HIGH-ELEVATION DENDROCLIMATIC RECORDS FROM VANCOUVER ISLAND

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INTRODUCTION

The basic tenet of dendroclimatology is that trees retain a record of the annual environmental limitations to growth in their rings. Fritts (1976) and others have established a methodological framework that uses statistical techniques to factor out the climatic influences on this radial growth. If this relationship can be calibrated, tree ring records can be compared with historical meterological records to illustrate climatic fluctuations for the extent of a tree-ring chronology. While several researchers have examined these relationships at broad scale in western North America (Fritts 1991; Schweingruber *et al.* 1991; Briffa *et al.* 1992; Fritts and Shao 1992), this type of tree-ring analysis has never been attempted on Vancouver Island. Instead previous tree-ring studies are largely restricted to: extracting fire histories (Schmidt 1970); to estimating tree growth rates from climatic data (Jozsa and Robertson 1987); and to extracting localized precipitation histories (Zhang, *personal communication*). Surprisingly, there is only a single report of dendroclimatological investigations at high-elevation on Vancouver Island (see Briffa *et al.* 1992), where strong climatic signals are expected (Luckman 1993).

This paper summarizes some results of research designed to describe the radial growth response of timberline stands to climatic changes on Vancouver Island. We chose to focus on high-elevation stands as previous research showed climate plays an important role in limiting tree growth and establishment this zone (e.g., Brooke et al. 1970; Kojima and Krajina 1975). Trees within this zone grow slowly, and changes in temperature and precipitation affect their growth response.

STUDY SITES

The forest vegetation of Vancouver Island is dominated by evergreen coniferous forests reflecting the biogeoclimatic influences of topography and climate (Kojima and Krajina 1975). While the wetter west mountain slopes are occupied by forests of western hemlock *(Tsuga heterophylla)* and western redcedar *(Thuja plicata),* the drier eastern slopes of the island are characterized by stands of Douglas-fir (Pseudotsuga menziesii). In contrast, the most common trees in the snowy subalpine regions of Vancouver Island are Amabilis fir *(Abies amablis),* mountain hemlock *(Tsuga mertensiana)* and yellow-cedar *(Chamaecyparis nootkatensis).* This vegetative diversity shows that disparate climatic factors limit tree growth over short distances on Vancouver Island.

Our findings are based on an assessment of increment core samples collected from trees at nine high-elevation sites in the Vancouver Island Insular Mountain Range (Figure 1). Since 1993 tree-ring research at the University of Victoria Tree-Ring Laboratory (UVTRL) has focused on developing an archive of tree-ring chronologies from Vancouver Island. The present network includes 12 ring-width chronologies collected at 9 sites positioned along the crest of the Vancouver Island Range (Figure 1). All of the sites reported on here are found within the mountain hemlock biogeoclimatic zone (Brooke *et al.* 1970; Klinka *et al.* 1991), at timberline sites that extend 175 km southwards from Mt. Cain to Heather Mountain (*ca.* Lat. 48° to 50° N).

The dominant tree at all the sites is mountain hemlock. Mountain hemlock is a long-lived species and some trees are at least 800 years old (Taylor and Taylor 1980; Edwards and Meagher 1994). Previous researchers in the Pacific Northwest established that the growth response of mountain hemlock is sensitive to changes in the growing season temperature and spring snowpack depth (Brubaker 1986; Graumlich and Brubaker 1986). While yellow-cedar trees were a common at many sites, the species has not been extensively used in tree-ring due to reports of missing and false rings (Brubaker 1982; LaMarche 1982). Nevertheless, we targeted yellow-cedar for sampling as it is one of the oldest living tree species in Canada (Luckman and Innes 1990; Jozsa 1992; Pojar and MacKinnon 1994).

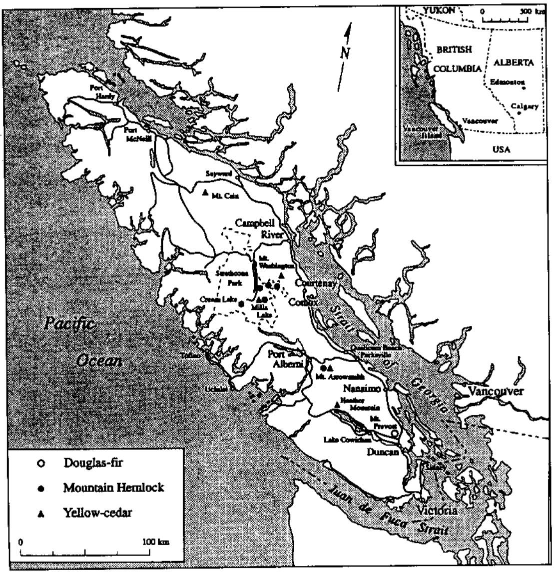


Fig. 1

Tree-ring sites on Vancouver Islands.

METHODOLOGY

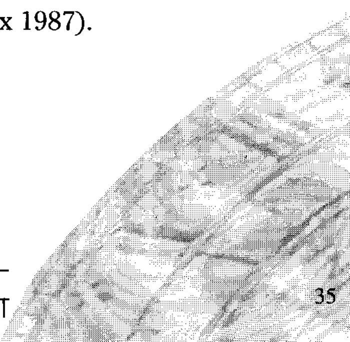
Tree-ring chronologies were developed from increment cores extracted at breast height from mountain hemlock and yellow cedar trees within restricted sampling areas. After air drying, the cores were mounted in wooden blocks and sanded with progressively finer sandpaper. Annual ringwidths were measured to the nearest 0.01 mm using a computerized image processing tree-ring measurement system or a measuring stage linked to a digital encoder. All of the cores were crossdated to marker rings and quality checked using the International Tree Ring Data Bank (ITRDB) software program COFECHA (Holmes, 1992).

Growth trends were removed from the crossdated series by fitting them to either a negative exponential curve or a linear regression line using ARSTAN (Holmes, 1992).

Two regional ring-width chronologies were developed by collating the standard (detrended) chronologies. In the case of mountain hemlock, four sites from within the Forbidden Plateau and Comox Glacier Nature Conservancy areas of eastern Strathcona Provincial Park were used by ARSTAN to produce the chronology shown in Figure 2. The regional yellow-cedar chronology was produced by combining five sites positioned along the eastern crest of the Vancouver Island Range (Figure 1).

The software program PRECONK (Ver. 4.0.3) was used to identify possible relationships between the standard growth indices and monthly records of temperature and precipitation (Fritts 1994). The program recalculates matrices of climatic data using principal component analysis to form new variables and maximize the variance in the factors influencing tree growth. These variables are graphically represented as response functions to establish which climate variables represent the limiting factors of growth (Cook and Briffa 1990). Response function analysis is a form of a regression equation that integrates two sets of data, a set of orthogonalized climate variables and a standardized tree-ring index for a site (Blasing *et al.* 1984). The Nanaimo station data (1901-1990) were used in all the PRECONK calculations.

Deep seasonal snowpacks play an important role in tree physiology within the mountain hemlock zone (Brooke *et al.* 1970; Graumlich and Brubaker 1986). To see if spring (April 1) snowpack depth, which influences the snow meltout date and summer soil moisture, had any influence on tree growth, snow survey data from a station (No. 3B01[1954-1995], Lat. 49° 39', Long. 125° 13'; B.C. Ministry of Environment 1995) at 1130 m on the Forbidden Plateau was examined using a response surface technique (Box 1987).



RESULTS

Ring-width statistics

High-elevation stands of mountain hemlock and yellow-cedar have proven to be valuable dendroecological indicators. Mature trees older than 500 years are common in both species. While the oldest tree sampled was a yellow-cedar with a minimum age of 1200 years at Milla Lake in Strathcona Provincial Park, 1000 year old yellow-cedars were common at both Mounts Arrowsmith and Cain (Figure 1).

Comparative statistics for the two Vancouver Island chronologies are given in Table 1. While mean sensitivity provides an index of between ring variability (Fritts 1976), autocorrelationmeasures the degree to which growth in the previous year influences growth in the current year. Series correlation is a measurement of the entire series and it describes the degree of common signal. While both chronologies have acceptable sensitivity and intercorrelation values, the high first-order autocorrelation value (0.71) shown by the yellow-cedar chronology indicates growth in a given year is strongly conditioned by factors in preceding growth years.

The mountain hemlock and yellow-cedar chronologies extend more than 600 (1374-1994) and 1200 (798-1994) years respectively (Table 1). Nevertheless, the early portion of both chronologies is poorly replicated and, consequently, our discussion is limited to the period from 1450 and 1200.

Table 1. *Summary statistics for measured cores used in chronology development.*

	mountain hemlock	yellow-cedar
Number of sites	4	5
Number of trees	108	169
Number of cores	158	297
Interval	1374-1994	798-1994
Mean sensitivity	0.263	0.245
First-order autocorrelation	0.629	0.713
Mean interseries intercorrelation	0.519	0.418

Interchronology Comparison

The mountain hemlock and yellow-cedar chronologies are similar to one another in many respects and exhibit regionally consistent patterns of ring-width variation, even at sites more than 175 km distant. Both chronologies have similar growth trends from the mid 1650s to 1994 ($r^2 = 0.27$). This behaviour includes shared intervals of reduced growth in the early 1970s, the early 1920s, the early 1860s, the late 1830s, the late 1760s, during the early 1700s, and the mid 1580s (Figure 2). Corresponding periods of enhanced growth occur in the mid 1960s, the early 1900s, the late 1880s, the mid 1850s, the mid 1820s, the late 1790s, and the early 1700s (Figure 2).

While the two ring-width chronologies are similar, close examination of these trends shows some divergence in their short-term growth response. For instance, during intervals of reduced growth, mountain hemlock responds by producing far narrower rings than those grown by yellow-cedar. Furthermore during certain periods, the growth behaviour of the two species diverges (Figure 2). Consequently, while similarities in the growth-response of the two species suggest they are responding to a regional environmental factor, their individualistic ecophysiological response to these changing conditions may provide a key to reconstructing the details of these changes (Graumlich and Brubaker 1986).

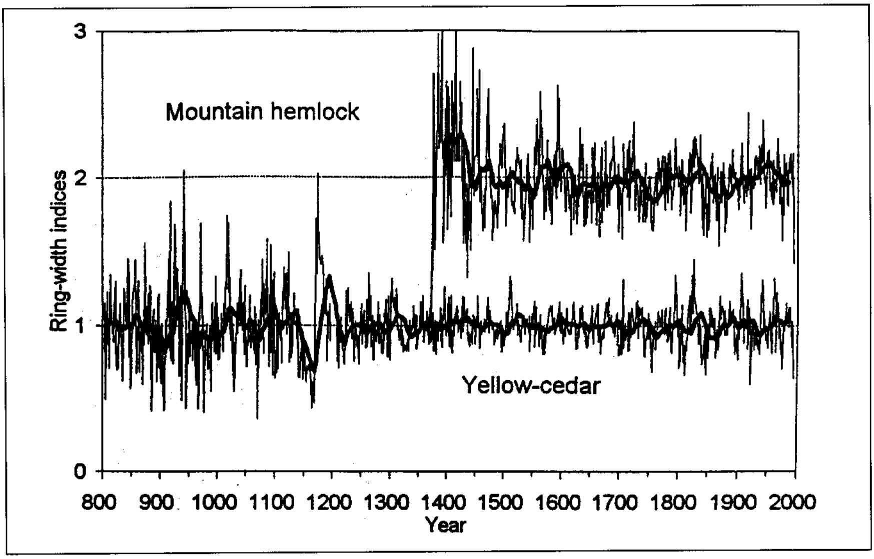


Fig. 2.

Mountain hemlock and yellow-cedar chronologies for Vancouver Island. Solid line running through both chronologies is the 25 year running mean.

CLIMATE-GROWTH RELATIONSHIPS

The response function analysis showed that mountain hemlock growth was most strongly correlated to temperature in July of the growing season and to precipitation in the preceding November. These results show that 60% of the ring-width variance detected within mountain hemlock (1902-1990) could be attributed to the climate (46%) variables and tree growth in the previous year (16%)(Figure 3a). In contrast, the growth response of yellow-cedar growth was complex with six different temperature and precipitation variables accounting for only 31% of the variance in ringwidth (Figure 3b). Furthermore, as predicted by the high first-order autocorrelation value noted in Table 1, 30% of the variance in growth was related to growth in previous years. In short, until there is a better appreciation of the dendroecological behaviour of yellow-cedar, it's dendroclimatological will remain limited.

The association between mountain hemlock growth and growing season temperature is a reflection of how warm air temperature enhance metabolic processes within conifers (Owens and Blake 1985). The physiological effect of November precipitation is likely related to its contribution to the deep seasonal snowpacks that characterize these elevations. Graumlich and Brubaker (1986) discuss how deep spring snowpacks decrease mountain hemlock growth rates no matter the growing season temperature. To assess whether a similar relationship existed in this area, a response surface was constructed which expressed tree growth (1954-1991) as a polynomial function of the average July temperature and April 1 snow depth. The combined effect of July temperature and April 1 snow depth on mountain hemlock growth is presented in Figure 4. The response surface analysis showed that good radial growth within mountain hemlock trees requires either cool summers and shallow winter snowpacks, or warmer than normal summers and moderately deep snowpacks (<4m).

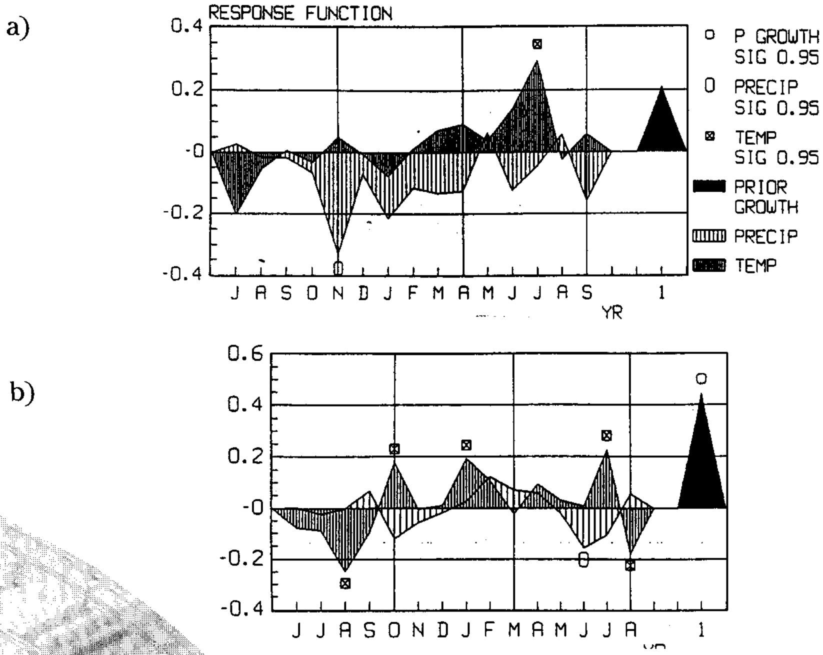


Fig. 3.

Response functions for a) mountain hemlock and b) yellow-cedar.

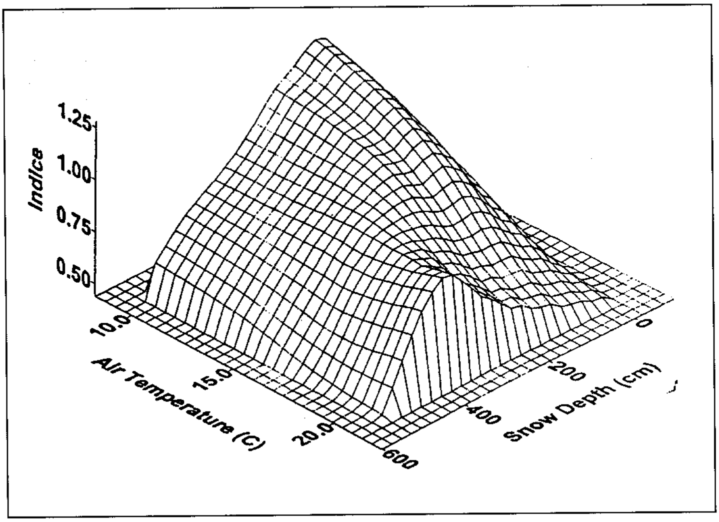


Fig.4

Response surface for mountain hemlock. The height of the surface shows the growth response to a given July temperature and April 1 snow depth conditions.

The complex interplay of the various climatic variables to the growth response of both mountain hemlock and yellow-cedar precludes development of a proxy climate model at this time. Nevertheless, as the growth of these trees was shown to be related to seasonal environmental variations, it is interesting to note that both chronologies demonstrate a persistent long-term trend of recurring intervals of reduced and enhanced growth (Figure 5). In the case of yellow-cedar 15 phase changes have occurred since 1200, with an event cyclicity averaging 54 years. This pattern is similar to that described by Briffa *et al.* (1992), and possibly describes a climate-growth response to significant temperature deviations.

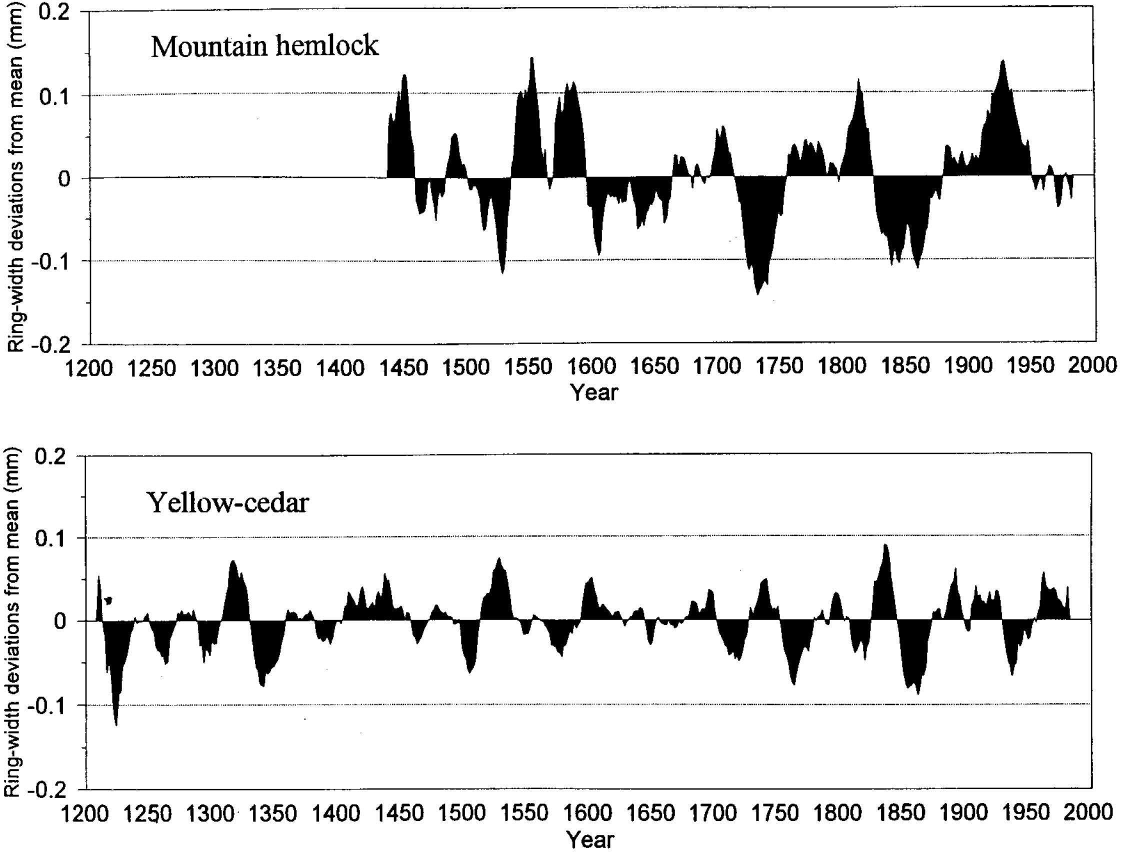


Fig. 5

Long-term trends in ring-width growth increments on Vancouver Island.

CLIMATE CORRELATIONS

Historical climatic changes

The mountain hemlock ring-width chronology developed as part of this research program is similar to that developed in the Cascade Range by Graumlich and Brubaker (1986). While the Cascade chronology shows some correspondence to the regional Vancouver Island chronology, it is marked by much greater growth after 1900 (Figure 6). Graumlich *et al.* (1989) attribute this behaviour to regionwide changes in environmental factors rather than to site-specific stand dynamics. Nevertheless, there is little indication of a comparable historical increase in ring-width dimensions on Vancouver Island. Consequently, it seems that the climatic changes noted by Graumlich and Brubaker (1986) in the Cascade Range were not as extreme in the Vancouver Island Island Ranges.

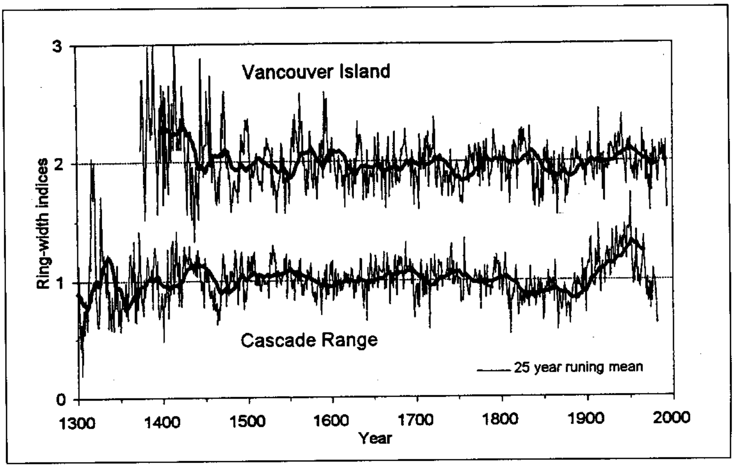


Fig. 6

Comparison of the Vancouver Island and Cascade Range mountain hemlock chronologies.

El Niño/Southern Oscillation records

The climate of Vancouver Island region is dominated by the presence of the Pacific Ocean, with local topographic influences affecting the patterns of climate variation. On going research efforts in the northeast Pacific Ocean show that short-term climatic variability within this region is directly influenced by recurring El Niño/Southern Oscillation (ENSO) events (e.g., Bonsal *et al.* 1993). From the meteorological standpoint, as an ENSO sets in a northward extension of the North Pacific subtropical high results in an weakening of the Aleutian Low in winter and increasing pressures over the Vancouver Island region in the summer (e.g., Alexander 1992). Attendant climatic changes drastically reduce winter snowpack accumulations on Vancouver Island (Moore and McKendry *(in press)* and should be manifest in the long-term climate-growth response of high-elevation trees.

Figure 7 compares the historical frequency of El Niño events (Quinn and Neal 1987, 1992) to the historical mountain hemlock growth trends since 1500. Despite various interpretative difficulties and the fact that many El Niño events in the early part of the record may have been overlooked, it is still possible to appreciate that long-term ring-width variation trends reflect long-term changes in the ENSO frequency. In particular, it is interesting that the periods of increased El Niño frequency (1539-1578, 1600-1624, 1701-1728, 1792-1802, 1812-1832, 1864-1891) generally correspond to intervals of enhanced ring-width growth (Figure 7). Based on the climate-growth relationships described above, these intervals are interpreted as consisting of a series of cool summers that began with a shallow snowpack or series of very warm summers that began with deep spring snowpacks. In either case, it seems likely that the long-term growth trends being recorded reflect a system response to climatic forcing associated with large-scale ENSO events.

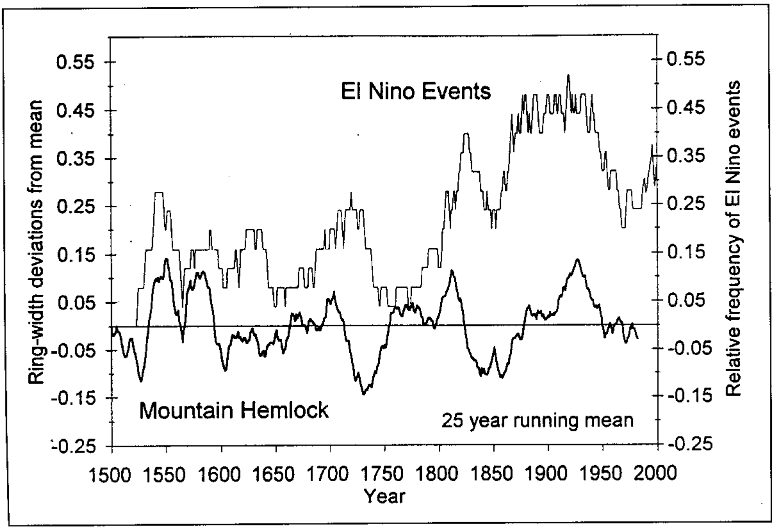


Fig. 7
Comparison of trends within the historical record of El Niño occurrences and the mountain hemlock chronology.

CONCLUSIONS

This study shows that mountain hemlock and yellow-cedar trees growing at high elevation on Vancouver Island are sensitive to climatic changes and contain some useful dendrochronologic records. The synchronous ring-width variations within the chronologies cross-date with each other, suggesting they share a common forcing mechanism. This observation shows there is considerable potential for a high-precision reconstruction of the climate on Vancouver Island from high-elevation tree ring records. Complex interactions between climate and growth preclude a proxy climatic reconstruction, until comparative data is extracted from both tree species. Considering that long-term changes in tree growth show a relationship to the historical ENSO event record, it appears additional dendroclimatological research will provide added insight into the temporal and spatial impact of these near-global-scale climatic changes.

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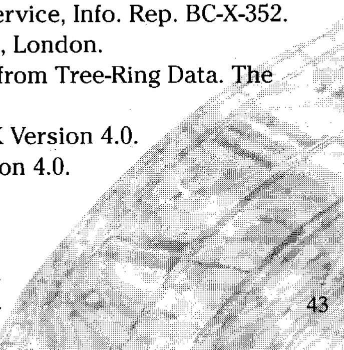

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