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LIBOCEDRUS BIDWILLII TREE-RING CHRONOLOGIES IN NEW ZEALAND[1]

LIMIN XIONG

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ABSTRACT

Twenty-three *Libocedrus bidwillii* (New Zealand cedar) tree-ring chronologies have been developed from New Zealand. This total consists of twelve new sites collected by the authors and eleven previously collected by others (five of which we have updated and six of which were not). Standardization of the tree-ring series from each site used a double detrending method (linear-exponential or linear regression or a horizontal detrending plus spline detrending fitted to 2/3 the length of each tree-ring series). ARSTAN modeling using the Aikaike Information Criterion (AIC) to determine the filter model removed all significant autocorrelations from the residual chronologies. The average chronology length is around 500 years, and the sites are spread over 8° of latitude (i.e., 38° - 46°S) and nearly 1000 m in elevation (i.e., 244 - 1220 m.a.s.l.). The species tends to grow slowly (mean ring-width 0.7 mm), and the tree rings have a high autocorrelation value (0.79). The average mean sensitivity was 0.17, and the average mean correlation between all radii within chronologies was 0.55. Comparison of the chronologies showed a highly consistent and significant pattern among most of the sites. There was a reduction in interchronology correlation with separation distance; however, there was no clear relationship, or an effect, due to elevation. The spatial extent and temporal length of the network of sites offers the most comprehensive opportuntiy for New Zealand climate reconstruction to date.

INTRODUCTION

In New Zealand, early dendrochronological research was largely unsuccessful, and a pessimistic attitude developed toward this technique (Bell 1958; Bell and Bell 1958; Cameron 1960; Franklin 1969; Scott 1964, 1972; Wardle 1963; Wells 1972). However, since the mid-1970s, modern dendrochronological techniques have been successfully applied to mesic forest trees in New Zealand (Norton and Ogden 1987). Initial sampling concentrated on seven coniferous species with 21 chronologies produced (Dunwiddie 1979; LaMarche et al. 1979). Additional chronologies have been developed subsequently for *Agathis australis* (Ahmed 1984; Ahmed and Ogden 1985; Fowler 1984; Palmer 1982;), *Nothofagus solandri*, *N. menziesii* (Norton 1983b, 1983c), *Phyllocladus trichomanoides*, and *P. glaucus* (Palmer 1989). Up to 1992, 72 modern and two subfossil chronologies had been produced from nine species (Norton and Palmer 1992).

Libocedrus bidwillii is widely distributed throughout New Zealand and is one of the main species from which chronologies have been developed (Norton and Palmer 1992). The longest chronology was also from this species and extended back to A.D. 1256. This has been further extended to reach A.D. 1140. Prior to now, eleven chronologies had been established from this species by LaMarche et al. (1979) and Norton (1983a). This paper discusses the development of a *Libocedrus bidwillii* chronology network from 23 sites. The total is made up of twelve new sites, five updated sites, four nonupdated sites sampled by LaMarche et al. (1979), and two nonupdated sites sampled by Norton (1983a).

SITES AND SAMPLING

The most appropriate regions for dendroclimatic investigations tend to be those where trees grow at or near their climatic distribution limit and where climatic factors strongly affect tree-ring variability without being so strong that virtually no growth occurs. Another favored approach has been the selection of the oldest possible trees. In this study, site selection concentrated, as far as possible, on mature forests in which no previous logging or other type of disturbance was known to have occurred. A few of the stands (such as HIT, TKP, TOC; Table 1) contained some dead trees, while other sites (such as FLG, WBF) largely consisted of younger trees. The locations of the sites are shown in Figure 1, and the corresponding site characteristics are summarized in Table 1.

Tree selection for coring followed the widely used practice of avoiding those that were deformed, damaged, or growing close to large neighbors. Because old and large trees often had narrow outer rings which created crossdating difficulties, some younger trees (with relatively small diameters) were also cored at each stand. Two or three increment cores each were taken from 20 to 30 trees at each site.

Table 1. Characteristics of 23 *Libocedrus bidwillii* chronology sites.

Abbr.[1]	**Site Name**	**South Latitude**	**East Longitude**	**Elevation (m)**
Nonupdated Sites				
ARM[2]	Armstrong Reserve	43°50'	173°00'	731
CRC[3]	Cream Creek	43°05'	170°59'	800
CRG[2]	Mount Cargill	45°50'	170°32'	576
MWO[2]	Mangawhero R. B.	39°21'	175°29'	1000
OKA[2]	Owaka	46°23'	169°27'	305
TRK[3]	Tarkus Knob	43°05'	170°58'	925
Updated Sites				
AHA[2]	Ahaura	42°23'	171°48'	244
EMT[2]	Mount Egmont	39°15'	174°05'	1050
NET[2]	North Egmont	39°17'	174°06'	991
TKP[2]	Takapari	40°04.3'	175°59'	838
UWR[2]	Urewera	38°40.7'	177°11.8'	854
New Sites				
CLW	Clear Water	39°37.5'	176°06.3'	1220
FLG	Batten Range (Flanagans Hut)	41°16.3'	172°35.5'	950
HIT	Hihitahi	39°32'	175°44'	976
MOA	Moa Park	40°56'	172°56'	1036
OHT	Ohutu Ridge	39°37.3'	176°07.7'	1140
RUC	Ruahine Corner	39°38.2'	176°10.7'	1200
RUH	Rahu Saddle	42°18.95'	172°07'	672
STR	Stratford Side (East Egmont)	39°18.5'	174°07.25'	860
TOA	Hauhungatahi site A, Tongariro	39°14'S	175°26'	1160
TOB	Hauhungatahi site B, Tongariro	39°14'S	175°26'	1100
TOC	Hauhungatahi site C, Tongariro	39°14'S	175°26'	1000
WBF	Wilberforce	43°04'S	171°16.5'	780

[1] Sources
[2] LaMarche et al. 1979
[3] Norton 1983a

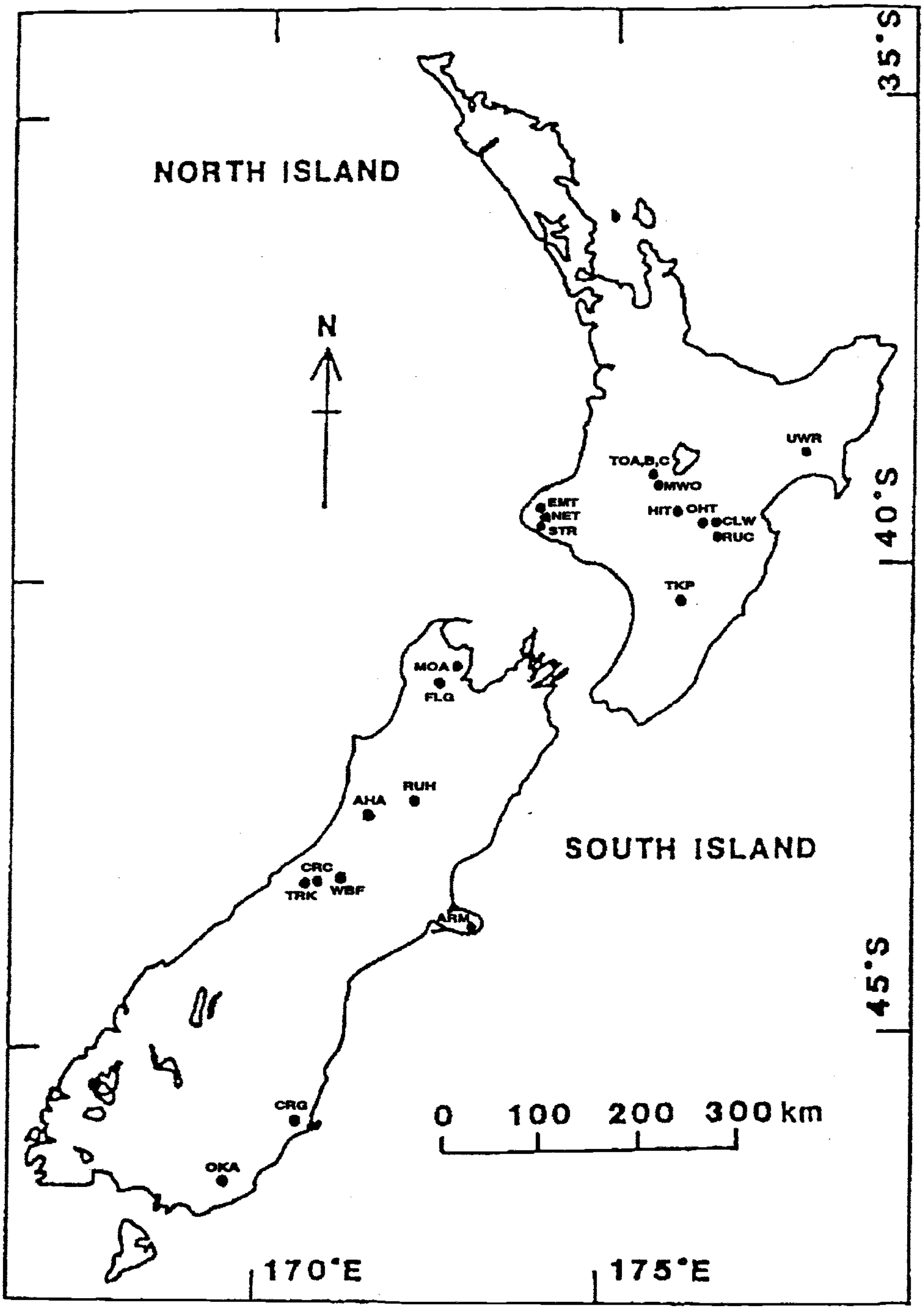

Figure 1. The locations of the *Libocedrus bidwillii* chronology sites. Site codes are given in Table 1.

CROSSDATING AND MEASUREMENTS

Core mounting and sample preparation followed standard procedures (Stokes and Smiley 1968). Cores from each site were examined under a binocular microscope, and visual crossdating was attempted. "Marker" years (some very narrow or wide years) were used to help with crossdating. All the cored sites have been successfully crossdated. This is in contrast to the success rate of LaMarche et al. (1979), where only 9 out of 23 (or c. 40 percent) *Libocedrus bidwillii* sites they sampled were able to be crossdated. The improvement in success is thought to be attributable to two main factors. The first is improved technological support, with crossdating software like COFECHA (Grissino-Mayer et al. 1992; Holmes 1983; Holmes et al. 1986) being readily available. Such software does not replace manual crossdating (and was never intended to) but does greatly assist the process. The second factor for the higher success rate is thought to be greater ecological understanding of the species. *Libocedrus bidwillii* is well known for its cohort stand dynamics (Ogden and Stewart 1995; Veblen and Stewart 1982) resulting in patches of trees showing senescence and die-back. Consequently, in many old stands, there is a noticeable suppression of growth in the outer (recent) portion of the trees. As mentioned earlier, to overcome this troublesome period for crossdating, younger trees from the same stands were also cored. Such an improved success rate implies that there is a need to review the earlier collections by LaMarche et al. (1979) and revisit some of the unsuccessful sites.

On average, around 80 percent of cores collected from the sites were able to be crossdated. Some cores were rejected because they had indistinct ring boundaries or weakly crossdated with others from the same site. Because the growing period of trees in New Zealand begins in one calendar year and ends in the next, rings were assigned to the year in which growth commenced (Schulman 1956). Ring widths were measured to the nearest 0.01 mm using a computer-based measuring system and program TRIMS (Madera Software 1988).

In order to check the quality of the tree-ring measurements, at least three cores were randomly picked from each site and remeasured. Following this, the program in ITRDBLIB (Grissino-Mayer et al. 1992) was used to check the measurements. Eighty-six percent of the remeasured cores were accepted at the 0.01 level, while all cores were accepted at the 0.05 level.

The strength of the crossdating between cores and trees was evaluated using program COFECHA (Grissino-Mayer et al. 1992; Holmes 1983; Holmes et al. 1986). Table 2 gives the general COFECHA statistics for all the sites. It includes the number of cores and trees, the chronology period, mean correlation with the Master Dating Series, unfiltered data series statistics, and filtered data series statistics. The table includes six sites that used the original measurements of LaMarche et al. (1979) and Norton (1983a). The five updated sites include the data series measured by LaMarche et al. (1979) and our new data. Based on correlations with the Master Dating Series (the default correlation coefficient 0.32 in COFECHA was used as a threshold), some cores were rejected from several sites. In all updated sites, the new cores had very high correlations with the original data series (all significant at 0.01 level).

Table 2. Descriptive COFECHA statistics for 23 chronology sites.

Site[1]	Total Trees / Cores (no. in parentheses refer to the contribution by this paper)	Period	Mean Corr. With Master	Mean Msmt	Max Msmt	Std Dev	Auto Corr	Mean Sens
AHA[*,2]	32 (15) / 59 (26)	1525 - 1992	.511	.60	4.35	.312	.818	.228
ARM[#,2]	22 / 46	1446 - 1958	.644	.81	2.92	.327	.775	.222
CLW	(18 / 45)	1450 - 1991	.516	.69	2.78	.288	.787	.212
CRC[#,3]	15 / 25	1460 - 1978	.464	.58	2.99	.282	.792	.263
CRG[#,2]	12 / 43	1492 - 1975	.598	.89	2.61	.324	.793	.197
EMT[*,2]	22 (8) / 60 (12)	1616 - 1990	.618	.98	3.06	.391	.727	.241
FLG	(20 / 33)	1683 - 1991	.560	.79	3.00	.299	.734	.209
HIT	(49 / 52)	1431 - 1991	.536	.68	3.80	.297	.770	.255
MOA	(20 / 49)	1490 - 1991	.540	.47	2.26	.228	.838	.222
MWO[#,2]	19 / 69	1464 - 1976	.527	.50	2.80	.211	.780	.199
NET[*,2]	35 (10) / 69 (16)	1625 - 1990	.597	.79	3.63	.353	.806	.232
OHT	(17 / 40)	1585 - 1991	.546	.82	3.72	.317	.773	.203
OKA[#,2]	14 / 47	1732 - 1976	.566	.99	3.42	.419	.815	.212
RUC	(29 / 73)	1473 - 1991	.545	.71	2.59	.282	.780	.208
RUH	(20 / 40)	1560 - 1992	.514	.52	2.96	.285	.811	.247
STR	(7 / 11)	1626 - 1990	.489	.94	3.15	.380	.798	.214
TKP[*,2]	37 (11) / 63 (17)	1256 - 1992	.590	.66	3.07	.308	.820	.222
TOA	(25 / 43)	1511 - 1992	.545	.60	2.74	.249	.755	.215
TOB	(15 / 27)	1332 - 1992	.569	.50	2.65	.249	.820	.235
TOC	(14 / 24)	1213 - 1992	.477	.56	2.34	.291	.806	.266
TRK[#,3]	21 / 27	1526 - 1978	.527	.53	2.44	.248	.737	.267
UWR[*,2]	38 (14) / 68 (29)	1140 - 1992	.593	.55	2.44	.266	.805	.256
WBF	(15 / 31)	1674 - 1992	.556	.98	3.51	.374	.719	.216

[1] Site status
* Updated
# Nonupdated

[2] LaMarche et al. 1979

[3] Norton 1983a

STANDARDIZATION

A major step in dendroclimatology is the standardization of the raw ring-width series. The type of standardization used depends on the nature of the data and the research objectives. Standardization was done by using the program ARSTAN (Cook 1985; Cook and Briffa 1990) to detrend and index the tree-ring series. In order to maximize the climate signal in the chronologies, a double detrending method of standardization (linear-exponential or linear regression or a horizontal detrending plus spline detrending fitted to two-thirds the length of each tree-ring series) was employed. This selection was based on the comparison of trends in the raw data and the instrumental climate records (Xiong 1995; Xiong and Palmer 1995, 2000).

Standardized tree-ring data often contain significant autocorrelations that violate the independence assumption necessary for most statistical analyses. All the chronology sites had significant autocorrelations (Xiong 1995) that needed to be removed before any climate reconstructions were attempted. Autocorrelation in the chronologies was removed by the ARSTAN program using the Aikaike Information Criterion (AIC) to determine the filter model. After filtering, no significant autocorrelation was left in the residual chronologies.

Standard and residual chronology statistics given in Table 3 are: mean sensitivity (MS), standard deviation (SD), lag-1 autocorrelation coefficient (AC1), expressed population signal (EPS), and signal to noise ratio (SNR). Most of these parameters are frequently used to assess dendroclimatological quality of tree-ring chronologies (Briffa and Jones 1990; Fritts 1976). In general, higher MS, EPS, and SNR indicate a greater climatic influence on tree growth. The removal of autocorrelations increased MS, EPS, SNR and decreased SD in nearly all the chronologies (Table 3). On average, MS is about 20% higher, EPS 5% higher, and SNR 20% higher in residual than in standard chronologies. EPS and SNR were lower only in the residual chronologies of sites CRG, RUH, and STR. Figure 2 shows the residual chronologies for all 23 sites.

Table 3. Descriptive statistics for the 23 *Libocedrus bidwillii* tree-ring chronologies.

Site	Period	Standard Chronology[1]					Residual Chronology[1]				
		MS	SD	AC1	EPS	SNR	MS	SD	AC1	EPS	SNR
ARM	1446 - 1958	.1602	.2202	.5643	.837	5.135	.1864	.1646	.0052	.859	6.074
CRC	1460 - 1978	.1659	.2885	.6608	.839	5.203	.0000	.1914	-.0267	.858	6.053
CRG	1492 - 1975	.1618	.2518	.7039	.849	5.608	.1924	.1715	.0208	.837	5.139
OKA	1732 - 1976	.1170	.1727	.6473	.799	3.982	.1482	.1290	-.0168	.853	5.817
TRK	1526 - 1978	.1763	.2350	.5761	.823	4.645	.2113	.1858	-.0557	.846	5.474
AHA	1525 - 1992	.1371	.2097	.6535	.865	6.405	.1556	.1396	-.0050	.888	7.914
EMT	1616 - 1990	.1493	.1835	.4795	.898	8.766	.1705	.1501	.0041	.919	11.41
MWO	1464 - 1976	.1158	.1549	.5616	.803	4.087	.1348	.1195	-.0048	.872	6.794
NET	1625 - 1990	.1440	.1858	.5106	.920	11.514	.1689	.1491	-.0131	.940	15.601
TKP	1256 - 1992	.1351	.2530	.7699	.933	13.842	.1758	.1568	-.0257	.939	15.408
UWR	1140 - 1992	.1705	.2466	.6053	.842	5.334	.1900	.1642	-.0045	.906	9.639
CLW	1450 - 1991	.1268	.2230	.7064	.862	6.224	.1641	.1557	-.0459	.896	8.579
FLG	1683 - 1991	.1236	.1848	.6067	.928	12.937	.1564	.1418	.0040	.934	14.080
HIT	1431 - 1991	.1399	.1976	.5830	.842	5.322	.1759	.1567	.0044	.842	5.322
MOA	1490 - 1991	.1269	.2112	.7139	.791	3.790	.1597	.1388	-.0187	.862	6.247
OHT	1585 - 1991	.1481	.2297	.5839	.863	6.277	.1867	.1837	-.0844	.895	8.505
RUC	1473 - 1991	.1230	.2046	.6778	.907	9.791	.1541	.1450	.0104	.921	11.719
RUH	1560 - 1992	.1589	.4198	.7334	.833	4.999	.1958	.1956	.0165	.832	4.949
STR	1626 - 1990	.1454	.2335	.6292	.643	1.801	.1755	.1690	-.0178	.607	1.543
TOA	1511 - 1992	.1301	.1969	.6237	.885	7.704	.1700	.1524	-.0272	.907	9.785
TOB	1332 - 1992	.1425	.2458	.7075	.811	4.286	.1875	.1720	.0052	.846	5.476
TOC	1213 - 1992	.1512	.2623	.6681	.734	2.766	.1865	.1842	-.0523	.775	3.454
WBF	1674 - 1992	.1406	.2336	.6667	.882	7.475	.1742	.1627	-.0414	.906	9.586

[1] Symbols

MS: Mean Sensitivity
SD: Standard Deviation
AC1: First Order Autocorrelation
EPS: Expressed Population Signal
SNR: Signal to Noise Ratio

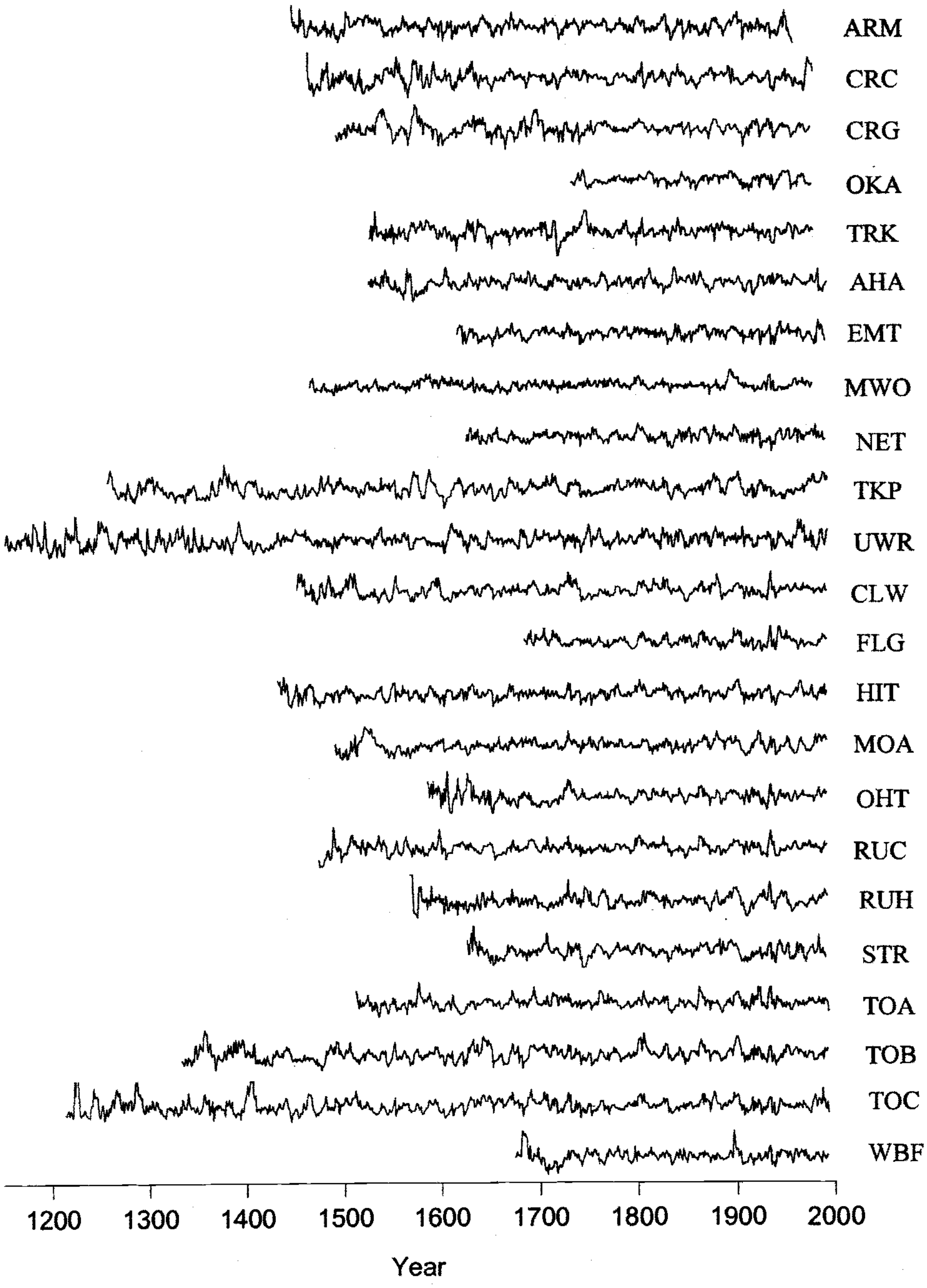

Figure 2. Time-series graphs of residual tree-ring chronologies. Chronology codes are explained in Table 1.

The average length of the chronologies is nearly 500 years and the mean correlation value among all the cores from each site is 0.55. Such values emphasize the potential of the species for climate reconstruction in New Zealand (Xiong and Palmer 2000) especially since earlier efforts to date have only extended back to the early A.D. 1700's (e.g., Salinger et al. 1994). However, this potential is not unique to *Libocedrus bidwillii*; several other species hold as greater promise but either lack spatial replication (such as pink pine, *Halocarpus biformis*; D'Arrigo et al. 1995), or have encountered some crossdating difficulties (such as kauri, *Agathis australis*). The EPS and SSS (Wigley et al. 1984) in Table 4 were calculated from the residual chronologies. The periods in which SSS exceeds 0.85 are given for reference for subsequent climate reconstructions. In order to retain SSS > 0.85 meant an average loss of 200 years from the early portions of the chronologies. The other point is that, on average, around six trees were needed to attain a SSS>0.85.

Table 4. Comparison of time periods and the number of trees where EPS and SSS are greater than 0.85.[1]

Site	**Chronology**	**EPS > 0.85**		**SSS > 0.85**	
	Time-span	**Period**	**N**	**Period**	**N**
ARM	1446 - 1958	1700 - 1869	11	1591 - 1941	5
CRC	1460 - 1978	1745 - 1978	12	1684 - 1978	6
CRG	1492 - 1975	N. A.	10	1754 - 1975	4
OKA	1732 - 1976	N. A.	10	1797 - 1976	5
TRK	1526 - 1978	1798 - 1978	14	1713 - 1978	7
AHA	1525 - 1992	1717 - 1976	14	1627 - 1976	7
EMT	1616 - 1990	1714 - 1975	9	1697 - 1987	6
MWO	1479 - 1976	1723 - 1976	16	1555 - 1976	8
NET	1625 - 1990	1677 - 1976	9	1670 - 1990	6
TKP	1256 - 1992	1539 - 1976	9	1459 - 1986	6
UWR	1140 - 1992	1433 - 1976	11	1390 - 1992	6
CLW	1450 - 1991	1700 - 1991	11	1616 - 1991	6
FLG	1686 - 1991	1751 - 1991	9	1718 - 1991	6
HIT	1431 - 1991	1497 - 1988	13	1457 - 1991	7
MOA	1490 - 1991	1624 - 1991	14	1556 - 1991	7
OHT	1585 - 1991	1756 - 1991	9	1713 - 1991	5
RUC	1473 - 1991	1611 - 1991	7	1609 - 1991	5
RUH	1560 - 1991	1779 - 1982	16	1660 - 1991	7
STR	1626 - 1990	N.A.	15	1670 - 1990	3
TOA	1511 - 1992	1646 - 1992	10	1597 - 1992	6
TOB	1332 - 1992	1578 - 1992	9	1445 - 1992	4
TOC	1213 - 1992	N. A.	16	1430 - 1990	6
WBF	1674 - 1992	1794 - 1992	8	1733 - 1992	5

[1] Symbols

EPS: Expressed Population Signal
SSS: Subsample Signal Strength
N: Minimum Number of Trees for EPS > 0.85 or SSS > 0.85
N.A.: EPS Did Not Exceed 0.85 for Any Period

INTERCHRONOLOGY CORRELATION

The interchronology comparison is based on the correlation matrix for the common period, A.D.1734-1958 (224 years), of all 23 chronologies. The cross correlations (Table 5) generally show a highly similar pattern between the chronologies. Most of the chronology correlations are significant at the 0.01 level. Site TRK, however, is noticeably different with nine of 22 crosscorrelations being nonsignificant at the 0.01 level. Two other South Island sites (AHA and CRC) also did not significantly crosscorrelate with other sites. The specific reasons for these sites' being "outliers" are unknown but the high crosscorrelation value between "outlier" sites TRK and CRC (0.765; Table 5) implies a strong regional influence.

Table 5. Cross correlations between the different chronologies for the common time interval, A.D. 1734-1958.

	ARM	CRC	CRG	MWO	OKA	TRK	AHA	EMT	NET	TKP	UWR	CLW	FLG	HIT	MOA	OHT	RUC	RUH	STR	TOA	TOB	TOC
ARM	1.0																					
CRC	.141	1.0																				
CRG	.535	.190	1.0																			
MWO	.305	.334	.264	1.0																		
OKA	.353	.218	.519	.255	1.0																	
TRK	.070	.765	.133	.276	.148	1.0																
AHA	.084	.237	.204	.246	.316	.168	1.0															
EMT	.425	.163	.450	.361	.375	.098	.249	1.0														
NET	.438	.287	.481	.361	.384	.248	.230	.739	1.0													
TKP	.459	.381	.332	.553	.281	.277	.216	.437	.467	1.0												
UWR	.401	.012	.360	.285	.322	-.052	.260	.572	.497	.347	1.0											
CLW	.449	.345	.361	.560	.237	.227	.209	.443	.422	.669	.445	1.0										
FLG	.373	.444	.301	.444	.369	.288	.403	.506	.469	.470	.353	.574	1.0									
HIT	.486	.300	.477	.580	.349	.175	.224	.577	.557	.729	.495	.683	522	1.0								
MOA	.461	.107	.427	.294	.363	.038	.348	.483	.463	.420	.450	.429	.430	.442	1.0							
OHT	.383	.318	.323	.615	.286	.263	.179	.400	.447	.573	.339	.819	.566	.622	.403	1.0						
RUC	.446	.335	.375	.653	.295	.223	.236	.512	.495	.648	.414	.856	.605	.738	.443	.827	1.0					
RUH	.303	.463	.312	.421	.407	.336	.680	.323	.321	.388	.261	.399	.570	.384	.503	.371	.396	1.0				
STR	.369	.246	.387	.415	.248	.126	.206	.707	.652	.516	.432	.515	.476	.545	.391	.469	.531	.332	1.0			
TOA	.429	.368	.425	.549	.303	.288	.271	.466	.487	.556	.305	.687	.602	.616	.474	.670	.716	.536	.436	1.0		
TOB	.467	.411	.427	.559	.305	.295	.220	.536	.606	.677	.390	.737	.582	.750	.453	.674	.742	.425	.529	.797	1.0	
TOC	.470	.367	.463	.576	.377	.243	.260	.622	.646	.688	.445	.668	.622	.760	.482	.604	.710	.470	.585	.713	.806	1.0
WBF	.225	.384	.261	.286	.255	.295	.096	.291	.326	.275	.155	.292	.414	.336	.109	.279	.330	.237	.215	.356	.319	.299
Sig.[1]	3	4	1	0	1	9	4	2	0	0	3	0	0	1	3	1	0	0	1	0	0	0

[1] Number of cross correlations not significant at 1% level for each site. The critical value for the 5% significance level is 0.138 and the 1% level is 0.181.

CHRONOLOGY CORRELATION AND SEPARATION DISTANCE

Following the approach used to analyze a group of European oak chronologies (Briffa 1984), the relationships between separation distance and the correlation coefficients were analyzed using simple regression. The fitted linear relationship for all points had an F value of 94.85 and was statistically significant at the 0.001 level (Table 6). By calculating linear regressions in successive steps, with points separated by progressively greater distances being included at each step (Table 6), it was shown that correlation decreases with distance (as measured by B, the slope of the line becomes less negative). Consequently, some transformations of distance were performed. When simple $\log_{10}$ transformation was used, the resulting F value for the regression between chronologies and the log of the separation distance for all points rose to 133.55. Repeating the regressions for the same steps as shown in Table 6, the slope of the line is more stable, indicating that the transformation was a reasonable one.

Table 6. Summary of simple regressions of correlation coefficients between chronologies and their separation distance for the period A.D. 1734 - 1958.

	F[1]	A[2]	B[3]	N[4]
Correlation Coefficient vs Separation Distance (km)				
All pairs (up to 1100km)	94.85***	.534	-.000035	253
Pairs separated by <300 km	66.62***	.658	-.00122	123
Pairs separated by <400 km	57.11***	.623	-.000864	146
Pairs separated by <500 km	86.70***	.599	-.000669	177
Pairs separated by <600 km	111.52***	.578	-.000530	218
Pairs separated by <700 km	113.74***	.573	-.000507	224
Correlation vs Log Transformed Separation Distance				
All pairs (up to 1100km)	133.55***	.875	-.196	250
Pairs separated by <300 km	39.89***	.873	-.194	120
Pairs separated by <400 km	45.30***	.863	-.188	143
Pairs separated by <500 km	76.76***	.890	-.203	174
Pairs separated by <600 km	112.09***	.894	-.205	215
Pairs separated by <700 km	117.81***	.893	-.205	221

[1] F-value with a * is significant at 0.05 level, with ** is significant at 0.01 level and *** is significant at 0.001 level

[2] A is the regression constant

[3] B is the slope

[4] N is the number of pairs included in the regression

The overall regression is given by:

$$Y = 0.875 - 0.196 \log_{10} X$$

where X is the separation distance, and Y is the correlation coefficient.

Figure 3 shows the correlation coefficients plotted against the distance between the sites. The correlation analysis of all 23 *Libocedrus bidwillii* sites shows that there is a significant relationship between correlation coefficients and distance. The strength of the correlations declined with increasing distance. However, this relationship is not entirely explained by the regression line, because at about 200-400 km, 700 km, and 800-900 km, the correlation coefficients obviously do not fit the curve. The correlation matrix shows these points to be associated with correlations between sites CRC, TRK, and other sites less than 500 km distant (as mentioned above these two sites have very low correlations with other sites). At 800-900 km distance, the correlations between site CRG and some North Island sites are very high, which implies a macroclimatic influence. Ahmed and Ogden (1985) reported that the regression curve of the correlation coefficient between each crossdated kauri (*Agathis australis*) chronology pair on their separation distance was not significant ($Y=0.467-0.000263X$; where Y is the correlation coefficient and X is the distance between sites, which is up to 350 km away; $r=0.224$, $n=55$, N.S.). Norton (1983a) showed that the regression of the correlation between each pair of timberline *Nothofagus solandri* chronologies and their distance apart was significant (the curve was: $Y=0.691-0.011X$, $r=-0.340$, $n=91$, $p<0.001$; the maximum distance between the sites was only about 14 km). The results presented here showed that only with a large sample size over a wide geographic distribution is any trend discernible. The lack of a significant pattern for *Agathis australis* (Ahmed and Ogden 1985) may be a constraint imposed by the species' more limited geographic distribution. However, the significant regression from *Nothofagus solandri* (Norton 1983a) would tend to imply that the response is highly variable and species specific.

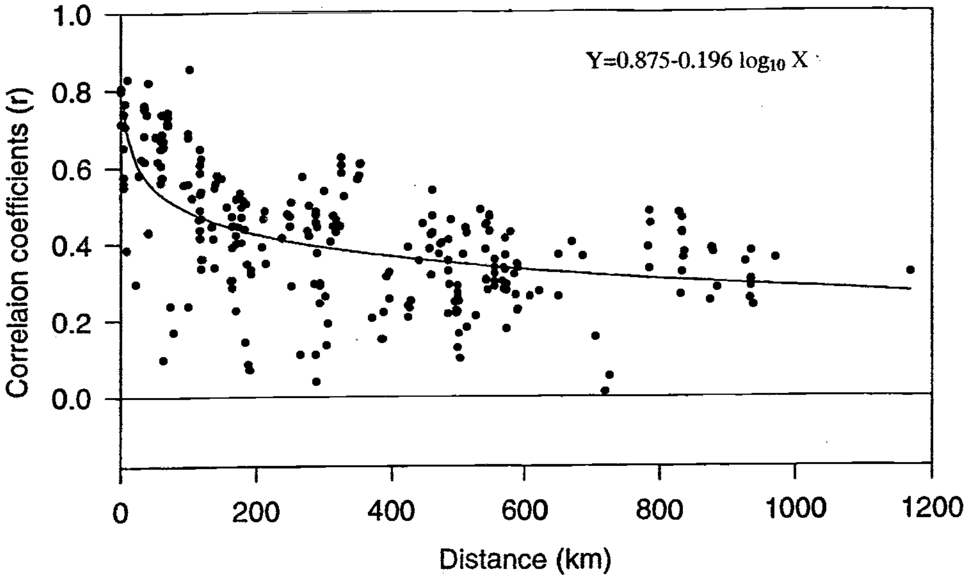

Figure 3. Correlation coefficient between chronologies plotted against their separation distance. The solid line is the fitted regression line.

THE INFLUENCE OF ELEVATION

The influence of elevation was evaluated in a manner similar to the study of the effect of separation distance. The interchronology correlations with elevation were investigated by looking at the significance of the regression (Table 7). The sharp decline in the slope of the regression line as pairs of sites are introduced with a difference of less than 300 m suggests that some transformation may be necessary. However, the log transformation does not improve the value and so is not used.

Table 7. **Summary of simple regressions of correlation coefficients between chronologies and their elevation difference between paired chronologies for the period A.D. 1734 - 1958.**

	F[1]	A[2]	B[3]	N[4]
Correlation vs Elevation Difference (m)				
All pairs (up to 1000m)	36.82***	.488	-.000265	253
Pairs < 100m	5.69*	.566	-.00252	56
Pairs < 300m	2.07	.485	-.000258	161
Pairs < 500m	5.90*	.481	-.000217	212
Correlation vs Log of Elevation Difference				
All pairs (up to 1000m)	25.36***	.682	-.118	252
Pairs < 100m	3.90	.749	-.191	55
Pairs < 300m	1.70	.557	-.0533	160
Pairs < 500m	4.91*	.582	-.0669	211

[1] F-value with a * is significant at 0.05 level, with ** is significant at 0.01 level and *** is significant at 0.001 level

[2] A is the regression constant

[3] B is the slope

[4] N is the number of pairs included in the regression

The best fitted linear relationship has an F-value of 36.82 (statistically significant at the 0.001 level). The overall regression is:

$$Y = 0.488 - 0.000265\,X$$

where X is the difference in elevation and Y is the correlation coefficient. Figure 4 shows the correlation coefficients plotted against the differences in elevation between the sites.

In general, no clear relationship was observed between ring width and elevation for *Agathis australis* either (Ahmed and Ogden 1985). Norton (1983a) did report a general reduction of autocorrelation and higher mean sensitivity and standard deviation with increasing elevation. Our analysis shows that the correlation values have a large range when the elevation is similar. This may be because the sites are from different latitudes and longitudes and other environmental factors (such as rainfall) have a stronger influence.

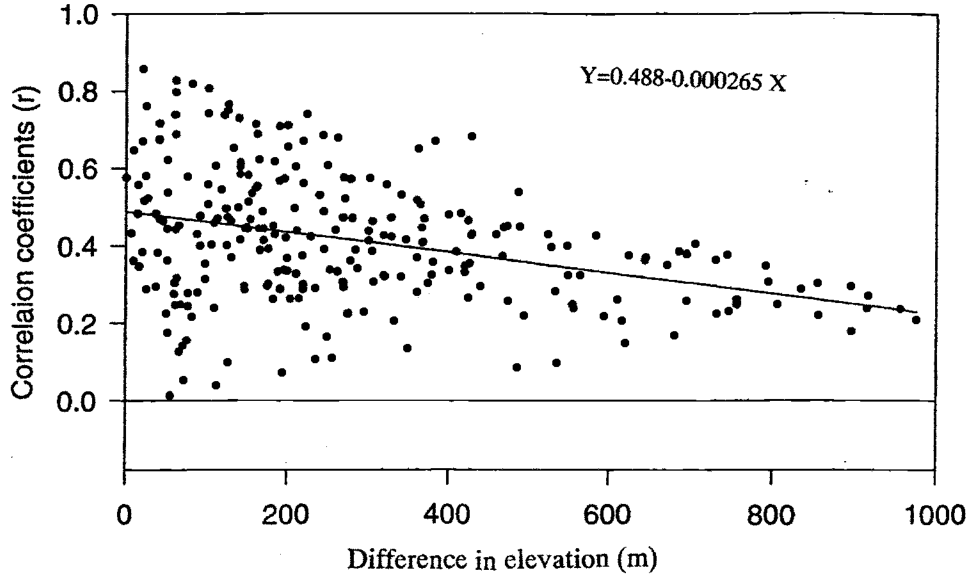

Figure 4. Correlation coefficient between chronologies plotted against their elevation difference. The solid line is the fitted regression line.

SUMMARY AND CONCLUSIONS

1. All the sampled sites could be crossdated. The sampling of a range of different tree sizes (and ages) contributed to this success. Many of the larger trees were senescent and contained suppressed outer growth that could not be crossdated. This problem was overcome by the use of younger trees.
2. About 80 percent of the cores were crossdated. The remeasurement of selected cores showed that the measurements were acceptable (more than 86 percent accepted at 1 percent level, and all others accepted at 5 percent level).
3. Based on COFECHA statistics, some measured data series were rejected. All the cores included in the final chronologies were highly correlated with each other.
4. In order to keep more climate information in the chronology, double detrending (linear-exponential or linear regression or a horizontal detrending plus spline detrending fitted to two-thirds the length of the tree-ring series) was selected as the final standardization method.
5. All the chronologies contained significant autocorrelation, which was modeled by the ARSTAN program with AIC model selection. No significant autocorrelation was left in the residual chronologies produced by this method. Autocorrelation removal also improved EPS and SNR.
6. Comparison of the chronologies showed a highly consistent and significantly correlated pattern among most of the sites.
7. There was a high linear relationship (significant at 0.001 level) between the correlation coefficient and log transformed separation distance. A simple linear regression was applied to characterize the relationship between the correlation coefficients and differences in elevation. Crosscorrelation between sites decreased with increasing distance.

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NOTES

[1] Chronologies may be obtained from: http://ngdc.noaa.gov/paleo/treering/

[2] Current address: School of Archaeology and Palaeoecology, The Queen's University of Belfast, UK.

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