Tree-ring analysis of yellow-cedar (*Chamaecyparis nootkatensis*) on Vancouver Island, British Columbia

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Abstract: Yellow-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach) are the oldest known coniferous trees in Canada. This paper reports on the first dendrochronological investigation of yellow-cedar trees at montane sites on Vancouver Island. Mature yellow-cedar trees were selected for study at four sites along a 200-km northwest–southeast transect. Trees older than 500 years were common at three of the four sites, with numerous individuals older than 750 years identified. Carefully prepared cores proved well suited for ring-width measurement, with 220 cores from 156 trees included in our final four chronologies. The best replicated segment of the four chronologies (1800–1994 A.D.) show common intervals of reduced radial growth in the 1800s, 1840s, 1860s, 1920s, 1950s, and 1970s. While the relative strength of the between-site signals varies over this interval (r = 0.424–0.908), it is apparent that the chronologies share a common radial growth signal. Our efforts to identify the role climate played in this relationship were successful and the results appear to have a dendroecological basis within the annual yellow-cedar growth cycle. Six different temperature and precipitation variables explain 61% of the annual ring width variance. Our results suggest that further dendrochronological and dendroclimatological studies using this long-lived species are warranted.

Résumé : De tous les conifères du Canada, le cyprès jaune (*Chamaecyparis nootkatensis* (D. Don) Spach) est celui qui atteint les âges les plus avancés. Cet article constitue la première étude dendrochronologique du cyprès jaune en montagne sur l'île de Vancouver. Des arbres matures ont été échantillonnés sur quatre sites, le long d'un transect nord-ouest – sud-est de 200 km. Les individus âgés de plus de 500 ans sont communs sur trois des quatre sites, plusieurs étant même âgés de plus de 750 ans. L'incorporation dans les quatre chronologies finales de 220 carottes prélevées sur 156 individus montre que des carottes bien préparées se prêtent bien à des mesures de croissance. Le segment le mieux représenté de ces quatre chronologies (1800–1994 A.D.) montre des intervalles communs de croissance radiale réduite au cours des décennies 1800, 1840, 1860, 1920, 1950 et 1970. Les chronologies partagent un signal de croissance radiale commun, même si la corrélation entre les sites varie (r = 0,424–0,908). Le rôle du climat dans cette interrelation a été mis en évidence. Le cycle de croissance annuel du cyprès jaune semble posséder une base dendroécologique. Six variables différentes de température et de précipitation expliquent 61% de la variance dans la largeur des cernes annuels. Nos résultats suggèrent que d'autres études dendrochronologiques et dendroclimatologiques utilisant cette espèce à longévité élevée sont justifiées.

Introduction

Yellow-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach, Cupressaceae) trees are common associates of high-elevation stands in the Pacific Northwest (Dobrý et al. 1996). They are the oldest known coniferous trees in Canada (Luckman and Innes 1991; Jozsa 1992; Pojar and MacKinnon 1994), with reports in the literature of individual trees having more than 1824 annual rings (Pojar and MacKinnon 1994). While assorted tree species with similar lifespans hold useful dendrochronological records (Schweingruber 1993), yellow-cedar has only rarely been used in tree-ring research because of reports of "basal ring-width asymmetries" (Brubaker 1982) and false and missing rings from other Cupressaceae species (Dobrý and Kyncl 1992). Nevertheless, the exceptional longevity of yellow-cedar (Brown 1996) and its unsubstantiated crossdatability (Josza 1981; Hennon et al. 1990*a*; Dobrý et al. 1996) suggest a detailed inquiry of its potential in tree-ring studies is imperative.

Yellow-cedar is a member of the cypress family and is related to only six other species worldwide. In southeast Asia, Hinoki cedar (*Chamaecyparis obtusa* (Siebold & Zucc.) Endl.) (Takata and Kobayashi 1987; Schweingruber 1993) and sawara cedar (*Chamaecyparis pisifera* (Siebold & Zucc.) Endl.) (Mitsutani and Tanaka 1990) have proven useful in dendrochronology. In North America, both eastern white cedar (*Thuja occidentalis* L.) (Kelly et al. 1994) and western red cedar (*Thuja plicata* Donn.) (Atwater and Yamaguchi 1991; Yamaguchi et al. 1997) have also been used successfully in a number of tree-ring studies. The proven success of these related species calls into question reports describing yellow-cedar radial growth trends as problematic for tree-ring studies.

Background

Yellow-cedar is restricted in distribution to the Pacific Northwest region of North America (Krajina et al. 1982;

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Fig. 1. A 550-year-old yellow-cedar tree from the Mountain Hemlock Zone in the insular mountains of central Vancouver Island. Note the person near the base of the tree for scale.

Burns and Honkala 1990). Considered a “generalist” by Russell (1993) and a “stress tolerator” species by Antos and Zobel (1986) and Alaback (1992), yellow-cedar grows throughout the montane Mountain Hemlock and wetter Coastal Western Hemlock zones of the Pacific Northwest (Krajina et al. 1982). Stands of yellow-cedar are common in coastal maritime regions extending southward from Alaska to the Siskiyou Mountains in northern California (Antos and Zobel 1986). Disjunct populations found in the interior of British Columbia and in Washington and Oregon are interpreted as remnants of pre-glacial populations (Antos and Zobel 1986; Burns and Honkala 1990; Alaback 1992).

Yellow-cedar is abundant on Vancouver Island at sites where the climate is hypermaritime and where the soil is moist and derived from base-poor igneous rock (Klinka 1992). At sites with deep fertile soils, yellow-cedar trees are uncommon, as they are unable to compete with faster-growing tree species such as western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and grand fir (*Abies grandis* Dougl. Lindl.) (Antos and Zobel 1986; Burns and Honkala 1990; Hawkins 1992).

Mature yellow-cedar trees have a slightly buttressed base and tapering trunks that grow to heights of between 30 and 50 m (Fig. 1) (Hoise 1990; Pojar and MacKinnon 1994). The longevity of yellow-cedar is believed to be closely related to the production of antifungicidal nootkatin and chamic acids, which provide a resistance to both disease (Barton 1976) and insect infestation (Hennon 1992). While this life-history “strategy” leads to low mortality and a long life, it means that less energy is devoted to reproduction and growth (Alaback 1992). Fungal infections causing internal decay are considered to be the greatest cause of yellow-cedar mortality (Hennon 1990). Documented cases of brown bear damage in Alaska and northern British Columbia attest to the contributory role open wounds may play in assisting the growth of destructive fungi (Hennon et al. 1990b). Although a large dieback of yellow-cedar over the last 100 years has occurred within some yellow-cedar stands in southeastern Alaska and northwestern British Columbia, the probable abiotic causes of this decline are not well understood (Hennon and Shaw 1994).

Yellow-cedar is regarded as a frost-hardy species (Hawkins 1993; Russell 1993), with maximum hardiness reached by the beginning of January (Hawkins 1992). Nevertheless, yellow-cedar seedlings are sensitive to both soil temperature (Grossnickle 1992; Koppenaal and Mitchell 1992) and soil moisture extremes (Grossnickle and Russell 1996). The drought resistance of yellow-cedar apparently varies through the year, increasing as spring shoot development decreases (Grossnickle 1992).

The relationship between site environmental conditions and yellow-cedar growth are poorly understood. While research by Dobrý et al. (1996) noted the importance of pregrowth temperature and precipitation to radial growth trends near Vancouver, B.C., limited sampling precluded an adequate assessment of this characteristic. Observations by Auclair et al. (1990) of significant physiological damage following seasons of unusual cold, dry winters and early, warm spring climates reflect a general sensitivity of mature yellow-cedar trees to temperature extremes.

Based on these assessments, we hypothesized that high-elevation stands of yellow-cedar on Vancouver Island grow at the extremes of the environment for the species and that their annual radial growth would be highly sensitive to subtle climatic changes. This paper reports on the first dendrochronological investigation of yellow-cedar trees at montane sites on Vancouver Island and considers the effects of climate on the radial growth of yellow-cedar.

Study sites

On Vancouver Island, yellow-cedar trees are found from sea level to above 1500 m asl (Hosie 1990; Antos and Zobel 1986). The highest elevation stands of yellow-cedar on Vancouver Island are located within the Mountain Hemlock (MH) zone (Kojima and Krajina 1975). Above 1000 m asl, the MH zone typically grades from subalpine forests characterized by mixed stands of yellow-cedar, mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), and amabilis fir (*Abies amabilis* (Dougl.) Forbes), to a parkland belt dominated by mountain hemlock but containing isolated populations of subalpine firs (*Abies lasiocarpa* (Hook.) Nutt.) and krummholtz forms of yellow-cedar (Brooke et al. 1970).

The climate of the MH zone in southwestern British Columbia is characterized by cool conditions and a short growing season (Kojima and Krajina 1975). Characteristically,

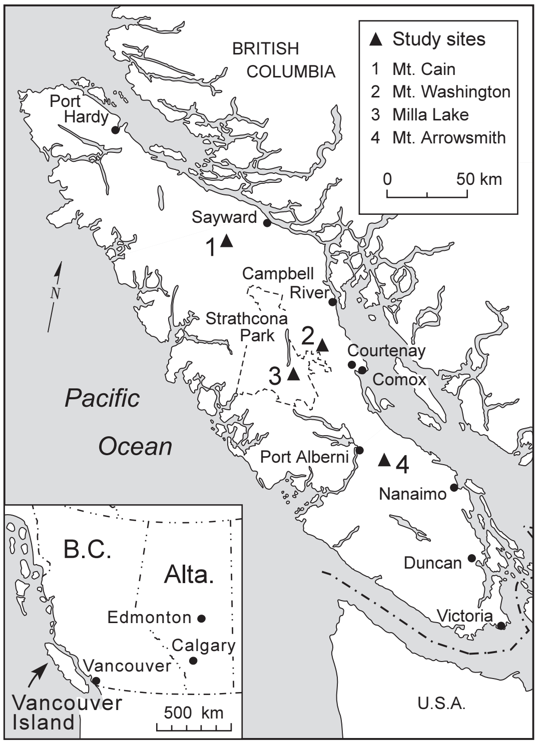
Table 1. Site characteristics and chronology statistics.

	Mount Cain	Mount Washington	Milla Lake	Mount Arrowsmith
Latitude (N)	50°14′00″	49°45′6″	49°14′47″	49°33′16″
Longitude (W)	126°19′55″	125°17′40″	124°34′50″	125°23′00″
Sampling elevation (m asl)	1355–1460	1270–1440	1380–1480	1180–1290
Aspect	S	SSE	WSW	ESE
Slope (°)	27	25	39	26
n = Trees (cores)	42 (44)	48 (91)	22 (24)	44 (61)
Range (years A.D.)	1205–1994	1702–1994	798–1994	1105–1994
Length of chronology (years)	789	292	1196	889
Mean series correlation	0.45	0.47	0.3	0.43
Mean sensitivity	0.26	0.21	0.28	0.24
Mean autocorrelation	0.62	0.81	0.7	0.72
No. of trees >500 years	21	—	7	10
No. of trees >750 years	2	—	2	2

fewer than 50 days per year reach temperatures above 10°C and precipitation totals often exceed 2600 mm/year. More than 30% of the precipitation in the MH zone falls in the form of winter snowfall and total accumulations exceeding 4 m are common (Klinka et al. 1991). Largely because of the insulating effect of these deep snowpacks, the soil within the MH zone generally remains unfrozen throughout the year (Klinka et al. 1991).

Mature yellow-cedar trees were selected for study at four sites in the MH zone in the summer of 1994. The dominant tree species at all study sites was mountain hemlock, with a minor constituent of yellow-cedar and amabilis fir. The sites selected for study were located along a 200-km northwest–southeast transect within the Vancouver Island Insular Mountain Range (Fig. 2). Three of the sites share similar topographic characteristics (elevation, slope angle, and aspect): Mount Cain; Mount Washington; and Mount Arrowsmith (Table 1). The Milla Lake site in Strathcona Provincial Park was steeper and had a more westerly aspect than the other sites but had similar old-growth stand characteristics (Laroque 1995). Only the Mount Washington site exhibited dissimilar stand characteristics, presumably the result of a fire which scars indicate occurred in 1668 A.D. Evidence of fire-charred coarse-woody debris on the forest floor and charcoal fragments in the uppermost soil profile suggest this is a post-fire stand.

Fig. 2. Location of study sites on Vancouver Island, British Columbia.



Methods

At each site we identified representative trees with minimal bole and crown damage for sampling. Samples were collected from 50 trees using an increment borer at three of the sampling sites (Table 1). Only 25 trees were sampled at Milla Lake, where the limited areal extent of the stand restricted the number of yellow-cedar trees available. Two cores were extracted from cross-slope positions at breast height on each tree. Individual cores were air-dried, glued into slotted mounting boards, and sanded to a high polish in preparation for ring-width measurement.

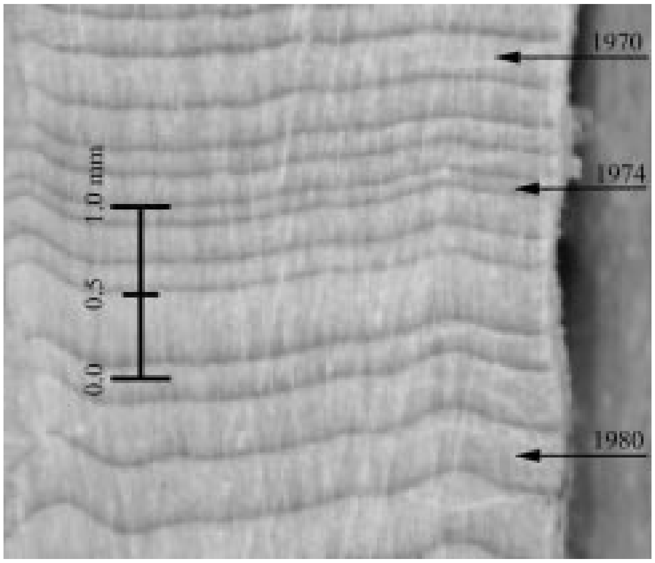
Cores were first visually crossdated (Stokes and Smiley 1996) with reference to prominent pointer or marker years. The cores were subsequently measured to the nearest 0.01 mm using a computerized WinDENDRO™ (version 4.1.2, 1994) scanner-based image processing tree-ring measurement system (Guay et al. 1992; Sheppard and Graumlich 1996). Whenever the ring boundaries were difficult to distinguish, the samples were repolished and a detailed examination of the problem area was completed using a 40× microscope mounted on a Velmex-type stage measurement system. To identify any cross-dating errors introduced during ring measurement, each series was graphically reexamined with reference to a common set of marker years using skeleton-plots (Stokes and Smiley 1996). Signal homogeneity was verified using the COFECHA computer program (Holmes 1983). After crossdating, the individual core measurements were standardized using the computer program ARSTAN. A two-stage method was used in which the program first detrended each core tree-ring indice using a negative exponential curve or a linear trend and then detrended a second time using a cubic-smoothing spline to remove any remaining inherent age or growth trends (Holmes et al. 1986). Site chronologies were then compiled for each group using the standard

Table 2. Summary of marker years in the yellow-cedar site chronologies from 1800 to 1994 A.D.

Year	Mount Cain	Mount Washington	Milla Lake	Mount Arrowsmith
1801	x	x	x	x
1810	X	X	X	X
1824	x	x	x	x
1833	x	x	x	x
1838	x	x	x	x
1845	x		x	x
1849	x	x	x	x
1862	X	X	X	X
1894	x		x	
1899	x	x	x	x
1909	x	x	x	x
1916	x	x	x	x
1921	X	X	X	X
1964	x	x	x	x
1974	X	X	X	X

Note: A lowercase x denotes common marker rings. The uppercase X denotes regionally significant narrow pointer rings.

Fig. 3. A sample set of tree rings from a 200-year-old yellow-cedar tree. Note that the narrow pointer ring observed in 1974 had a width of 0.15 mm. This value compares with an average measured ring width of 0.52 mm.



ARSTAN output within the program, with the intention of enhancing the collective yearly growth patterns.

A basic tenet of dendroclimatology is that trees retain a record of the environmental limitations to growth in their annual rings. Fritts (1976) and others have established a methodological framework that uses statistical techniques to identify the climatic influences on this radial growth. In our study, we used the software program PRECONK (version 5.1) to identify possible relationships between our yellow-cedar chronologies and monthly records of temperature and precipitation (Fritts 1994). PRECONK recalculates matrices of climatic data using principal component analysis to form new variables that maximize the variance in the factors influencing tree growth. These variables are then graphically represented as response functions to establish which climate variables represent the most important limiting factors of growth (Briffa and Cook 1990). Response function analysis is a form of regression 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). Unfortunately, there are relatively few long-term (>50 years) climate stations on Vancouver Island, and there are no stations at high elevation in the Insular Mountain Range. Consequently, we used the Nanaimo, B.C., climate station data (1901–1990) in the PRECONK calculations. These data are felt to be representative of the environmental variations along the latitudinal gradient of this study, insomuch as they avoid complications that would be introduced were longer term records from sites in the very wet west coast (e.g., Port Alberni) or very dry southern coast (e.g., Victoria) of Vancouver Island used (Fig. 2).

Results and discussion

A total of 350 cores were measured from 175 trees, with 220 cores from 156 trees included in the final chronologies (Table 1). Series illustrating the impact of site competition or anomalous radial growth trends were excluded from further analysis. Analyses of the cores showed that trees older than 500 years are common at high-elevation sites on Vancouver Island, except at fire-influenced sites like Mount Washington. While less common, trees older than 750 years were found at all three old-growth sites (Table 1). A single individual ca. 1200 years in age was sampled at Milla Lake (Table 1).

Visual distinction and demarcation of the latewood to earlywood ring boundary in yellow-cedar occasionally proved to be problematic with our scanner-based measuring system, especially when a sequence of very narrow rings were encountered. As Jozsa (1992) notes, the annual rings of yellow-cedar have a very small density difference, averaging 0.37 g/cm^3 for earlywood to 0.54 g/cm^3 latewood. While this property sometimes made chronology development troublesome, experimentation revealed that a re-examination of suspect margins with a high-power ocular microscope effectively solved most questions about false ring and (or) ambiguous ring boundaries. Firm confirmation that our four yellow-cedar series were correctly cross-dated was aided by a common set of pointer rings produced in 1810, 1862, 1921, and 1974 (Table 2). These annual rings were narrow in virtually all of the cores examined and, in the context of a pattern of highly variable ring widths, provided good marker year control (Fig. 3).

Our four cross-dated chronologies range in age from 292 to 1196 years. Comparative statistics for the four chronologies are given in Table 1. Mean series correlation describes the strength of a chronology by averaging the internal correlations of all of the cores in a chronology (Holmes et al. 1986). The mean series correlations (0.30–0.47) recorded for yellow-cedar signify that all four chronologies contain a collective signal significant at the 95% confidence interval when using 50-year chronology segments. These correlation values are lower than those reported for other high-elevation tree species on Vancouver Island (e.g., mountain hemlock, $r = 0.53$; Smith and Laroque 1998) but are comparable to those associated with trees found elsewhere in the Pacific Northwest (e.g., subalpine fir, $r = 0.32–0.51$; Ettl and Peterson 1995). Mean sensitivity provides a measure of between-ring variability (Fritts 1976), and the values recorded for the

Table 3. Number of replicated trees and cores used to compare the sites and incorporated into regional chronology.

	Common interval			
	1800–1849	1850–1899	1900–1949	1950–1993
Mount Cain	34 (38)	37 (39)	39 (41)	39 (41)
Mount Washington	36 (37)	46 (67)	48 (87)	48 (91)
Milla Lake	14 (19)	14 (22)	13 (22)	13 (24)
Mount Arrowsmith	39 (44)	42 (55)	44 (56)	44 (61)
Regional chronology	123 (132)	139 (183)	144 (206)	144 (217)

Note: Values are the number of trees (and cores in parentheses) that represent each 50-year segment.

Table 4. Pearson's *r* correlation values showing the relationship of the standard chronology between the four sites.

	Correlation coefficients						
Segment length	Mount Cain vs. Mount Arrowsmith	Mount Cain vs. Milla Lake	Mount Cain vs. Mount Washington	Mount Arrowsmith vs. Mount Washington	Mount Arrowsmith vs. Milla Lake	Mount Washington vs. Milla Lake	Critical value at the 99% confidence interval
1800–1993	0.68	0.65	0.7	0.79	0.71	0.71	0.17
1800–1849	0.68	0.68	0.72	0.91	0.87	0.87	0.33
1850–1899	0.56	0.63	0.73	0.71	0.42	0.49	0.33
1900–1949	0.88	0.78	0.82	0.81	0.67	0.65	0.33
1950–1993	0.68	0.67	0.7	0.65	0.63	0.78	0.35

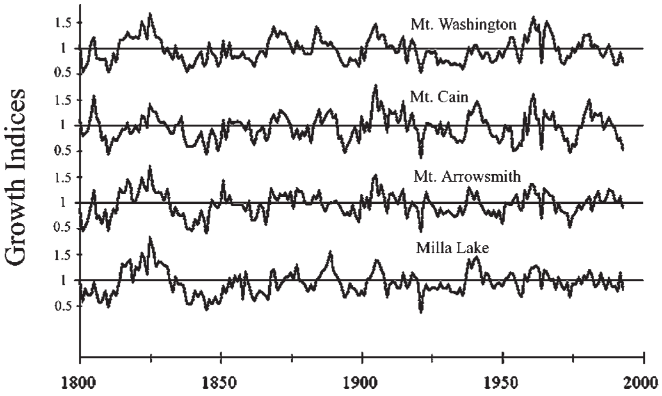
Note: All values are significant at the 99% confidence interval.

yellow-cedar tree-ring series are characteristic of climatically responsive high-elevation tree species in the Pacific Northwest (Peterson and Peterson 1994; Ettl and Peterson 1995). Autocorrelation is a measure of the correlation between successive increments, and the positive values from our chronologies indicate yellow-cedar growth in this region was strongly conditioned by factors in preceding growth years. Similar relationships have been noted within amabilis fir (Dobrý and Klinka 1998), mountain hemlock (Wiles et al. 1996), and subalpine fir (Ettl and Peterson 1995) trees in the Pacific Northwest.

As we were seeking to substantiate the dendrochronological reliability of yellow-cedar, only the most well-replicated segments of the four chronologies were used in our assessment (Table 3). Similarities in the radial growth trends in the interval between 1800 and 1994 A.D. are shown in Table 4 and Fig. 4. A common signal in the chronologies is reflected by highly significant correlations (0.65–0.79; Table 4) and consistently reduced growth in the 1800s, 1840s, 1860s, 1920s, 1950s, and 1970s (Fig. 4). These observations are supported by collective periods of higher growth in the mid-1820s, 1880s, 1910s, 1940s, and 1960s (Fig. 4). To assess the temporal strength of these among-site relationships, a correlation matrix was constructed for four growth intervals over the last 194 years of the chronologies (Table 4). While the relative strength of the between-site signal has varied over this interval (r = 0.42–0.91), the matrix shows that the chronologies share a common significant radial growth signal over the entire length of the transect (see Fritts 1976).

Recognition of a common radial growth signal in yellow-cedar allowed us to confidently develop a chronology for Vancouver Island. Raw measurements from the four sites, spanning the interval 1800–1994, were collated and collectively detrended using ARSTAN to produce a standard chronology of the radial growth behaviour of high-elevation yellow-cedar trees on Vancouver Island (Fig. 5).

Fig. 4. The ARSTAN standard chronologies from the four yellow-cedar study locations on Vancouver Island. Note narrow pointer years in 1810, 1838, 1921, and 1974.



Influence of climate on radial growth of yellow-cedar

Figure 6 illustrates the climate–growth relationships, and indicates that 61% of the annual variance in yellow-cedar growth can be explained by climatic factors (33%) and prior growth characteristics. The relatively high percentage of the variance explained by prior growth (28%) confirms the high autocorrelation values found in the COFECHA analysis (Table 1).

Three different temperature variables and three precipitation values are shown to significantly influence radial growth.

Fig. 5. The ARSTAN standard chronology of regional yellow-cedar growth on Vancouver Island.

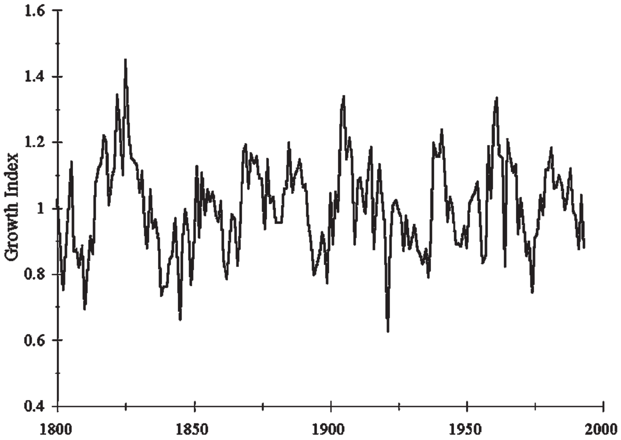
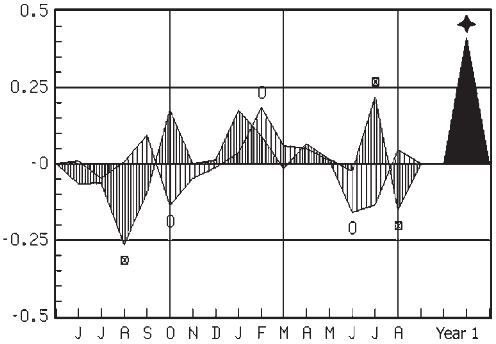
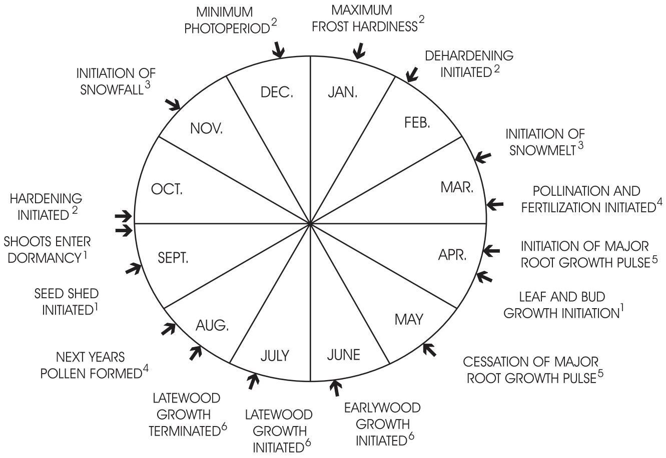


Fig. 6. The response function produced by PRECONK showing the climate–growth relationships that exist between the regional yellow-cedar chronology and climate data from Nanaimo, BC. Significant temperature variables are designated by a square (⊠), precipitation variables by a circle (0), and previous-year growth by a star (✦). Sixty-one percent of tree-ring variation is explained by climate parameters, with 33% occurring in the growth year and 28% associated with the prior year's growth.



Yellow-cedar trees respond positively to warm July air temperatures but negatively to excessive August heat in both the current and preceding year. Figure 6 illustrates the negative impact of excessive precipitation in June and preceding October on radial growth and a positive relationship to February precipitation.

Fig. 7. The yearly growth cycle of yellow-cedar trees growing at high-elevations on Vancouver Island. Our sampling on Vancouver Island indicates that, except for the southernmost portion of the island, earlywood production commences mid-June and continues until ca. mid-July. At most sites on Vancouver Island, latewood cell growth continues until mid-August. Sources of data are as follows: (1) Owens and Molder 1974; (2) Hawkins 1992; (3) Moore and McKendry 1995; (4) Owens et al. 1992; (5) Coleman et al. 1992; and (6) this study.



The ecological behaviour that underlies these climate–growth relationships is related to the annual growth cycle of yellow-cedar in high-elevation stands (Fig. 7). During the minimum photoperiod in December, upper elevational yellow-cedar are dormant and by early January achieve their maximum frost hardiness (Hawkins 1993). By the beginning of February, the lengthening photoperiod triggers dehardening (Hawkins 1993). This activity continues until mid-March in conjunction with seasonal snowmelt. By late March, pollen release and cone fertilization commences (Owens et al. 1980). The thinning snowpacks release meltwater that begins to infiltrate into the ground and by mid-April a major period of root growth is initiated that continues until mid-May (Coleman et al. 1992). Bud burst and shoot elongation begin in mature trees by late April and continue as the dominant growth process until early to middle June (Owens and Molder 1974). Although shoot growth is typically replaced by cambium development at this time, the period over which earlywood production commences in high-elevation yellow-cedars has not previously been documented. Nevertheless, our empirical observations suggest that on Vancouver Island, except for the southernmost portion of the island, earlywood cells are being produced by late June. Earlywood cell production appears to continue for 3–4 weeks until mid-July, when our first observations of latewood cells have been made. At most sites on Vancouver Island, latewood growth continues until mid-August when pollen formation begins (Owens et al. 1980). Following a 2-year cycle of seed formation, seed shed begins in mid-September (Owens and Molder 1974). This activity is followed by predormancy behaviour (Owens and Molder 1974) and winter hardening processes (Hawkins 1993).

Based on this phenological information, we interpret our climate – radial growth relationships as follows. First, high August air temperatures appear to stress yellow-cedar, hastening the cessation of radial growth and negatively impacting radial growth in the following season. Second, the significant positive response to July air temperature presumably signifies an extension of the earlywood growth season and the delay of latewood production. This explanation is supported by our observations of annual ring cross sections, which rarely show differences in year-to-year latewood widths. Finally, the significant relationships between monthly precipitation totals and radial growth are interpreted as related to early snowfall accumulations (October), which disrupt the hardening process, lead to high winter snowpacks, and retard spring growth. Winter rainfall (February) hastens seasonal snowmelt and (or) increases the soil moisture reservoir. The negative impact of June rainfall on radial growth is assumed to be related to the accompanying cloudy conditions, which result in a reduction in photosynthetic activity, essential for finishing bud growth and initiating earlywood production.

Although numerous tree-ring studies in the Canadian cordillera have focused on climate–growth relationships at montane sites (cf. Colenutt and Luckman 1995), prior to our study, only a few exploratory analyses of high-elevation tree populations were carried out in the Coast Mountains of British Columbia (e.g,. Briffa et al. 1992; Dobrý and Klinka 1998). Our findings compare favourably with other studies in this region where complex responses to yearly climate cycles are incorporated into tree growth. Similarly, previous researchers in the Pacific Northwest have also found that late summer heat is a dominant factor in inhibiting the radial growth (Ettl and Peterson 1995; Dobry and Klinka 1998), that large seasonal snowpacks lead to significant delays in the timing of certain physiological processes (Graumlich and Brubaker 1986), and that weather patterns during earlywood production greatly influence the magnitude of annual radial growth (Peterson and Peterson 1994).

Conclusions

Previous attempts to crossdate yellow-cedar chronologies suggested that the species might be unsuitable for dendrochronological analysis (e.g., Brubaker 1982). Little information exists on the cross-dating challenges encountered, but at least one anatomical characteristic probably played a role in this assessment. Many old-growth yellow-cedar trees, particularly those found growing at low elevation, are characterized by a wide buttressed base. Our experience suggests that cores sampled within this part of the tree contain anomalous ring-width patterns that impede crossdating. By identifying trees with minimal buttressing or by sampling higher up the bole, we have successfully crossdated the majority of individuals sampled at our four sites. Given this success, we argue for the inclusion of yellow-cedar on any future lists of species useful in tree-ring studies (Grissino-Mayer 1993; Schweingruber 1993).

The key to the success of yellow-cedar on Vancouver Island, and likely through the coastal Pacific Northwest region, has been its ability to persist in marginal habitats for very long periods of time (Laroque 1995). Our discovery of a common growth signal within high-elevation stands of yellow-cedar on Vancouver Island connotes a relationship with strong similarities over a broad regional area. Our efforts to identify the role climate plays in this relationship were successful, and the results appear to have a dendroecological basis within the annual yellow-cedar growth cycle.

Our findings indicate that yellow-cedar has an unexploited potential in tree-ring research. Given its longevity and dendroclimatological sensitivity, yellow-cedar potentially offers forest ecologists and resource managers insight into long-term climate–growth dynamics over the last millennia, information essential for understanding changes in growth dynamics accompanying future changing climates. Furthermore, the proven crossdatability of yellow-cedar means that archeologists should now be able to confidently use this species in their attempts to date First Nation artefacts. Given that yellow-cedar has a significant ceremonial ancestry within this region, recognition of this potential is exceptionally noteworthy.

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