chronology loading most highly on each PC with the other 52 chronologies. These teleconnection patterns are plotted next to the corresponding PC in Figure 2b; the maps identify similar northern, southern and eastern groups. Correlation and congruence coefficients of ≥0.84 and 0.91 respectively indicate that the rotated PCs have "properly depicted" the patterns *and* magnitude of the modes of variation in the between-chronology correlation matrix from which they were derived (Richman 1986; Richman and Lamb 1985). Congruence coefficients can range from -1 to 1 but are biased to higher values than the corresponding correlation coefficients.

Temporal Subsets of the Data

In order to evaluate the temporal stability of the regions identified in the 53 chronology RPCA, the common interval was split into two ~60 year (1876–1936 and 1937–1996) halves and separate PCAs were computed. Although three 'regions' were identified in both subsets, the maps for the late interval (1937–1996; not shown) more closely resemble those for the full interval.

A southern region, corresponding to PC 1 in the full network (Figure 2a), is found in both the early and late subsets (congruence coefficients 0.91 and 0.92 respectively). The congruence coefficients between early PCs 2 and 3 (the eastern and northern sub-regions) and full period PCs 2 and 3 are 0.84 and 0.70, which can be viewed as "borderline" and "poor" matches respectively (Richman and Lamb 1985). The major differences are: (1) the chronologies in SW British Columbia load quite highly on early PC 2; and (2) the strongest loadings on PC 3 (the 'northern group') are found much further east.

These results suggest that the relationships between the chronologies change through time. Figure 5 displays correlations between the time series of the three PCs calculated for 30-year moving windows between 1876 and 1996 (values plotted on the central year). Over their full length, the three PCs are orthogonal, yet Figure 5 reveals that there are changes in the relationships between the chronology PCs through time. Given the demonstrated sensitivity of Douglas-fir and ponderosa pine chronologies from similar sites in the area to precipitation (Watson 1998), these changes may

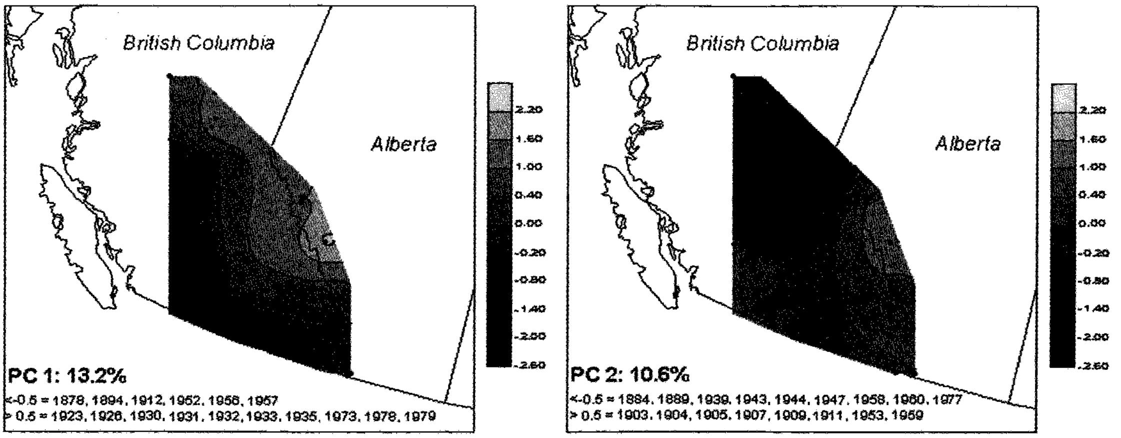

Figure 4. Contoured component scores for the first two components retained from a t-mode RPCA conducted on the full 53 RW chronology dataset. The thick line is the 0.0 isoline and percentage values indicate the percentage of total variance accounted for by each component. The years with loadings <−0.5 and >0.5 on each component are listed.

reflect changes in the spatial extent of dry or wet anomalies over time, which may be triggered by changes in larger-scale circulation anomalies. It is also possible that the variability is related to differences in the spatial scale of wet as opposed to dry anomalies.

Spatial Subsets

Previous studies (*e.g.* Richman and Lamb 1985) have subdivided the spatial domain used in their PCA and conducted separate PCAs to verify patterns identified in similar analyses carried out for the full domain. The chronologies were divided into northern and southern groups (> and <51°00′N) and separate RPCA were conducted on each group. Based on the scree test, two PCs (varimax rotated) were retained for both the northern and southern datasets (not shown). Overall, the two subsets identified the north-western chronology group (full dataset PC 3; Figure 2a); the eastern groups centred around Jasper, Waterton and the isolated Prince George site (full dataset PC 2); and the large group that spans most of the southern interior (full dataset PC 1).

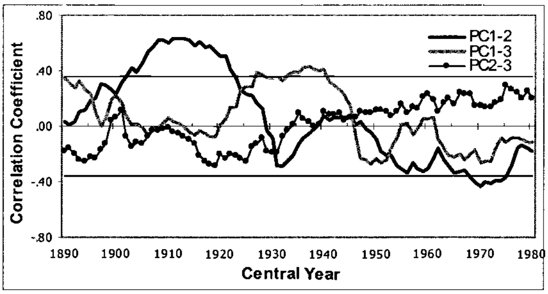

Figure 5. Correlations between the three PCs derived from the full length of the 53 chronology dataset through time. Values were calculated using a 30 yr moving window and are plotted at the central year. The solid horizontal lines denote statistical significance at the 0.05 level.

An additional test of the spatial patterns identified in the complete dataset RPCA was conducted by performing separate RPCAs on the eastern and western halves of the network. The eastern group included all Alberta sites plus the two Cranbrook sites. The initial PCA of these 13 chronologies was dominated by the clusters in Jasper and Waterton. When each of these clusters were represented by a single PCA series only a single PC was identified (loadings ranged from 0.62 to 0.87), indicating that the chronologies in the eastern 'region' (as defined here) exhibit coherent tree growth anomalies and do not split into separate northern and southern groups.

The 40 chronologies in the western group were also subjected to RPCA (not shown). The western region split into a northern, central and southern group with some overlap between the central and northern region. The central region coincides with the area of overlap between the southern and northern groups (PCs 1 and 3) identified in the original 53 chronology PCA (Figure 2a). Given the overlap in the centre of this western dataset, the northern and southern regions identified in the original RPCA for the full dataset (Figure 2a) appear to provide a reasonable approximation of regions of coherent tree-growth.

Reduced Dataset Analysis

Due to the natural distribution of appropriate tree-ring sites, chronologies in tree-ring networks tend to be unevenly distributed with dense clusters of chronologies in some regions and none in others. Karl *et al.* (1982) noted that irregularly spaced data can introduce errors that affect the spatial patterns in eigenvectors extracted using PCA. Gridding of either the climate data to be reconstructed (*e.g.* Cook *et al.* 1996; 1999) or the tree-ring chronologies themselves (*e.g.* Meko *et al.* 1993) has been used successfully to minimize problems associated with spatial bias in dendroclimatic studies. However, prior to gridding, tree-ring chronologies should be evaluated to ensure that they are responding primarily to a common factor (*e.g.* precipitation); otherwise the grid will not exclusively represent one variable and will therefore complicate subsequent spatial analyses.

The overall distribution of chronologies displayed in Figure 1 is very 'patchy'. There is a large gap in the area south and immediately west of the Rocky Mountain trench that runs from NW to SE though the area. This 'gap' results from the natural distribution of Douglas-fir and ponderosa pine plus the presence of large lakes that occupy many valley floor sites in this intervening area. In some areas, chronologies are clustered within a relatively small area (sometimes with both species sampled at the same site) and tend to exhibit marked similarities in annual growth through time (*e.g.* the four chronologies in the Jasper area). A two-step method was used to try and eliminate any bias resulting from these 'localized clusters' in the data set.

The objective of the first step is to identify clusters (or subgroups) on the chronologies that covary similarly and re-express them as an individual series so that they do not dominate PCA analysis. Eder *et al.* (1987) suggest that the "best method" to produce single summary scores for subgroups is to take the first component from a separate PCA conducted for each subgroup. Based on an examination of clusters of proximal chronologies (*e.g.* Jasper) and from sites where both Douglas-fir and ponderosa pine were sampled, nine clusters were delineated. A cluster analysis (Johnston 1991) set to identify nine clusters grouped the chronologies in virtually an identical manner. PCA was used to generate a single time series for each of the nine clusters. These nine time series were input into a subsequent PCA along with the remaining chronologies to identify the larger scale associations within these chronology data.

Table 4. Correlations (1876–1996) between the component scores derived from the full 53 chronology dataset and the reduced (red.) chronology dataset.

	Full PC1	Full PC2	Full PC3
Red. PC1	0.935	0.060	0.238
Red. PC2	−0.186	0.018	0.803
Red. PC3	0.006	0.926	−0.022

Again, three components were retained and subjected to a varimax rotation. The results of this analysis are almost identical to those described for the original RPCA except that more of the variance (58.5%: 50.2%) in the original dataset is explained due to the elimination of noise. A northern, southern and eastern group are clearly identified. The largest differences between the two analyses is that the northern group of chronologies in the reduced analysis do not extend as far south (the chronologies located along the Fraser and Chilcotin north of Clinton are excluded). This difference may occur because these chronologies have a very strong common variance (mean r = 0.61) and may therefore have biased the original analysis. Regardless, the time series of the first three regions both the full and reduced analyses (Figures 3a and 3b; Table 4) are remarkably similar suggesting the three regions defined by these two analyses are very similar.

Conclusions About the RPCA Regionalization

The regions identified in the full chronology RPCA appear to be quite robust as similar regions

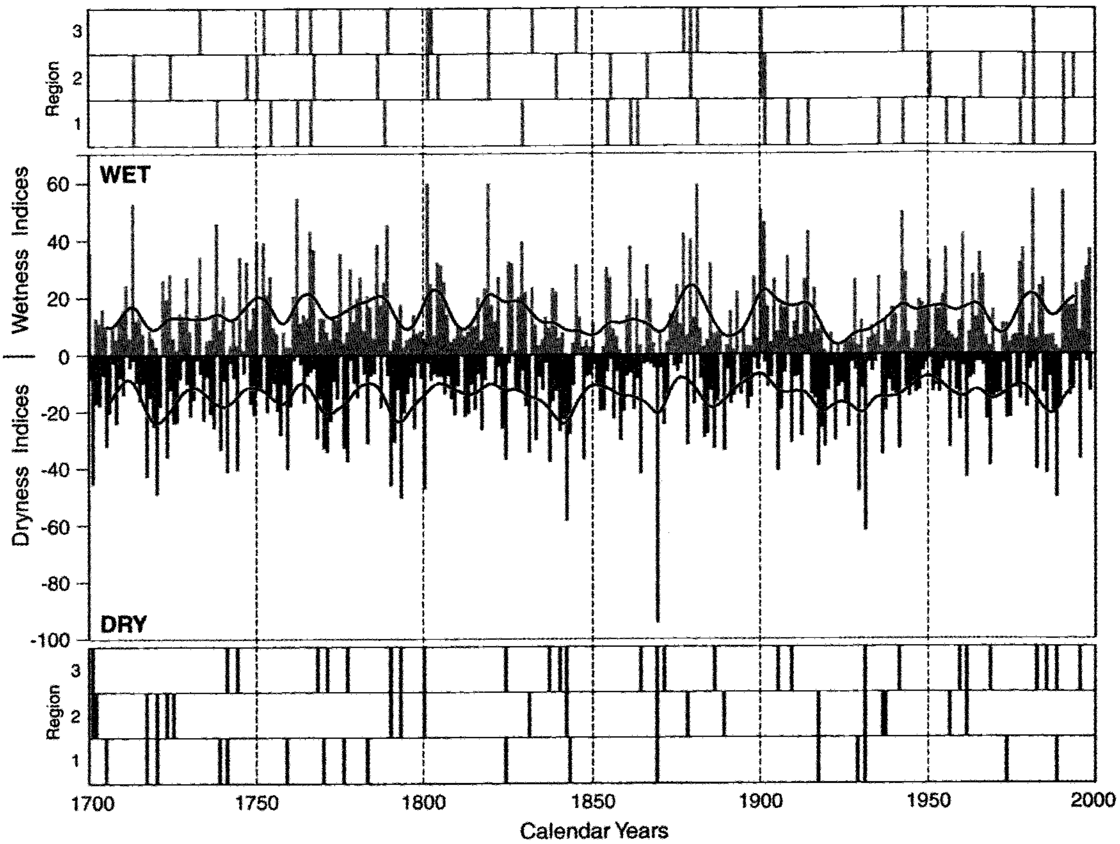

Figure 6. Summary wetness and dryness indices (1700–1996) for the full region. The thick line through the series is a 15 year filter which emphasizes lower frequency variations. The vertical lines in the plots above and below the time series indicates years when the standardized ring-width anomalies of 50% or more of the chronologies in the specified region were >1 SD above ('wet') or below ('dry') the mean. Regions 1, 2 and 3 refer to the southwestern, eastern and northern sub-regions identified in the full chronology RPCA (Figure 2a). Note that sample depth decreases from 53 chronologies in 1996 to 39 in 1700.

emerge in the four verification procedures outlined above. The lowest loadings are for the northern chronologies of Prince George and Pinchi Lake. The fact that many chronologies load quite highly on more than one component suggests that transitions between 'regions' are not abrupt and are likely complicated by the slightly different responses of the Douglas-fir and ponderosa pine chronologies (see Watson 1998). The results also reveal variations in the spatial groupings of chronologies over time which probably reflect shifting patterns of precipitation. However, the identification of coherent regional groupings is encouraging because it demonstrates that site specific conditions are not the dominant control of tree growth. Future analyses of the instrumental climate records and assessment of the climate signal in the individual tree-ring chronologies may help explain and evaluate these chronology groupings.

Preliminary Analysis of Extreme Years in the Chronology Network

A complete analysis of the climate signal contained in these chronologies is in progress. Nevertheless, a cursory analysis of the extreme years in these chronologies can be used to (1) derive some preliminary observations about the spatial and temporal variability of tree growth across the

Table 5. The most extreme years based on the analysis of marker rings. Years after 1550 where the regional index is ≥50% plus the most extreme year prior to 1550 are listed. Values represent the percentage of chronologies in each of the three subregions and the full region overall which display extreme wide or narrow rings (>1 SD from the chronology mean) in selected years. N indicates the number of chronologies available in the network for the specified year. The years that are bold are mapped in Figure 7.

Percentage of Chronologies Wide						Percentage of Chronologies Narrow					
Year	Southwest	East	North	Full	N	Year	Southwest	East	North	Full	N
1632	52.9	75.0	88.9	72.3	31	**1869**	**100.0**	**83.3**	**100.0**	**94.4**	**52**
1654	40.0	83.3	70.0	64.4	35	1639	94.4	80.0	100.0	91.5	35
1572	88.9	33.3	60.0	60.7	19	1593	71.4	66.7	85.7	74.6	26
1881	70.4	50.0	57.1	59.2	53	1657	40.0	83.3	70.0	64.4	36
1819	80.8	50.0	46.2	59.0	51	1931	63.0	50.0	71.4	61.5	53
1801	**68.0**	**83.3**	**23.1**	**58.1**	**50**	1842	44.4	66.7	61.5	57.5	52
1990	25.9	66.7	78.6	57.1	53	1634	29.4	75.0	66.7	57.0	32
1762	66.7	50.0	50.0	55.6	45	1629	70.6	25.0	66.7	54.1	31
1697	85.0	28.6	50.0	54.5	39	1793	28.0	54.5	69.2	50.6	49
1551	44.4	66.7	50.0	53.7	15	1627	29.4	100.0	22.2	50.5	31
1713	45.5	42.9	66.7	51.7	41	1988	59.3	25.0	64.3	49.5	53
1900	55.6	75.0	21.4	50.7	53	**1929**	**74.1**	**33.3**	**35.7**	**47.7**	**53**
1942	74.1	16.7	57.1	49.3	53	1554	33.3	100.0	0.0	44.4	16
1960	**14.8**	**25.0**	**85.7**	**41.8**	**53**	**1741**	**60.9**	**12.5**	**58.3**	**43.9**	**43**
1978	**3.7**	**100.0**	**7.1**	**36.9**	**53**	1961	3.7	75.0	50.0	42.9	53
1474	75.0	50.0	100.0	75.0	8	1489	67.0	100.0	100.0	89.0	8

Southern Cordillera beyond the common interval used in the RPCA and (2) assess their potential to reconstruct paleo-preciptation patterns. Individual wide or narrow "marker" rings that are temporally synchronous within and between chronologies suggest a common forcing of tree growth. Based on previous work with these species in this region (Watson 1998; Watson and Luckman 2001), these common marker rings are most likely related to precipitation and are probably indicative of extreme wet and dry years.

The 53 prewhitened (*i.e.* residual) RW chronologies were converted to z-scores and marker rings were defined as those years >1 standard deviation (SD) above or <1 SD below the mean in each series. These marker rings were used to develop a series of "wetness" (wide rings) and "dryness" (narrow rings) indices that could be used to derive spatial and temporal patterns. Wet and dry indices were initially developed for each of the three regions identified by the RPCA of the full dataset (Figure 2a; Table 3). For each region the number of chronologies showing wide and narrow rings were summed for each calendar year. Cook *et al.* (1997) developed a "drought area index" for the continental US from their gridded PDSI reconstructions (Cook *et al.* 1996, 1999) in a similar manner. Regional wetness and dryness indices were computed by converting these totals to percentages to adjust for differences in the number of chronologies available for each year (Figure 6). The summary indices for the full network were developed as the average of the regional indices (*e.g.* summary wetness index = (region 1 + region 2 + region 3)/300). Calculating the summary indices in this way reduces bias due to the differing numbers of chronologies in each region.

Figure 6 summarizes the occurence of extreme years in the complete network from 1700– 1998. Annual wetness and dryness indices are plotted for the entire chronology network, plus a summary of those years in which >50% of the chronologies in each region exhibit extreme wide or narrow rings ('wet' or 'dry' years). Both wide and narrow marker rings are remarkably synchronous within chronologies from within the same region and often across regions (*e.g.* 1869 and 1981, Figure 6). At the largest scale, examination of the wetness/dryness index for the full region clearly shows several periods of spatially extensive wetter and

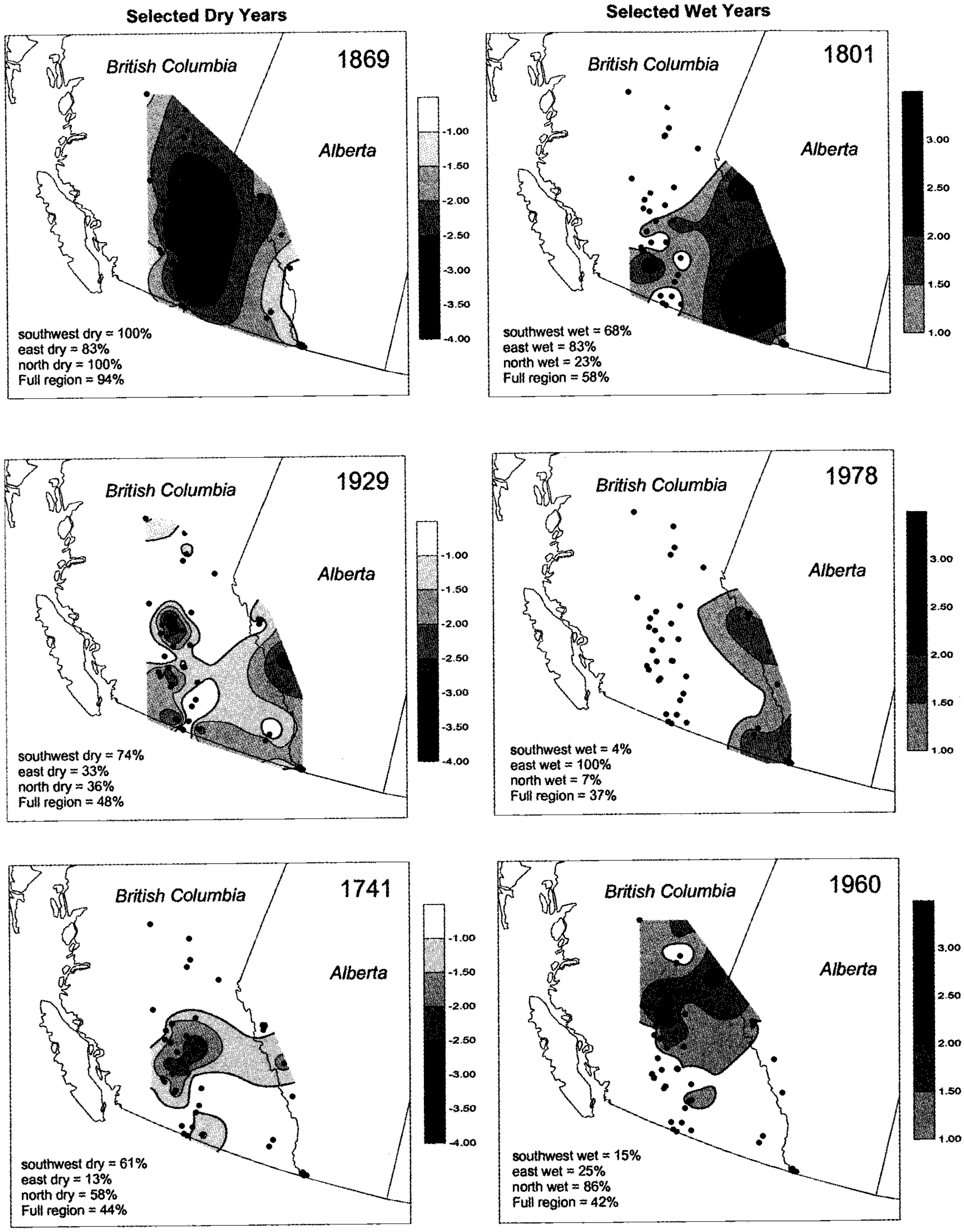

Figure 7. Plots of standardized ring-width anomalies (prewhitened chronologies) for selected individual years.

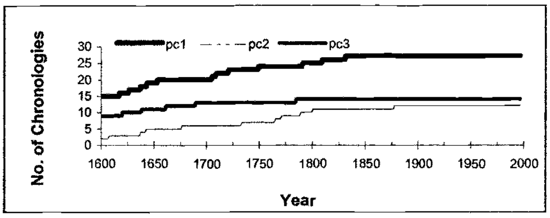

Figure 8. Sample depth through time (1600–1996) in the three sub-regions identified in the RPCA conducted on the full 53 chronology dataset. PCs 1, 2 and 3 are the southwestern, eastern and northern sub-regions.

drier conditions throughout the record. For example the 1760s, 1790s, 1840s and 1920-1940 have several very dry years while the 1800–1830s, 1870s, 1980–1990s were generally wetter. However, more detailed analysis indicates that these variations are not necessarily synchronous across the southern Cordillera and that variations occur within the sub-regions identified by the RPCA.

Examples of some of the most extreme years are given in Table 5 and Figure 7 where the actual z-scores of the residual chronologies are mapped to show both the distribution and intensity of these extreme values. The most extreme year in the network is 1869 where 50/52 chronologies are >1 SD below the mean (32 > 2 SD). Interestingly, Stockton and Fritts (1973) reconstructed very low water levels for Lake Athabasca in northeastern Alberta for the three year interval 1866–1868. The years 1489, 1593, 1639 and 1931 also showed a pattern where over half the sites in each region were dry (Table 5). Although there are many fewer chronologies in the earliest part of these records (Table 5, Figure 8), the coherence of the signal across the network in these years indicates that these were probably also quite severe events. Figure 7 also shows examples of years with more regional droughts: the "southern" area in 1929 and a central area (east and west) in 1741. Differing patterns of sub-regional drought can also be seen in the regional dryness records (Figure 6).

The wetness indices show similar diversity of patterns though there are fewer examples of very strong signals across the region. 1881, 1819, and 1801 (Figure 7) are the "wettest" years overall in the last three centuries and show slightly different patterns; 1801 was the most extreme in the southern part of the network (Figure 7; Table 5). Examples of more regionally wet years include 1978 (wet in the east) and 1960, which was wet in the more northern sites (Figure 7).

SUMMARY AND CONCLUSIONS

A network of 53 RW chronologies has been developed from 43 low-elevation, open grown sites in the southern Canadian Cordillera. EW and LW chronologies were also developed for 28 of these sites. Seventy-four and fifty-one percent of the chronologies in the network extend back to 1700 and 1600, respectively. On average, the Douglas-fir and ponderosa pine chronologies display similar mean summary statistics (mean sensitivity, autocorrelation, etc.) which closely resemble those from other Douglas-fir and ponderosa pine chronologies within the area that have been used to develop high-quality precipitation reconstructions (Watson 1998; Watson and Luckman 2001). The EW chronologies are generally similar to their RW counterparts because most of the annual ring is EW. The LW chronologies, however, display much higher year-to-year variability (as measured by standard deviation and mean sensitivity) and lower autocorrelation and are not reliable as far back in time as their RW and EW counterparts (based on EPS).

Further analysis of the relationships (coherence) between the chronologies in the RW chronology network were explored using RPCA and an analysis of extreme marker rings. The RPCA identified three regions of coherent tree growth variability: a northern, southwestern and eastern group. The robustness of these groupings was verified through a reduced dataset analysis, separate RPCAs for temporal and spatial subsets of the full dataset and through an assessment of correlation fields. Very similar groups were also identified using prewhitened versions of the 53 RW chronologies. The evaluation of extreme marker rings also identified years with common growth anomalies shared between many of the chronologies (*e.g.* 1869 was narrow in 50/52 chronologies). Examination of the preliminary chronology data from this network and the patterns of marker rings demonstrate that there is both complex and systematic variation of ring-width across this region that indicates a strong climate (likely precipitation) control of ring-width variability. This occurs at a wide range of both temporal and spatial scales that appear appropriate for the reconstruction of precipitation patterns from this chronology network. Ultimately, the larger scale temporal and spatial patterns recovered from this network may be related to the atmospheric and oceanic circulation patterns that influence precipitation patterns over this region.

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