The Dendrochronology and Dendroclimatology of Yellow-cedar on Vancouver Island, British Columbia

by

Colin Peter Laroque
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We accept this thesis as conforming to the required standard

[redacted]

Dr. D.J. Smith, Supervisor (Department of Geography)

[redacted]

Dr. M.C. Edgell, Departmental Member (Department of Geography)

[redacted]

Dr. J.A. Antos, Outside Member (Department of Biology)

[redacted]

Dr. R.J. Hebda, External Examiner (Department of Earth and Ocean Sciences)

Universty of Victoria

Supervisor: Dr. D.J. Smith

Abstract

The purpose of this study was to investigate the dendrochronological and dendroclimatological potential of yellow-cedar in the Pacific Northwest of North America. A primary objective was to establish whether the growth response of yellow-cedar is sensitive to climate fluctuations. Once it was determined that yellow-cedar was inherently sensitive, further dendroclimatological investigations were attempted.

Trees were sampled at five sites between latitudes 50° and 51° on Vancouver Island. A total of 380 increment cores were collected in the summer of 1994. The samples were subsequently visually cross-dated, prior to ring-width measurement. Site indices were created and the five sites revealed a strong visual and statistical similarity. A regional index was constructed that represents the oldest living chronology for tree growth in Canada.

A response function analysis was initiated to determine the significant climatic parameters to ring growth. This analysis identified previous August temperature as the variable most likely to influence variation in ring width. This variable was used to estimate current August temperature and associated parameters. The chronologies were compared to other relevant research on Vancouver Island and a common climate signal was apparent.

Examiners: [redacted]

Dr. D.J. Smith, Supervisor (Department of Geography)

[redacted]

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[redacted]

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[redacted]

Dr. R.J. Hebda, External Examiner (Department of Earth and Ocean Sciences)

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And lastly without a firstly, to the producer. Look what you've made now Dawn. Thanks for being there from the start to the finish, and believing in me every step of the way. I wouldn't have tried it without you watching my back and can only hope to give back the same support from above...♥ CPL

Forward

A Hesquiat story about the origins of yellow-cedar tells of three young women who were drying salmon on a beach. Raven came up to them and wanted to steal their salmon. He found out they were scared of owls and he hid in the bush and made noises like an owl. The three women became scared and ran away. They ran up the mountainside and got tired and stopped halfway up the slope. The women were so tired they decided to stay there and they turned into yellow-cedar trees. Then raven snuck out and ate their drying salmon. That is why yellow-cedar are found on the mountain side and are such nice looking trees, with smooth trunks and few branches. The softness of the inner bark and the long drooping branches are a result of the women's hair.

(Turner and Efrat 1982; Pojar and MacKinnon 1994)

1.0 Introduction

There is growing interest in understanding the nature of past climate change. Canadian weather data does not address this issue, as the oldest instrumental records date from 1840 (Colenutt and Luckman 1991). Nevertheless, many species of long-lived trees exist in Canada and data from some of these have been used successfully to model variations in prehistoric climates (e.g., Colenutt and Luckman 1991; Jozsa 1992a; Kelly *et al.* 1994). This type of analysis compares tree ring data to known climatological parameters and uses the resulting relationships to develop proxy records of past climatological conditions. In the Pacific Northwest, this type of dendroclimatological research has been undertaken at a number of sites (Brubaker 1982; Heikkinen 1984, 1985; Graumlich *et al.* 1989; Dobry and Klinka 1993; Smith 1994), but there remains considerable scope for further investigation (Brubaker 1982; Luckman and Innes 1990; Alaback 1992; Jozsa 1992a).

Tree species that are long lived and climatically sensitive are particularly useful for dendroclimatological research. For instance, cedar species such as eastern white cedar (*Thuja occidentalis* L.) (Kelly *et al.* 1994) and western redcedar (*Thuja plicata* Donn) (Atwater and Yamaguchi 1991), have been used for a number of dendroclimatological and dendrochronological applications in North America. Hinoki cedar (*Chamaecyparis obtusa* (S. *et* Z.) Endl.) (Takata and Kobayashi 1987) and sawara cedar (*Chamaecyparis pisifera* Sieb. *et* Zucc.) (Mitsutani and Tanaka 1990) also exhibit useful dendrochronological traits. Hinoki cedar has excellent dendrochronological value, providing a record extending back to 317 B.C. (Mitsutani and Tanaka 1990).

Yellow-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach, Cupressaceae) is the oldest known living tree species in Canada (Luckman and Innes 1990; Jozsa 1992a; Pojar and MacKinnon 1994) and is common in high-elevation stands in the Pacific Northwest. Nevertheless, yellow-cedar has never been extensively utilized in dendrochronological research because there are reports of missing and false rings (cf. Brubaker 1982; LaMarche 1982; Schweingruber *et al.* 1990). There appear to be only three reports describing the dendrochronological use of yellow-cedar (Jozsa 1981; Hennon *et al.* 1990a; Dobry and Klinka 1993).

The purpose of this research programme is to assess the dendrochronological potential of yellow-cedar and to evaluate its use as a dendroclimatological indicator on Vancouver Island. In assessing the dendrochronological utility of yellow-cedar, it is first necessary to evaluate its ring-width "sensitivity". Once it is established that the species is sensitive to climatic fluctuations, it is possible to statistically analyze site chronologies to evaluate its dendroclimatological potential. Should this analysis reveal that yellow-cedar contains a climatic signal, the climatological factors limiting yellow-cedar growth can then be extracted and used to develop a proxy record of climatic change for the duration of the ring-width chronologies.

The following chapters summarize the research programme, beginning with the background of the discipline in Chapter 2. Chapter 3 describes the study sites and Chapter 4 details the methodology used in the study. Chapter 5 and Chapter 6 present the results and discuss the dendrochronology and dendroclimatology of yellow-cedar respectively. Chapter 7 gives an inter-species comparison and Chapter 8 presents the summary and conclusion.

2.0 Research Background

Three topics are reviewed in this chapter: basic dendroclimatological theory; the history of related studies in the Pacific Northwest; and the physiological characteristics of yellow-cedar.

2.1 Dendroclimatological History

Paleoclimatic information is extracted from tree ring-width records by statistically comparing ring-growth indices to historical climate data (Brubaker 1982). Early in the history of dendroclimatology, the only method for linking climate data and tree indices was to perform simple correlations of ring-width series with climatic factors identified as important by the researcher (Guiot *et al.* 1982; Blasing *et al.* 1984). The selection of a factor was usually not problematic, since few climatic variables were being measured at that time. However, these initial correlations of ring-widths and climate were suspect due to autocorrelation in the operator-selected climate factors (Blasing *et al.* 1984).

It was not until the early 1960s and the application of stepwise multiple regression methods that there was any appreciable improvement in dendrochronological research methodologies (Fritts 1976; Guiot *et al.* 1982; Blasing *et al.* 1984). Sellars (1968) utilized empirical orthogonal functions in regional climatic studies to reveal that three principal components combined to explain almost all the variance in his study region. This form of eigenvector analysis was quickly applied by dendroclimatologists to tree-rings and climate (LaMarche and Fritts 1971), and within three years was renamed in the literature as "response function analysis" (Fritts *et al.* 1971). Both empirical orthogonal functions and response function analysis are simply forms of what is currently referred to as principal components analysis. The use of these statistical methods allows a short-term climatic data set to be used to extrapolate past climate as far back in time as a tree's lifespan, in a more statistically robust manner than was previously possible. In this way, long-term proxy records of climatic fluctuations were developed (Fritts 1976).

2.2 Dendroclimatological Principles

Dendroclimatological research is based on the principle of uniformitarianism. This principle states that the physical processes causing variation in today's environment are the same processes that have acted throughout time. In dendroclimatology, it is assumed that the effects of variations in climate on tree growth are the same today as in the past (Fritts 1976).

The "sensitivity" of a tree refers to the responsiveness of ring width variation to changes in environmental conditions (Schweingruber 1988). As the number of factors limiting tree growth decreases, the overall sensitivity of the tree increases (since there is less interference or "noise" among the factors and thus a stronger "signal") (Cook and Briffa 1990). Trees that lack sensitivity are referred to as being complacent (Stokes and Smiley 1968), as they exhibit little variation in ring width with changes in climate variables (Fritts 1976). Conversely, ring widths of a sensitive tree can vary dramatically in accordance with climatic variation (Stokes and Smiley 1968; Schweingruber *et al.* 1990).

Some species respond more quickly than others to environmental constraints and changes. Therefore, the ring record of a slower-responding species may "lag" behind actual climatic conditions. This lag is not evident upon inspection of the actual ring record, but by examining known pointer years (sections of unique ring-widths) in the ring record, this problem can be noted and rectified (Schweingruber 1988). By knowing the specific dates associated with these pointer years, a researcher can detect problems that may arise in chronologies due to any aberrations associated with an individual tree's growth.

2.3 Tree Growth

Dendroclimatological research is possible because of the physiological characteristics of trees growing in locations with seasonal climates. In almost all trees, growth in girth is achieved by the division of cells of the vascular cambium, which produces a new layer of xylem (wood) each year. In temperate climates this annual growth appears as "rings" (Mader 1987) that vary in width in response to fluctuating environmental variables (Schweingruber 1988). When growing conditions are favourable, the wide xylem cells are produced. As growing conditions deteriorate, the cells become smaller and thicker (Fritts 1987). In each year the result of this response is the appearance of a light and a dark ring representing a single growing season (Figure 2.0). The wider cells produced in the first part of the growing season are known as earlywood, whereas the narrower cells produced during late season conditions are known as latewood.

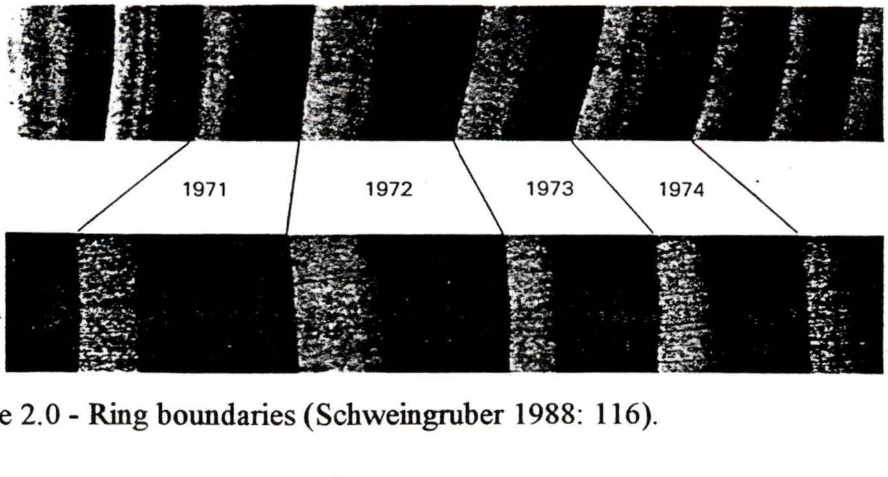


Figure 2.0 - Ring boundaries (Schweingruber 1988: 116).

Each tree species, and each individual, exhibits different growth peculiarities but there are some basic similarities as well (Schweingruber 1993). When a tree's growing season begins, hormones move to different areas of the tree to initiate growth. In many species, growth occurs in different areas of the tree at different rates, and at different times in the growth season. This variation in growth can cause various aberrations in a tree ring record. Three of the most common aberrations are missing rings (Figure 2.1) (Schweingruber 1988), intra-annual or false rings (Stokes and Smiley 1968) and, in conifers, compression wood (Fritts 1976).

False rings represent locations in an annual ring where cells resemble those at a latewood boundary. Some time later, cell growth changes again and resumes earlywood growth, giving the appearance of one extra ring in a chronology of ring-widths (Figure 2.2). This anomaly may be caused by a variety of climatic factors ranging from a temporary cold period in the growing season to a change in water supply (Fritts 1976).

The third common anomaly in ring patterns is compression wood. Compression wood refers to uneven radial growth in conifers resulting from leaning of the bole; i.e., more cells are created on the downslope side of the tree in an attempt to correct any tilting that the tree is experiencing (Figure 2.3). This pattern may occur in response to a destructive event that causes the tree to lean, but more often occurs in response to slope movement.

2.4 Limiting Factors

Limiting factors are an important concept in dendroclimatology because they are directly linked to tree sensitivity. The principle of limiting factors states that biological processes cannot proceed at a rate faster than that allowed by the most limiting factor (Kocharov 1990). Of course, this does not mean that the limiting factor is always the same, or that the limiting factor cannot change over time (Fritts 1976). Limiting factors can interact so that small effects may accumulate and additively affect ring growth (Fritts 1976).

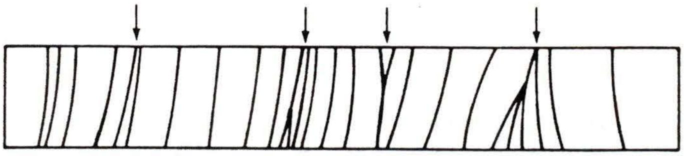


Figure 2.1 - Locally absent rings noted by arrows (Schweingruber 1988: 47).

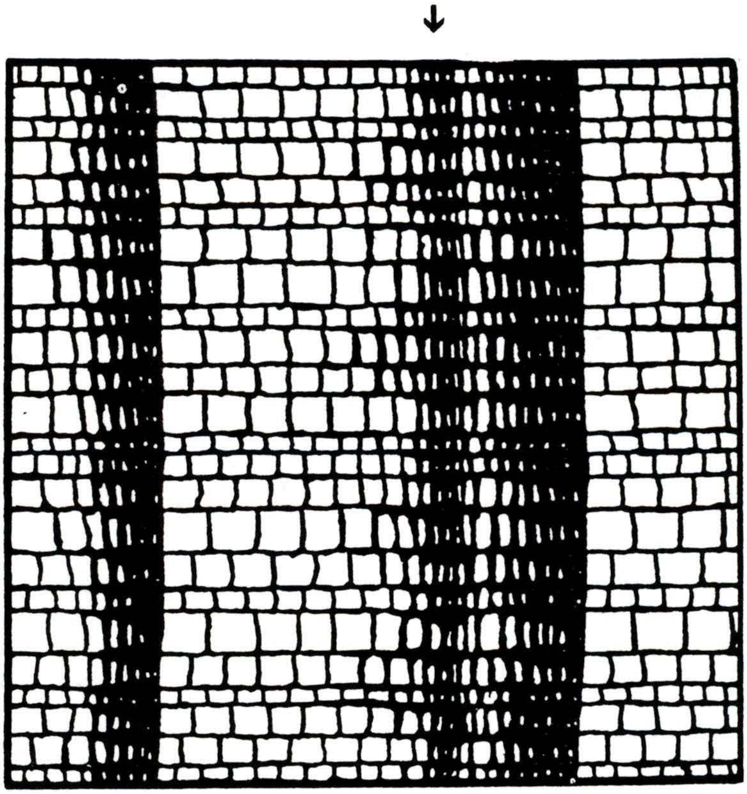


Figure 2.2 - A false ring, noted by arrow (Stokes and Smiley 1968: 17).

Figure 2.3 - Compression wood.

With so many variables affecting tree growth, it would perhaps seem impossible to define the most limiting factors in a given site. Nevertheless, experimental sampling has revealed that some of the most environmentally sensitive tree-ring records come from rocky locations with limited amounts of soil (Fritts 1976). Alternatively, sites with excessive soil moisture deter oxygen uptake in the root system and limit growth (Fritts 1976). Air temperature is also an important factor that can limit growth, because photosynthesis is most effective where the growing season temperature reaches between 15 and 20° C for most species (Fritts 1976). In addition, many researchers have shown that trees can be limited by reductions in the available moisture (Fritts 1976;

Schweingruber 1988).

Complicating limiting factors at high altitudinal sites are temperature constraints that inhibit optimum photosynthesis (Fritts 1976). It has been found that cambial growth at treeline sites occurs over a period lasting anywhere from 4 to 6 weeks (Fritts 1976) to as long as 8 weeks (Schweingruber 1988). Since upper elevational areas have such a short growing season, temperature is usually the factor most limiting to tree growth through its effect on photosynthesis (Fritts 1976; Schweingruber *et al.* 1990). Most dendroclimatological studies at treeline locations have tended to correlate ring variation most strongly with temperature changes (Heikkinen 1985; Robertson and Jozsa 1988; Colenutt and Luckman 1991; Wig 1992).

2.5 Dendroclimatological Studies in the Pacific Northwest

Dendroclimatological research programmes have taken place mainly in the Washington and Oregon Cascades (Parker 1964; Brubaker 1976), the coastal ranges of British Columbia (Fritts 1965; Dobry and Klinka 1993), and the British Columbia interior plateau (Fritts and Schulman 1964). A few studies have also been conducted at higher latitudes, in northern British Columbia (Schweingruber 1983), the Yukon (Henock and Parker 1975; Church and Fritts 1977) and Alaska (Schweingruber 1983). In most investigations it has been found that tree growth exhibits a positive correlation to summer temperatures, and in some cases negative correlations to fall, winter and spring precipitation (Brubaker 1982).

Many different tree species have been investigated for dendroclimatological purposes in the Pacific Northwest (Table 2.0). In Alaska, the Yukon and northern British

Columbia, species are investigated for properties limiting tree growth at the upper latitudinal boundaries of tree occurrence, and hence temperature is usually found to be a limiting factor (Brubaker 1982). Previous research has focused on upper elevation sites where tree growth is limited by temperature. Nevertheless, in the southern part of British Columbia, and in Washington and Oregon, species such as ponderosa pine (*Pinus ponderosa* Laws.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) provide a useful precipitation signal. Upper elevation maritime or hypermaritime sites may be distinct from others in the region, however, as more than one dominant factor may be limiting (Graumlich and Brubaker 1986), with tree growth perhaps limited by temperature in one year but by moisture in the next.

Few dendrochronological and/or dendroclimatological studies have been carried out on Vancouver Island. Most have been on a small scale and involved Douglas-fir (Parker *et al.* 1978; Robertson and Jozsa 1987; Jozsa 1988a; Robertson *et al.* 1988). Douglas-fir is a well-known indicator of precipitation-limited trees (Fritts 1976) and, therefore, much research has focused on moisture-stress relationships within the Vancouver Island Coastal Douglas-fir zone. Zhang (pers. comm. 1995) has developed a 2000 year precipitation history using Douglas-fir in the Victoria region of Vancouver Island. In a different type of study, Schmidt (1970) utilized coastal Douglas-fir as a marker to describe the pre-settlement fire history of Vancouver Island.

Upper elevational areas have been the focus of few investigations on Vancouver Island, which is surprising since these areas are expected to produce strong climatic signals (Luckman 1993). Schweingruber *et al.* (1991) and Smith (1994; 1995a) have produced mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) chronologies from five sites on central Vancouver Island. Schweingruber *et al.* (1991) found summer temperature to be a major factor in growth, whereas Smith (1995b) found summer temperature and spring snowpack to be the major factors related to growth.

Table 2.0 - Species established as dendrochronologically useful in the Pacific Northwest.

Species	**Location / Source**
Douglas-fir	Pavillion Lake, BC- Fritts (1965)
Ponderosa pine	Kamloops, BC- Fritts (1965)
Western hemlock	Wanlick Creek, WA- Brubaker (1975)
Englemann spruce	Rainy Pass, WA- Brubaker (1976)
Noble fir	Butte Camp, WA- Brubaker (1976)
Subalpine fir	Deer Park, WA- Brubaker (1976)
Whitebark pine	Sunrise Ridge, WA- Brubaker (1976)
Subalpine larch	Crater Mountain, WA- Heyerdahl (1989)
White spruce	Wolverine Plateau, YK- Henock and Parker (1975)
Mountain hemlock	Strathcona Park, BC- Smith and Laroque (1995)

Another related study in the Pacific Northwest was conducted by Dobry and Klinka (1993) in the Greater Vancouver Water District. Three tree species (Pacific silver fir [*Abies amabilis* (Dougl.) Forbes], western redcedar, and yellow-cedar) were sampled and examined for their dendrochronological potential. Cores were removed from 32 Pacific silver fir, 11 western redcedar, and 2 cores from a single yellow-cedar tree. Although no significant conclusion can be drawn from the use of two yellow-cedar cores in this study, the study was a positive indicator of the dendrochronological potential of yellow-cedar.

2.6 Yellow-cedar

The genus *Chamaecyparis* consists of only six species, three in southeast Asia, and three in North America (Hosie 1990). All members of this genus tend to be found in mixed stands, and most occur in upper elevational areas with mild maritime climates (Alaback 1992).

Yellow-cedar is restricted to the Pacific Northwest of North America, from as far north as Alaska to its southern limit in the Siskiyou Mountains of northern California (Antos and Zobel 1986). Its range in Canada is largely restricted to the coastal areas of mainland British Columbia and Vancouver Island (Krajina *et al.* 1982) (see Figure 2.4). In nearby Washington and Oregon states, yellow-cedar occurs primarily on the west side of the Cascade Mountains (Fowells 1965; Antos and Zobel 1986). A limited number of yellow-cedar stands are reported from interior locations in British Columbia, Washington, and Oregon (Fowells 1965; Alaback 1992). Many of the coastal and interior populations are disjunct, and assumed to be remnant populations of a once more contiguous distribution (Fowells 1965; Alaback 1992).

Mature yellow-cedar trees have a slightly buttressed base with a tapered trunk. Their branches have a drooping appearance, with small branchlets hanging down from the main bough. The crowns of the trees are conical with a noticeable droop to the leader. The leaves of the trees are flat, scale-like, and blue-greenish in color. They resemble those of western redcedar, but can usually be distinguished by their more sharply-pointed tips and four rows of similar leaves. Western redcedar, on the other hand, has two rows of folded and two rows of non-folded leaves (Pojar and MacKinnon 1994). Yellow-cedar bark has a silvery-grey color and narrow papery vertical ridges in the shape of strips up the bole (Hosie 1990; Coward 1992). The tree itself has a pleasant distinctive "cedar" odour, a result of defensive compounds within the plant (Barton 1976).

Figure 2.4 - Distribution of yellow-cedar in British Columbia (Krajina *et al.* 1982: 65).

Seed production by yellow-cedar in natural stands follows a two-year cycle (Owens and Molder 1975). The seed-bearing cones are initially small, light green and occur at the ends of branchlets (Pojar and MacKinnon 1994). In the first year, pollination usually occurs in April and fertilization in July, followed by a period of embryo development until October when dormancy sets in (Colangeli 1992). Embryo development begins again in the second spring and summer, and the seeds are finally released in the second fall (Owens and Molder 1975). In recent seed orchard tests, it has been found that the natural two-year system can be reduced to one year if seed development takes place in a warmer, lower-elevational location (Colangeli 1992).

Genetic testing has shown that the species has a large genetic variability (Russell and Cartwright 1992). Although the research is in the early stages, there seem to be many attributes that could be exploited, especially in the wood quality spectrum where there is much commercial interest (Russell and Cartwright 1992).

Yellow-cedar is remarkably adaptable (Antos and Zobel 1986; Karlsson and Russell 1990; Koppenaal and Mitchell 1992; Hawkins 1993) and is sometimes referred to as a "generalist" (Russell 1993) or a "stress tolerator" species (Antos and Zobel 1986; Alaback 1992). The only ecological factor delimiting its range is maritime climte, so it can grow throughout the Mountain Hemlock and the wetter Coastal Western Hemlock zones (Krajina *et al.* 1982). The only factor that seems to slow the spread of the species within or beyond the areas it currently grows is its inability to compete with other faster-growing trees (Fowells 1965; Russell 1993). Thus, yellow-cedar is commonly found at high elevations and on sites where other tree species do poorly, not because it necessarily grows best on these sites, but because elsewhere it often cannot compete effectively with other species (Barker 1992; Antos and Zobel 1986).

Within the Mountain Hemlock zone, yellow-cedar grows under various moisture regimes from xeric (dry) to subhydric (very wet), and within nutrient regimes from oligotrophic (poor) to eutrophic (rich) (Klinka 1992) (Figure 2.5). Under natural conditions yellow-cedar is most common in areas where the soil is very moist (Figure 2.6a), the climate is hypermaritime (Figure 2.6b), and the soil is derived from base-poor igneous rock (Figure 2.6c). Other locations may provide better conditions for growth, but in natural situations the yellow-cedar are out-competed. For example, Hawkins (1992) has shown that nitrogen-rich soils do provide optimum growth for yellow-cedar, but at such locations yellow-cedar simply cannot compete.

Yellow-cedar is long lived, as individuals are known to reach ages well over 1000 years (Table 2.1). On average yellow-cedar trees grow to heights between 30 and 50 metres, with diameters between 1 and 1.5 metres (Hosie 1990; Pojar and MacKinnon 1994). In recent clonal tests under optimal conditions, the growth rate of five year old yellow-cedar has been shown to be approximately 55 centimetres of height per year (Barker 1992). This is less than that of western hemlock (*Tsuga heterophylla*) at 61 centimetres per year but greater than that of grand fir (*Abies grandis*) at 50 centimetres per year for the same conditions (Barker 1992).

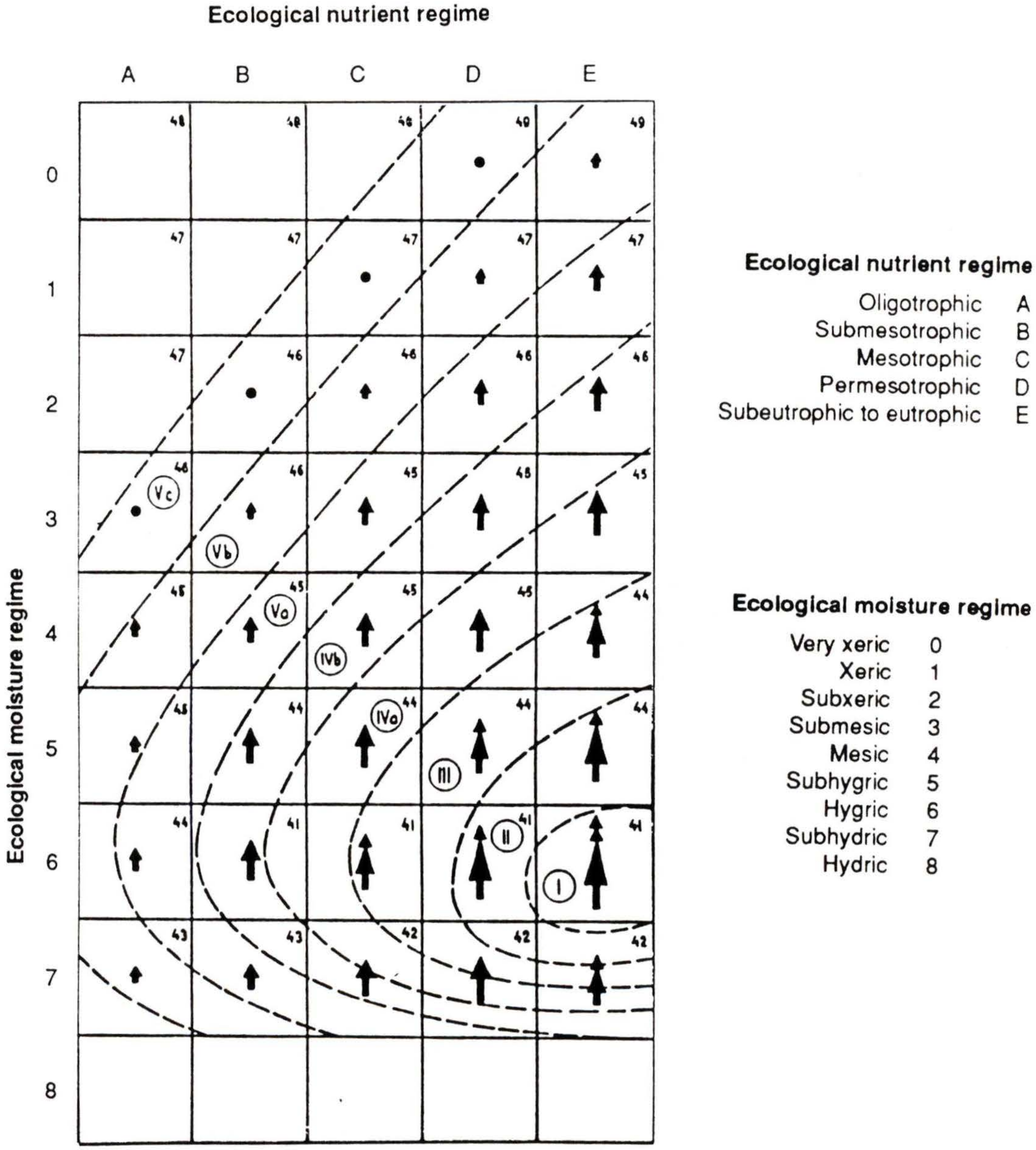


Figure 2.5 - Ecological quality of site condition in the mountain hemlock zone (Klinka 1992: 27).

Figure 2.6a - Yellow-cedar growth along a soil moisture gradient. The range of occurrence is represented by the bar (Klinka 1992: 25).

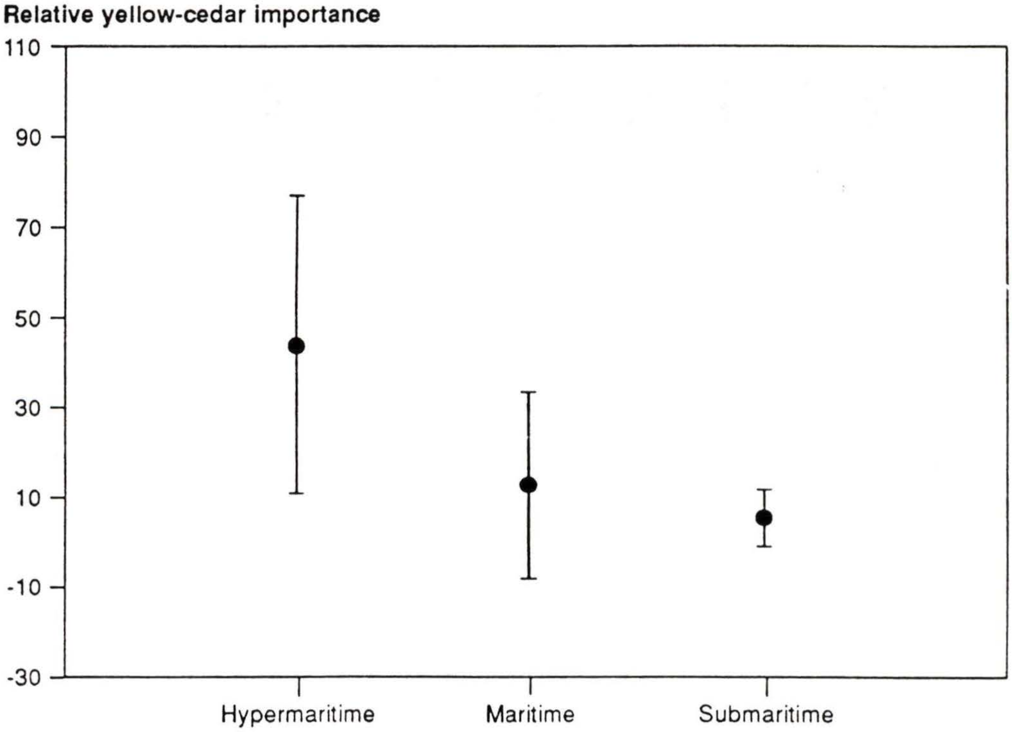


Figure 2.6b - Occurrence of yellow-cedar in relation to continentality (Klinka 1992: 26).

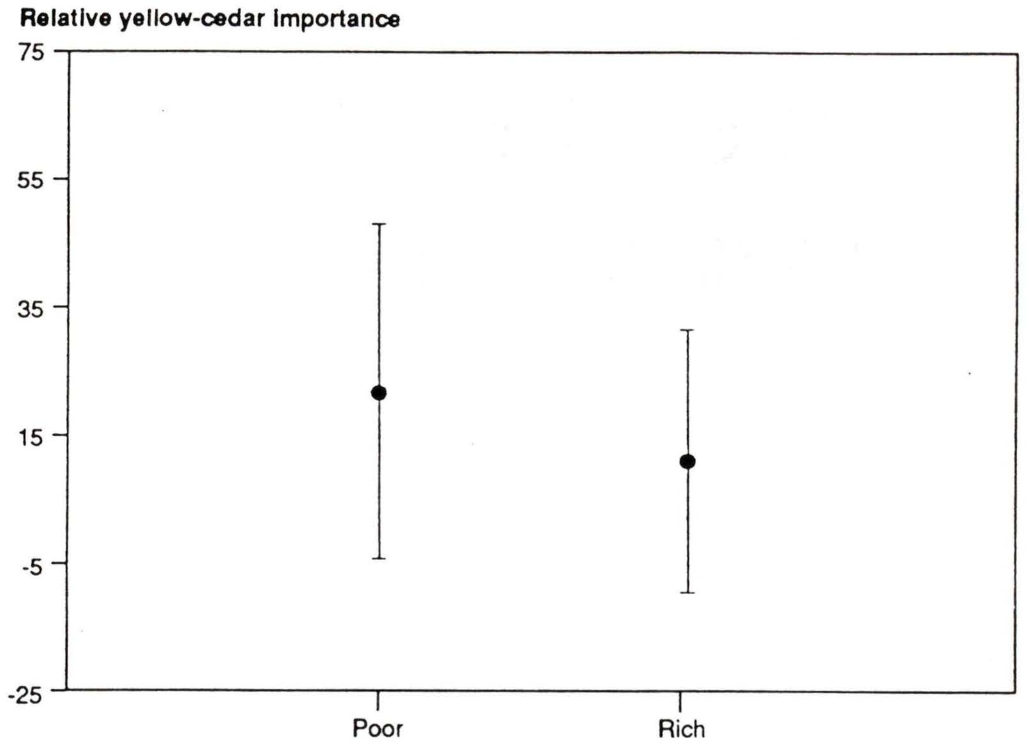


Figure 2.6c - Importance of nutrient quality to yellow-cedar growth (Klinka 1992: 26).

Yellow-cedar is considered frost hardy (Hawkins 1993; Hawkins *et al.* 1994). Its hardiness increases rapidly in fall and achieves a maximum at the beginning of January (Grossnickle 1992). This increase is triggered by the loss of light energy and a greater number of frost events. After the beginning of January, as the light energy increases, the frost hardiness of the plant decreases (Hawkins 1993), even though frost events may still be increasing in number. Drought resistance in yellow-cedar also varies, such that during spring shoot development tolerance is at a low. As with most tree species (Grossnickle 1992), drought tolerance increases as shoot system growth slows.

Table 2.1 - Age and location of some ancient yellow-cedar trees.

Age in years	Location	Source
1845	N/A	Pojar and MacKinnon (1994)
1700	Sunshine Coast	Steve Chatwin*, pers. comm.
1600	Campbell River, BC	Jozsa (1992b)
1200	North Vancouver, BC	Stoltmann (1987)

*Steve Chatwin, British Columbia Ministry of Forests, 1994.

Yellow-cedar is also regarded as shade tolerant, which means it can grow under moderately dense canopies (Fowells 1965; Antos and Zobel 1986). In addition, it is considered moisture sensitive, as it has been found to be more sensitive to reduced soil moisture than any other associated conifer species in the region (Grossnickle and Russell 1991).

Most of the locations where yellow-cedar grows are not subjected to temperature extremes because of strong maritime influences. However, yellow-cedar seedlings are intolerant of high soil surface temperatures in the summer (Koppenaal and Mitchell 1992) and are also sensitive to low soil temperatures in the fall and winter (Grossnickle 1992). In high-elevation stands, yellow-cedar easily withstands normal winter conditions because large insulating snowpacks reduce the likelihood of soil freezing. If the soil does freeze or temperature drops very low, the tree is usually not mortally injured but instead becomes prone to growth deformities. This is particularly true of younger trees (Koppenaal and Mitchell 1992).

A unique characteristic of yellow-cedar is its remarkable ability to resist disease

(Hennon *et al.* 1990b). This characteristic is primarily the result of two of its extractives, chamic acid and nootkatin (Barton 1976), which protect the tree from insect damage (Hennon 1992). Disease problems in yellow-cedar are largely restricted to nursery settings and few problems are known to occur in natural sites. Of the diseases that do occur, most consist of shoot blights on young trees or on planted seedlings (Hennon 1992). Fungal infection resulting in internal decay seems to be the greatest cause of mortality (Hennon 1990; Hennon 1992; Hennon *et al.* 1990b). Documented cases of brown bear damage in Alaska and northern British Columbia have shown that scarring can be fatal if fungi enter open wounds caused by teeth and claw marks (Hennon *et al.* 1990c). Other notable problems are associated with deer browsing, especially in the Queen Charlotte Islands, and occasionally porcupine browsing, although yellow-cedar does not seem to be this animal's favourite meal (Hennon 1992). One other case of tree die back was noted by Auclair *et al.* (1990), in which yellow-cedar was severely affected by a unique winter freeze-thaw cycle, followed by a summer of high temperatures.

Density profile readings of the wood of various Pacific northwest tree species revealed that yellow-cedar was the most uniform in cell density from earlywood to latewood structures (Figure 2.7). This means that there is little difference from cell to cell and is the reason that yellow-cedar was not considered suitable for densitometric study (Schweingruber *et al.* 1990).

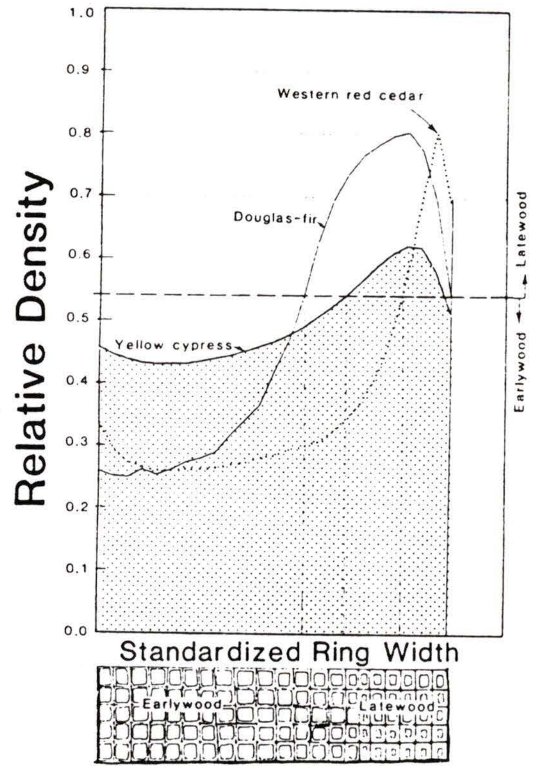


Figure 2.7 - Cell density of yellow-cedar in comparison with western red cedar and Douglas-fir (Jozsa 1992a: 10).

3.0 Study Sites

In dendroclimatology, it is important to hold constant as many growth factors and site conditions as possible to maximize the micro-scale climate signal (Schweingruber *et al.* 1990). Since this study dealt with a specific tree species, the first priority in site selection was given to considering the elevational constraints affecting most yellow-cedar trees. Yellow-cedar trees on Vancouver Island are found from sea level to timberline (Hosie 1990). At warmer, lower elevational locations, yellow-cedar growth is vigorous. In contrast, at high elevation yellow-cedar tends to grow at slower rates than co-occurring species (Hosie 1990). This behavior is attributed to the fact that a substantial portion of its energy resources is used for defensive purposes (Loehle 1987).

All sites chosen for this study lie within the Mountain Hemlock Zone (Klinka *et al.* 1991), sometimes referred to as the Subalpine Parkland Biogeoclimatic Zone (Pojar and MacKinnon 1994). This zone is usually distinguished by islands of trees made up of mountain hemlock, yellow-cedar, and sometimes amabilis fir (Pacific silver fir). The undergrowth is typically sparse because of poor soil development, high slope angles and exposed bedrock outcrops.

The Mountain Hemlock Zone of Vancouver Island is commonly associated with severe climatic conditions and a short growing season with only 1.7 months of the year exhibiting a mean temperature above 10° C (Klinka *et al.* 1991). Mean temperature in the zone is only 3° C but the amplitude of temperature is small, with the coldest month having an average of -5.1° C, and the warmest month 11.1° C (Klinka *et al.* 1991).

Annual precipitation in the zone averages 2620 millimetres, with 31% falling in the form of snowfall during the colder months. The wettest month receives 414 millimetres of moisture and the driest only 62 millimetres (Klinka *et al.* 1991). The soil remains unfrozen year-round in nearly all areas of the Mountain Hemlock zone, because temperatures do not drop very low before a deep snowpacks developes (Klinka *et al.* 1991).

3.1 Sites

Five sites were selected for study within the Insular Mountain Range of Vancouver Island (Figure 3.0). The three primary sites were extended along a latitudinal gradient from Mount Cain in the north, to Mount Washington and then Mount Arrowsmith in the south. Samples were collected at two secondary sites to evaluate growth conditions in different ecological settings. Heather Mountain had considerably more moisture available for growth than all other sites, whereas Milla Lake provided a high elevational site near an active glacier.

3.2.1 Mount Cain

Mount Cain was the northernmost site selected for sampling (126° 19' 55" west longitude, 50° 14' north latitude). The site was accessed from Highway #19 and the Mount Cain Regional Park and Winter Sports Area roads, maintained by Canadian Forest Products (Canfor) within Tree Farm License #37.

The upper elevational limit of yellow-cedar at Mount Cain is approximately 1480 m asl. Sampling was restricted to an area approximately 100 by 300 m, positioned between two ski runs on a south-facing slope with a slope angle of 27° (Figure 3.1).

Samples were collected at sites from 1460 to 1355 m asl (mean = 1393 m asl) (Appendix A).

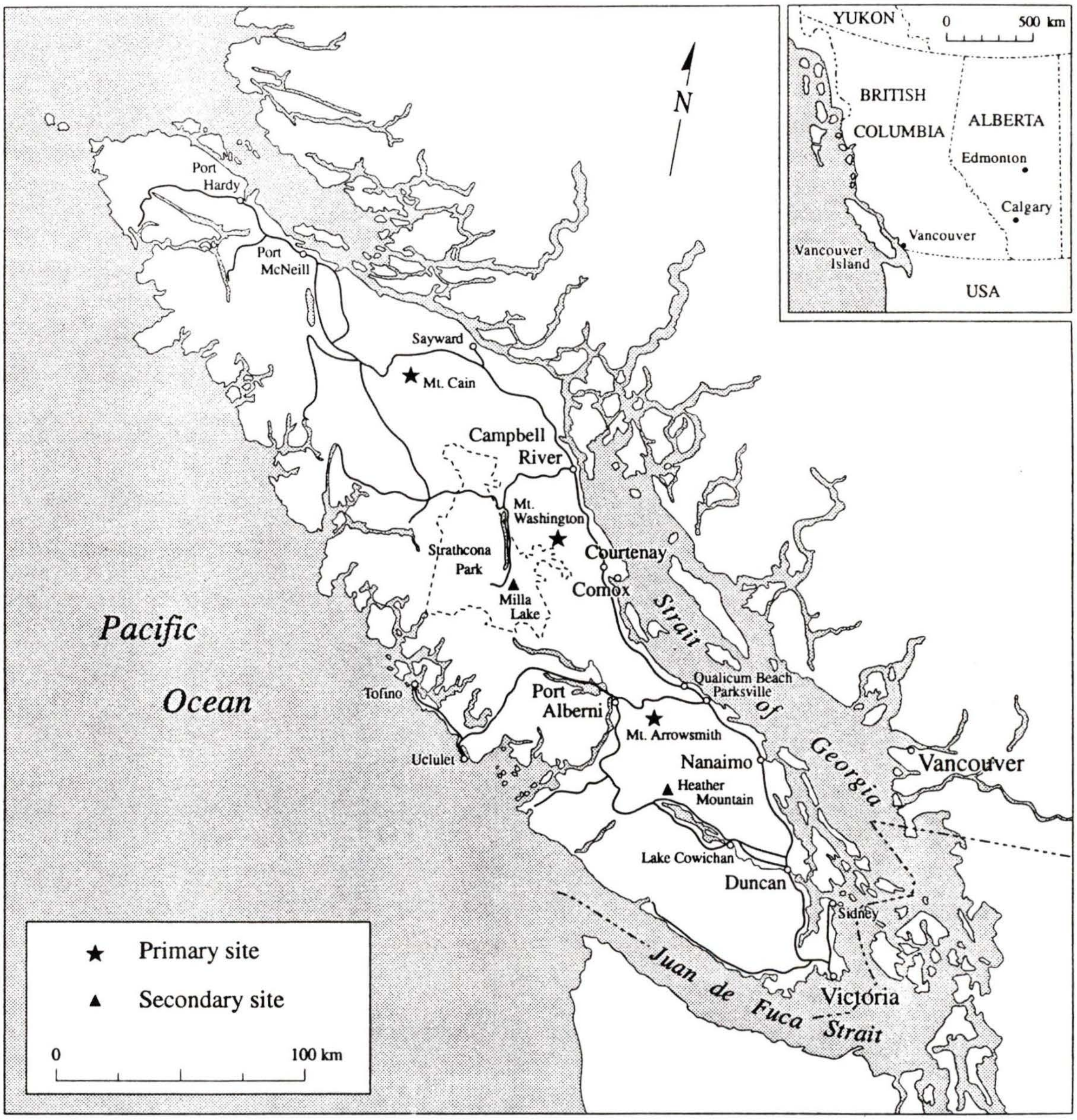


Figure 3.0 - Primary and secondary site locations.

Figure 3.1 - Mount Cain study site. Sampling locations were in the group of trees in the foreground of the photograph (indicated by arrow).

The Mount Cain site has mature and stunted yellow-cedar trees, many with slightly damaged crowns, and similarly stunted mountain hemlocks. The highest trees at the site had a shrub-like appearance and were not sampled. Butt rot was common in the heartwood of most of the yellow-cedar boles.

Some samples were taken at locations where the opening of the canopy along new ski runs could have affected growth rates. It was decided that this factor would pose little problem to the study, since the runs on the ski slope are only two years old (Alex Lapore, pers. comm. 1994) and those years could be eliminated from a growth chronology.

3.2.2 Mount Washington

The Mount Washington site is adjacent to the Mount Washington ski hill (125° 17' 40" west longitude, 49° 45' 6" north latitude), and is accessed via Highway #19 out of Courtney. The sampling area was located on a south-southeast facing slope (25°) within the property boundaries of the ski facility. A general site reconnaissance was undertaken and a few samples were collected near the summit at 1570 m asl (Appendix B). However, most samples were collected between 1440 and 1210 m asl (mean = 1470 m asl) in a 230 by 300 metre section on the eastern edge of the property (Figure 3.2).

The trees sampled were from a mixed stand, with a healthy undamaged 'droop' associated with their apical meristems (Pojar and MacKinnon 1994). Most of the trees exibited few physical blemishes. None of the boles had a large diameter, with most in the 0.4 to 0.5 metre range. Burned stumps and charred logs were found on the floor of the stand. This suggested a history of fire, as well as providing an explanation for the apparently young generation of trees dominating the site.

Other common tree species at this site included amabilis fir at upper elevations and Douglas-fir lower on the mountainside. A few of the trees samples were located near a freshly-cleared ski run called Fletcher's Challenge (Don Bradshaw, pers. comm. 1994). Since this run is the newest on the ski hill, it was felt that any release (abrupt growth change) in the tree rings due to increased light and moisture could be easily filtered out of the ring-width chronology.

Figure 3.2 - Mount Washington study site. Sampling locations were in the trees beside the last ski run on the right side of the photograph (indicated by arrow).

3.2.3 Milla Lake

The Milla Lake site is located within the boundaries of Comox Glacier Nature Conservancy (125° 23' 00" west longitude, 49° 33' 16" north latitude). Sampling from this secondary site was restricted to an area on the northwest side of Milla Lake, immediately above a prominent trimline left by the retreat of Moving Glacier (Figure 3.6). Samples were taken from trees on a west-southwest-facing slope (59°) positioned between 1590 and 1640 m asl (mean = 1601 m asl) (see Appendix E).

The forest cover at the Milla Lake site was dominated by mountain hemlock, with only a limited number of yellow-cedar present. The yellow-cedar at the site had limited sign of new growth, with many of the larger trees characterized by damaged boles and branches. The few younger yellow-cedar found at the site were growing in small openings in the canopy or adjacent to openings beside exposed bedrock.

Figure 3.3 - Milla Lake study site. Sampling locations were the trees across the foreground of the photogragh (indicated by arrow).

3.2.4 Mount Arrowsmith

Mount Arrowsmith is the southernmost of the three primary sites sampled (124° 34' 50" west longitude, 49° 14' 47" north latitude). Access to the area was via the Mount Arrowsmith Ski Resort road within Mount Arrowsmith Regional Park, accessible from Highway # 4.

The samples were collected from an east-southeast-facing slope with an average gradient of 26° (Figure 3.3). This stand of trees occurs along the boundary of Mount Arrowsmith Regional Park, below the summit of Mount Cokely. Sampling was restricted to trees situated between 1178 and 1290 m asl (mean = 1224 m asl) (Appendix C). Trees at this location had a "scrubby" appearance. Many of the stems and branches of the yellow-cedar were broken and damaged. Of all the sites yellow-cedar was most dominant at this location; mountain hemlock was the only other species present in abundance. The forest floor was characterized by mosses and heather and exposed bedrock.

Figure 3.4 - Mount Arrowsmith study site. Sampling locations were in the trees on the left side of the photograph (indicated by arrow).

Although the Mount Arrowsmith ski resort opened in the 1940s, the site has only recently (1992) had new ski runs cleared at higher elevations near the sample site (Lyle Price, pers. comm. 1994). For this reason release in growth due to any logging on the new ski runs was thought to be minimal, and like the other sites could be corrected if indeed present.

3.2.5 Heather Mountain

The Heather Mountain site was accessed via logging roads on the north shore of Lake Cowichan (124° 27' 23" west longitude, 48° 57' 37" north latitude). The site is located within an area managed by Fletcher Challenge Limited. Sampling was restricted to an area adjacent to a bog on the northeast side of the summit at 1135 m asl (Appendix D). Vegetation was dominated by mountain hemlock and western hemlock. Yellow-cedar made up a relatively small portion of the stand, and was common only at wetter locations. Heather and moss were dominant in the understorey vegetation, except at more boggy sites where sedges, grasses and ferns were also common (Figure 3.5).

Figure 3.5 - Heather Mountain study site. Sampling locations were in the trees surrounding the bog.

4.0 Methodology

This chapter describes the methodology used in the research programme. The procedures used in the selection of trees and in the extraction of cores are described, followed by a description of the way the cores were processed and the software used to analyze the ring-width data. This description is followed by an explanation of the climate information used in the dendroclimatological analysis which follows in Chapter 6.

4.1 Samples

Samples were collected at the five study sites during July, August and September of 1994. At each of the primary sites (Mount Cain, Mount Washington, and Mount Arrowsmith) two cores were extracted from each of 50 yellow-cedar trees. At Milla Lake, 50 cores from 25 trees were collected and at Heather Mountain 30 cores from 15 mature trees were sampled (Figure 4.0). At each site the micro-characteristics of the stand were assessed to determine final selection of individual samples. Boggy areas and trees with obvious bole damage and butt rot were not sampled. In the main bole, cracks in the upper parts usually signalled rot in the lower reaches of the trunks. Where this occurred, simply tapping the tree and hearing a solid versus a hollow noise was usually a good indication that the tree was sound. If any doubt persisted, a test core was extracted to ascertain if the tree could indeed provide useable cores.

4.2 Sampling

Ring-width samples were obtained using increment boring tools to extract 4.3 millimetre cores at breast height. Two cores were taken per tree, on opposite sides of the tree (Fritts 1976; Schweingruber *et al.* 1990). The cores were stored in plastic drinking straws for transportation to the lab. Each straw was labelled and designated with both the tree and core numbers. By taking two different cores from the same tree a direct comparison can be made of the number of rings and their widths. This procedure minimizes the amount of missing or inaccurate data resulting from missing bands or "false" rings (LaMarche 1982).

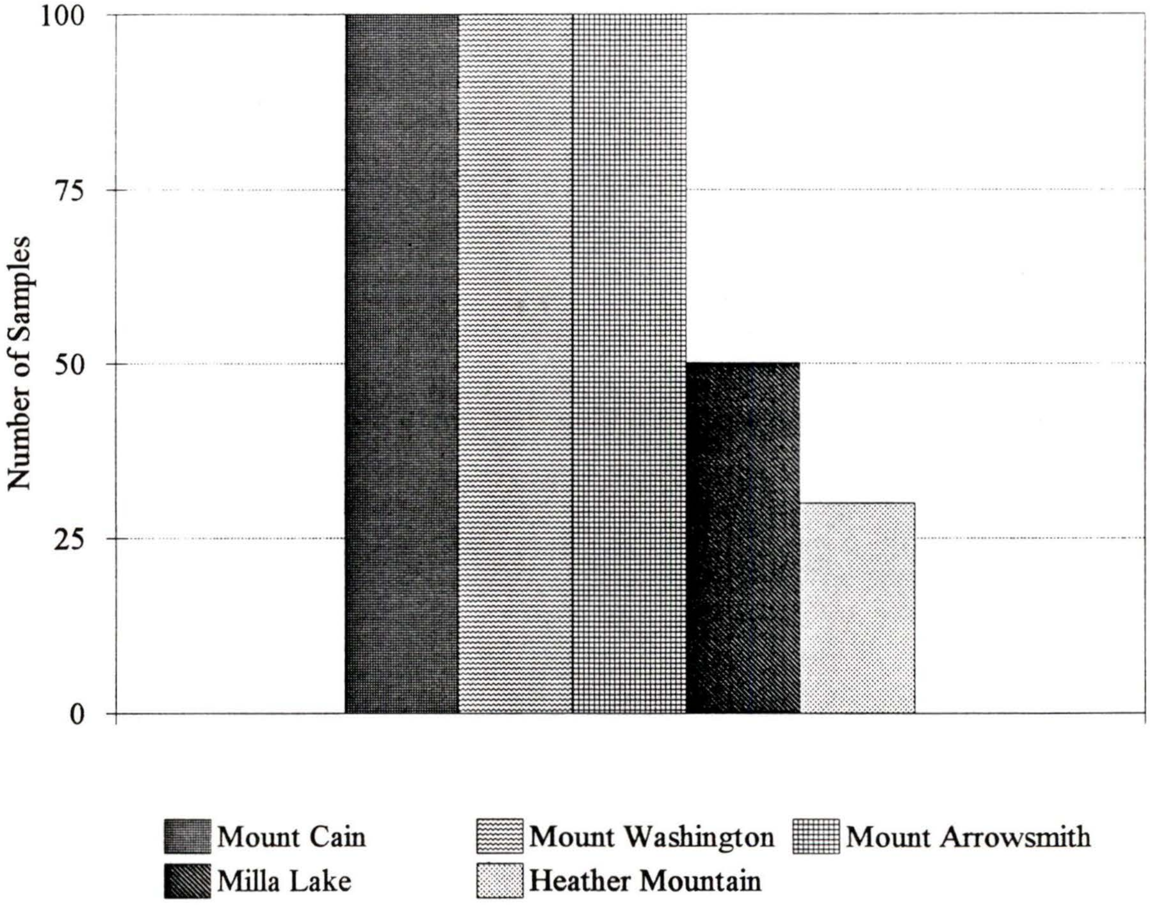


Figure 4.0 - Number of cores in the study.

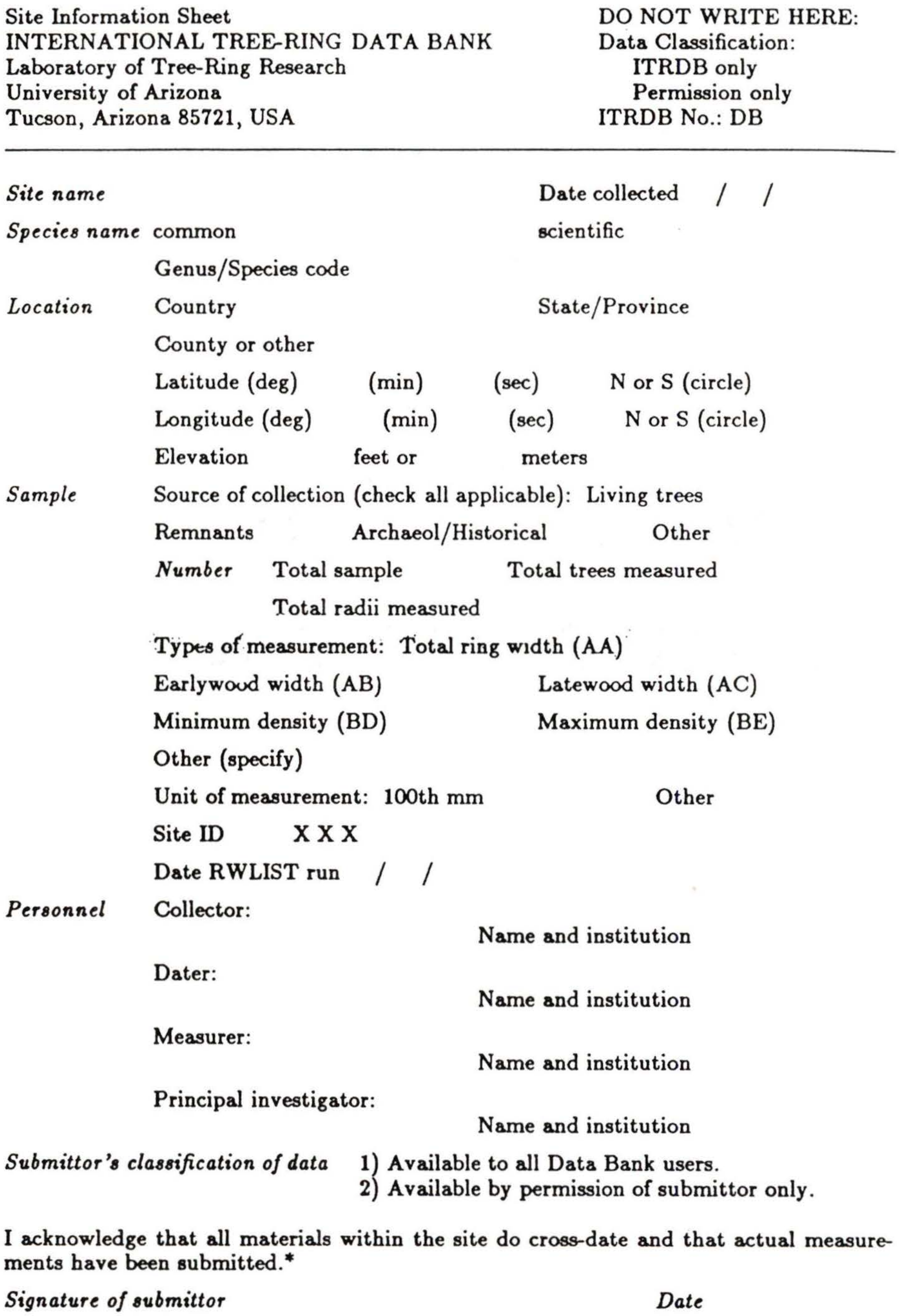
At each tree the notable site characteristics were recorded, as well as the general physiological qualities, approximate size and condition of each individual tree. Elevation was established with a hand-held altimeter (see Appendix A-E) and the approximate location on the slope for each tree was mapped. These characteristics were noted in order to describe the site according to the International Tree Ring Data Bank (ITRDB) methodology (Figure 4.1).

4.3 Processing

Individual cores were air-dried and glued onto slotted mounting boards. Special care was taken to ensure the cores were glued with their rings in a transversely-mounted position as opposed to a radially-mounted position (Fritts 1976). All the samples were sanded using a hand-held orbital sander with progressively finer grades of sandpaper. A final polish was applied by hand (600 grade paper) to assure a uniform surface; this step also allowed an opportunity for close final examination of the samples before continuation of the analysis.

4.4 Measurement

WinDendro II ™ (Version 4.1.2, 1994) is a computer-controlled measuring system for tree ring-widths. A digital image of the wood density of each tree core was created using a high resolution Hewlett Packard Scan Jet IIc ™ scanner (800 dpi x 400 dpi). Based on these density differences, an algorithm within WinDendro™ automatically assigned the ring boundaries. All cores were measured from the pith outward. If a ring boundary was missed or incorrectly assigned, or if cracks and other anomalous areas were included, menu-driven tools were used to edit the measurements. When the boundary divisions were finalized, the resulting ring-width measurements were saved in the Tucson format (Holmes 1994).



Site Information Sheet
INTERNATIONAL TREE-RING DATA BANK
Laboratory of Tree-Ring Research
University of Arizona
Tucson, Arizona 85721, USA

DO NOT WRITE HERE:
Data Classification:
ITRDB only
Permission only
ITRDB No.: DB

Site name Date collected / /

Species name common scientific

Genus/Species code

Location Country State/Province

County or other

Latitude (deg) (min) (sec) N or S (circle)

Longitude (deg) (min) (sec) N or S (circle)

Elevation feet or meters

Sample Source of collection (check all applicable): Living trees

Remnants Archaeol/Historical Other

Number Total sample Total trees measured

Total radii measured

Types of measurement: Total ring width (AA)

Earlywood width (AB) Latewood width (AC)

Minimum density (BD) Maximum density (BE)

Other (specify)

Unit of measurement: 100th mm Other

Site ID X X X

Date RWLIST run / /

Personnel Collector:
Name and institution

Dater:
Name and institution

Measurer:
Name and institution

Principal investigator:
Name and institution

Submittor's classification of data 1) Available to all Data Bank users.
2) Available by permission of submittor only.

I acknowledge that all materials within the site do cross-date and that actual measurements have been submitted.*

Signature of submittor *Date*

Figure 4.1 - International Tree Ring Data Bank site criteria (Cook and Kairiukstis 1990: 346).

4.5 Cross-dating

The measurement data were checked for homogeneity of signal using COFECHA

(Holmes 1994). COFECHA checks for measurement errors by flagging an area of a core that does not statistically fit into the normalized pattern created by all the tree cores of the set of data. When an area differs significantly, the program calculates correlation possibilities for sectors of the data that vary from the original position. The calculations are performed for yearly deviations in a plus and minus ten year span around the original segment of data.

In addition to cross-dating, COFECHA provides three main descriptor values that are useful for describing the individual data sets: series correlation, autocorrelation, and mean sensitivity. Series correlation is a measurement of the entire series and it describes the degree of common signal contained in the group of trees from a site. It is measured on a scale of +1.0 (a perfect positive correlation in the data set) to -1.0 (a perfect negative correlation in the data set). Values greater than +0.3281 or less than -0.3281 are considered to be significant at the 99% confidence interval (Holmes 1994).

Autocorrelation is a measure of the effect that the present year's growth has on the next year's performance. This measurement has a scale of 0 to 1.0. A value of 0.0 would indicate no autocorrelation in the data, and would signify that the growth in one year has no effect on the next year's growth. A measure of 1.0 signals that each year's growth completely dictates growth in the following year (Colenutt and Luckman 1991; Holmes *et al.* 1986). Mean sensitivity is defined as a measure of "mean percentage change from each measured yearly ring value to the next" (Douglass 1936, cited by Fritts 1976). It therefore shows how sensitive a tree or group of trees is to the year-by-year fluctuations in ring growth. A value of 0.0 indicates complacency or little variation, and 1.0 indicates extreme sensitivity to change.

The measures of autocorrelation and mean sensitivity are viewed as strong indicators of the dendroclimatological potential of a tree species (Graybill 1982). A species with a low autocorrelation and a high mean sensitivity has good potential for dendroclimatological studies focused on annual variation. Conversely, a species with a high autocorrelation and low mean sensitivity would not capture enough climate signal to be useful in a dendroclimatological study (Colenutt and Luckman 1991).

4.6 Standardization

Standardization refers to the elimination of variation in the widths of tree rings that results from changes associated with aging. The larger ring-widths of the younger, faster-growing portions of a tree are made comparable to the lesser ring-widths of the older, slower-growing portions of the tree (Fritts 1976). This process reduces the variation in ring width so that it reflects environmental constraints only. By standardizing individual tree measurements, all samples can be grouped to produce a homogeneous data set.

Standardization is a complex procedure, as it is necessary to mimic the average growth pattern of specific trees from the data extracted from a sample of subject trees. As tree species can grow at different rates and growth varies through time due to many factors in the environment, only an expected or "best fit" standardization is possible. The results of these standardization techniques are ring-width indices. In general, indices have an exponential rather than linear trend and their mean value is one. These standardized indices are thus expressed as a percentage of variation from a baseline of one (Stokes and

Smiley 1968; Cook and Briffa 1990) (see Figure 4.2).

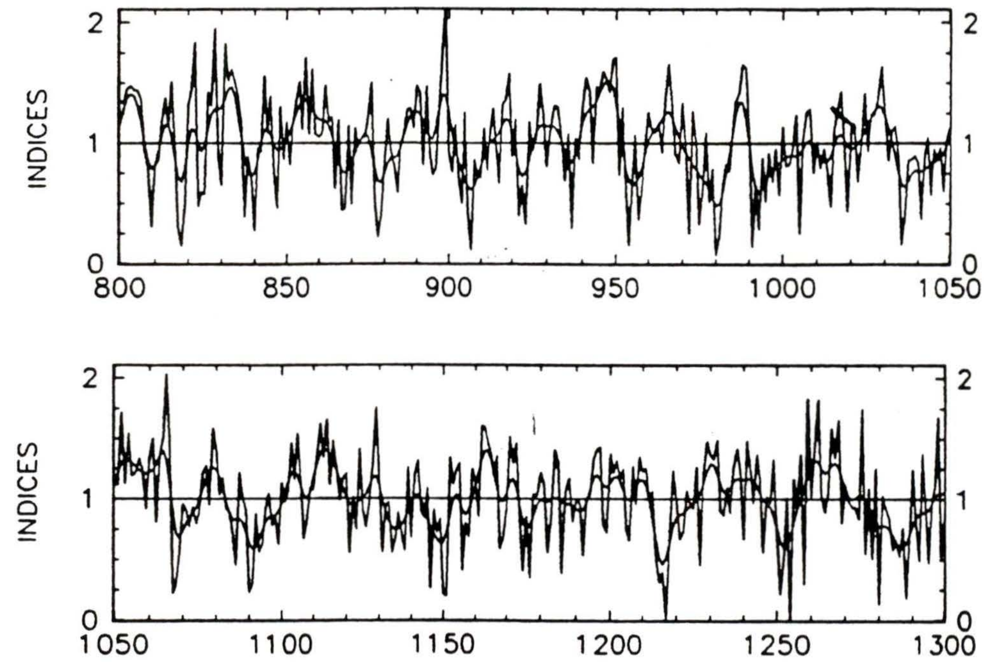


Figure 4.2 - Standardized tree-ring index (Fritts and Dean 1992: 54).

The program ARSTAN (Holmes 1994) was used to detrend (remove the biological growth trend) and standardize the tree ring data sets to eliminate any inherent growth patterns. Through a series of operator-controlled options, the detrending aspect of the program provides a best-fit growth curve that maximizes the signal to noise ratio using three possible methods. ("Signal" is defined as the relevant information contained in the tree-ring widths and "noise" defined as information irrelevant to growth features of the tree (Cook 1987; Cook and Briffa 1990)). The three methods available are the negative exponential curve, the cubic smoothing spline curve, and the linear regression line (Holmes *et al.* 1986; Cook and Briffa 1990).

Each tree-ring measurement series is run through the program and a curve is fit to each, before all measurement series are compiled together into the master chronology (Holmes 1994). The negative exponential curve describes the growth of most trees, where ring width decreases as trees grow older. This is the most common trend in trees that are growing in open-canopy stands (see Figure 4.3a). The cubic smoothing spline curve corresponds to slow early growth, a peak in growth rate in the middle of its life cycle, and then reduced growth again in old age. This type of growth trend is common in trees that grow in closed-canopy stands, which exhibit a spurt of growth as a result of the canopy opening to collect available sunlight (see Figure 4.3b). Finally, linear regression lines are straight lines that approximate the growth trend of trees with variable growth. These lines usually best characterize tree growth in a closed canopy stand in which a disturbance event will alter the regular growth cycle. The regression line is also commonly found to perform best when a tree's growth is highly variable; see Figure 4.3c (Cook and Briffa 1990).

The indexing feature of the program has two capabilities for outputting an index. The first is a division process (ratio) which divides the tree-ring measurement by the individual detrending curve value. The second is a subtraction process (residual) which subtracts each curve value from the tree-ring measurement.

Various chronology types are produced by ARSTAN. In this study a "Standard" chronology will be used for comparing sites and comparing values.

4.7 Climate Reconstruction

Climatic reconstruction was accomplished using the PRECON Version 4.0™

software program (Fritts 1994). The program recalculates matrices of climatic data using principal components analysis to form new variables that estimate ring-width indices (Fritts *et al.* 1971). These variables therefore maximize variance in the climatic factors influencing growth of the tree species (LaMarche and Fritts 1971). These variables are orthogonal to one another and explain successively lesser amounts of variance. The new variables are suitable for use in stepwise multiple regression, which requires that the predictor variables be independent (Guiot *et al.* 1982). This process is then tested for significance using a bootstrap method (Efron 1979) that constructs a probability distribution of the predicted variables and standard error estimate. This results in greater confidence levels in the prediction of climatic variables driving ring growth than if no cross-validation was done (Guiot 1990, 1991).Originally in this study, the five climate stations closest to the study sites were chosen for testing the relationship of the tree rings to climate. Where station relocation was known to occur (Table 4.0), climate data were averaged from both the new and old locations for the overlapping periods and placed into a master record for the site.

Where data were missing from the station records, the software program MET (Holmes 1994) was utilized to approximate the missing data. MET estimates missing values by calculating the mean and standard deviation for the month from all of the previous and following years of data for that month. It then calculates the departure from the mean for that month, from data collected at nearby stations. The departure from the mean is multiplied by the standard deviation of the month and is added to the monthly average to arrive at the final monthly estimation.

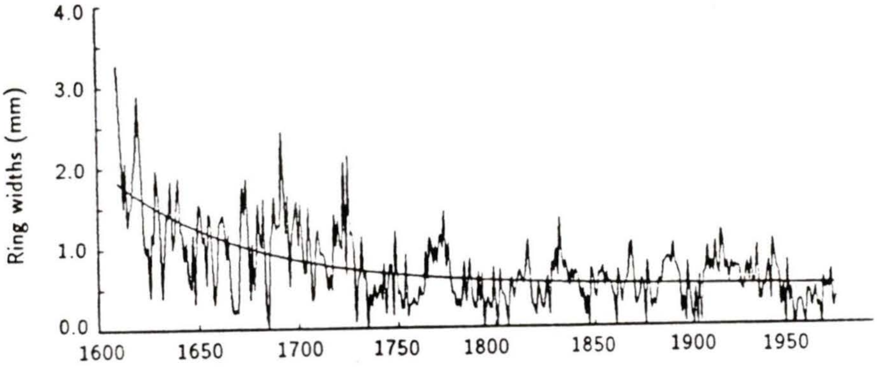


Figure 4.3a - The negative exponential curve (Cook and Kairiukstis 1990: 99).

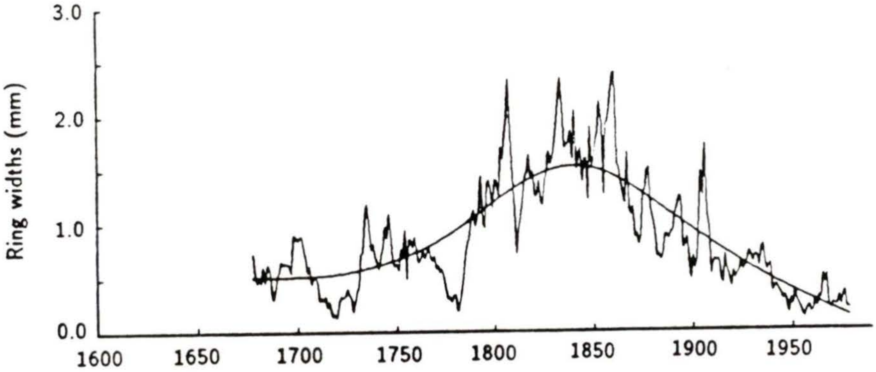


Figure 4.3b - The cubic smoothing spline curve (Cook and Kairiukstis 1990: 99).

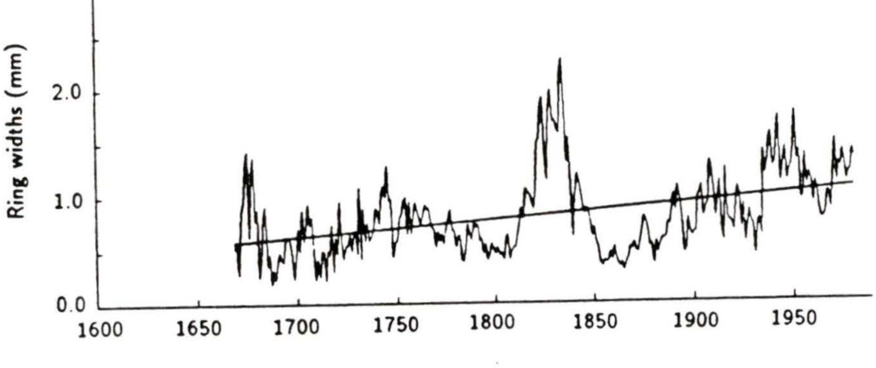


Figure 4.3c - The regression line (Cook and Kairiukstis 1990: 99).

Table 4.0 - Elevations and locations of climate stations.

Site Number	Location	Elevation	Date of Record
1021260	Campbell River	79 m	1936 to 1969
1021261	Campbell River A	106 m	1965 to 1991
1025340	Nanaimo	70 m	1892 to 1968
1025370	Nanaimo A	30 m	1947 to 1991
1027114	Sayward BCFS	15 m	1973 to 1982
1030180	Alberni Beaver Creek	91 m	1894 to 1959
1030185	Alberni City Reservoir	65 m	1962 to 1969
1030210	Alberni Lupsi Cupsi	9 m	1948 to 1974
1030220	Alberni McCoy Lake	43 m	1896 to 1973
1030230	Alberni Robertson Creek	75 m	1961 to 1991
1021830	Comox A	13m	1945 to 1991
No. 3B01	Forbidden Plateau (Snow survey data)	1130 m	1954 to 1995

4.8 Response Function Analysis

The outputs of PRECON were graphically represented as response functions (Fritts *et al.* 1971; Schweingruber 1988; Briffa and Cook 1990) to establish which climate variables represent the limiting factors of the species. Response function analysis is a form of a regression equation (Blasing *et al.* 1984) which integrates two sets of data, a set of orthogonalized climate variables (independant variables) and a standardized tree-ring index for a site (dependant variable). A two-step process occurs in which climatic variables are first transposed to form new principal components. The significant newly-formed orthogonal variables are then used in a multiple regression equation in the order of their ability to explain variation in the tree-ring index.

The resulting regression relationship explains climatic variation in the ring-width series. This information is used to form transfer function equations (Fritts 1976) that relate the ring index to the climatic signals over the time span of the tree series. The advantage of this procedure is that the orthogonalized predictor values do not intercorrelate, and thus show true relationships between tree-ring growth and climate (Heikkinen 1985).

The response function information can be presented graphically to show the relationship of the predictand and the predictors over time in a manner similar to factor loading scores (Figure 4.4). Response function coefficients that are above zero indicate a positive relationship with climatic variables, whereas coefficients lower than zero indicate a negative relationship with the climatic variables. For each component of the response function that is significant, the percentage of variance explained by the element in the year of interest is indicated by the coefficient value on the Y axis.

Following response function analysis a program called REC (Holmes 1994) was used to reconstruct a series of predicted climate factors using the outputs from the PRECON program. REC uses a chronology from ARSTAN and combines it with the significant monthly climate coefficients to produce a set of approximate climatic predictor values. These predictor values are representations of the significant climate parameters through time as estimated using the ring-width pattern of the tree-ring series in a multiple regression process. The predicted climate record, or proxy climate record, is then ready for verification in a goodness of fit process using a program called VFR (Holmes 1994).

VFR requires two inputs: the predicted values and the actual values being predicted. The first step measures a calibration time period and the second measures how close the predicted values come to the calibration measurements. Six main tests are conducted on the data (product sum test, correlation, reduction of error, T-value, sign-products test and negative first differences) and other descriptive statistics are also produced. The program highlights the tests that provide significant results above the 95% confidence level.

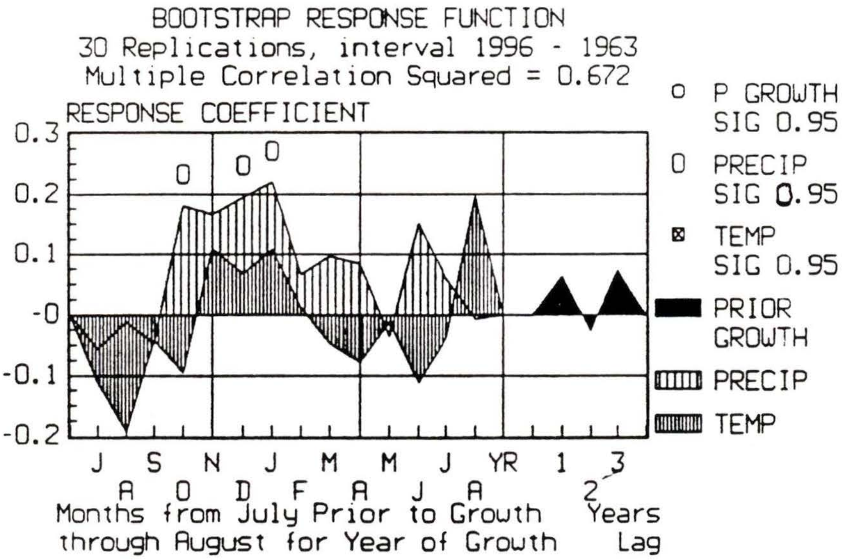


Figure 4.4 - An example of a response function (Fritts and Dean 1992: 44).

5.0 Dendrochronology of Yellow-cedar

I pray, friend, not to feel angry
On account of what I am going to do to you;
And I beg you friend, to tell our friends about what I ask of you!
-excerpt from "Prayer To A Young Cedar"
(Boas 1921)

This chapter describes the dendrochronological characteristics of yellow cedar. It presents observations regarding sampling procedures and numbers of cores/trees used in this analysis. Subsequent sections compare critical dendrochronological parameters at each of the sampling sites. The chapter ends with an assessment of the dendrochronological characteristics of yellow-cedar and the presentation of a regional master series.

5.1 Sampling Characteristics

The wood of yellow-cedar has a uniform density and increment corers work well. Most cores were extracted whole, with only a few examples of plugged or stuck cores encountered. This characteristic is assumed to be a result of the acid compounds within the wood that discourages binding with metals (Barton 1976).

A common problem encountered when coring yellow-cedar is that when extracting the core, care has to be taken with the initial bark plug as the first few millimetres tend to break while the coring tool is being inserted. Upon extraction of the core, this small plug tends to "jump" out and, without proper attention, results in its loss and attenuation of individual ring-width records.

5.2 Core Numbers

A total of 380 cores from 190 trees were analyzed in this study. Initially, the cores were visually crossdated and pointer years were noted. Three years of reduced growth (pointer years later revealed as 1974, 1921 and 1862) were used as indicators for the presence of a common signal in the cores. Following this assessment, the cores were measured and the ring-width data was compiled into common site files. Cross-dating began with an assessment of this file by COFECHA.

Individual core records were retained until all segments were compared to the master site record. If a particular core or section of a core did not cross-date, it was removed from the master site chronology at this point. Table 5.1 displays the final tally of trees and cores retained within each master site chronology. The cross-dated site chronologies are similar among sites, which indicates that the species responds consistently to climate over the geographical range sampled (Table 5.2). This was an important determination, as it validates the development of master site indices.

Table 5.1 - Number of trees and cores involved in the final chronologies.

Location	Original Number of Trees	Original Number of Cores	Number of Trees in Chronology	Number of Cores in Chronology
Mount Cain	50	100	42	65
Mount Washington.	50	100	48	92
Milla Lake	25	50	22	38
Mount Arrowsmith	50	100	44	77
Heather Mountain	15	30	13	25

5.3 Site Chronologies

5.3.1 Mount Cain

The Mount Cain site is distinguished by scrubby trees with abundant crown damage. This morphological characteristic suggests that the stand is old and stressed. As no unusual growth patterns were apparent within any of the ring-width records, it seems unlikely that the construction of ski runs at this site have influenced the growth pattern. The Mount Cain site is thus considered as representative of an "old growth" stand of trees. Due to the antiquity of yellow-cedar specimens in this study, a forest 500 years or older will be considered old growth.

Table 5.2 - COFECHA statistics of the five yellow-cedar site chronologies.

Location	Correlation with Master	Auto-correlation	Mean measurement	Standard Deviation	Mean Sensitivity
Mount Cain	0.453	0.62	0.36	0.156	0.257
Mount Washington	0.469	0.81	0.88	0.467	0.209
Mount Arrowsmith	0.433	0.72	0.52	0.239	0.238
Heather Mountain	0.437	0.73	0.67	0.338	0.269
Milla Lake	0.3	0.69	0.43	0.196	0.252

The cores at Mount Cain span the interval from 1205 to 1994 A.D. The last three hundred years are best represented in the sample with greater than 40 of the cores contributing to the cross-dated site chronology (Figure 5.1). Prior to this period, the number of cores contributing to the chronology progressively decreases: by 1600 only

25 cores make up the chronology; by 1500 only 20 cores are retained; and by 1400 only 12 contribute to the chronology. Only a single core extends the ring-width record to 1250.

Radial growth trends in the earliest part of the chronology from 1205 to 1350 appear quite variable, although this may be an artifact of the small number of records represented (Figure 5.1). The period between 1350 and 1700 is characterized by a relatively uniform growth rate compared to earlier and later growth periods. Nevertheless, short intervals of above average growth occurred in the early 1400s, the mid 1510s, the late 1550s and the mid 1620s. From the early 1700s until the mid 1750s, rapid fluctuations between above and below average growth occurs. From the mid 1750s until the 1990s, growth at this site has varied with similar amplitudes but at a slower rate. From a low in the early 1750s, growth does not peak until the mid 1790s. Reduced growth characterizes the 19th century, with low points in growth achieved in the mid 1810s, early 1840s, early 1860s and late 1890s. Growth rates then increase to above average values, with four strong peaks in the mid 1910s, mid 1940s, early 1960s, and mid 1980s. These last four peaks are interrupted by markedly reduced growth in 1921, 1954, and 1974.

The trees at Mount Cain provided an opportunity to examine the dendrochronological characteristics of several morphological forms commonly associated with yellow-cedar. In the first instance, a series of boles growing from the same root stock were each sampled and analyzed. This is a common pattern within yellow-cedar stands at high elevation and is attributed to snowpack damage (Koppenaal and Mitchell 1992). All four boles in one clump sampled at this site contributed similar patterns to the final chronology. In the second instance, several trees with fluted and buttressed bases were sampled at breast height. In all these cases, aberrant ring width patterns were extracted from the buttressed areas.

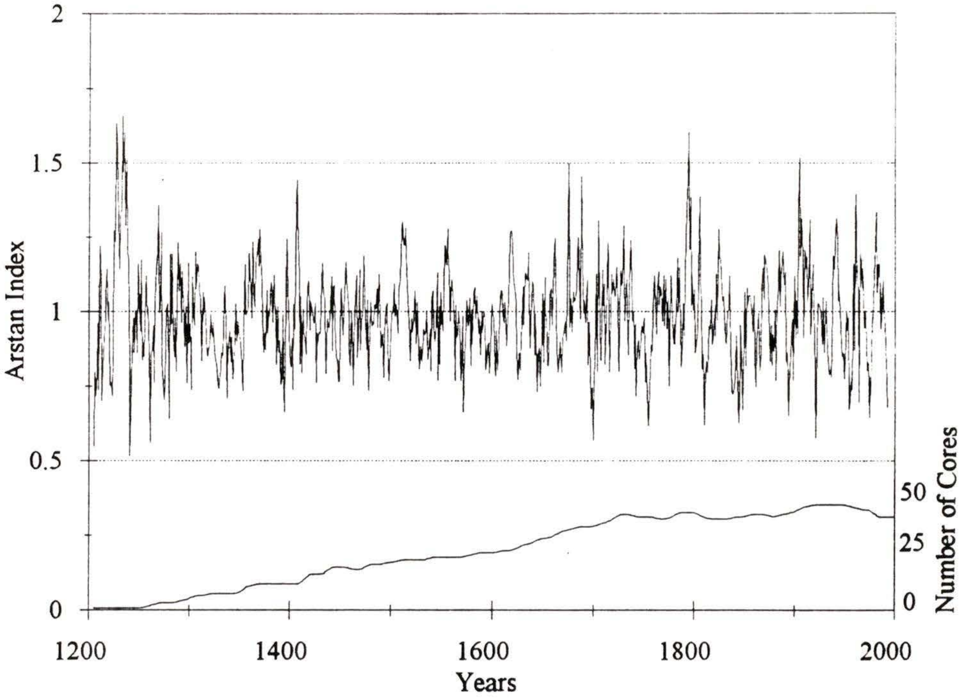


Figure 5.1 - The Mount Cain master chronology and the number of cores in the final index.

5.3.2 Mount Washington

The Mount Washington site contained a uniform aged population of yellow cedar resulting from a forest fire ca. 300 years ago. Although no fire-scars were detected, charred wood on the forest floor provides support for this interpretation.

The Mount Washington chronology covers the period 1702 to 1994. The site chronology was developed from 92 out of the original 100 cores (Table 5.1). The sampling depth of the chronology varies with time: 90 cores extend past 1900; 30 register past 1800; and by 1750 only 5 cores remain. Only a single core contributes to the chronology from 1725 to 1700 (Figure 5.2).

Figure 5.2 presents the detrended chronology compiled for the Mount Washington site. While extreme ring-width variations in the earliest part of the chronology may reflect the low number of cores represented, they may also be associated with post-fire nutrient influxes (Banks 1987). After this interval, the growth index decreases to minimum values in the early 1810s, then increases until 1825 and subsequently drops again until 1840. The second half of the 19th century is characterized by enhanced growth through the 1850s, followed by reduced rates of growth until 1862. This interval is followed by increasing rates of growth through the 1870s to1885. Growth rates subsequently decline through the late 1890s and remain low until the early years of the 20th century. By 1905 growth rates have recovered but then slowly decrease once again, reaching the lowest rates of growth in the 20th century by 1921. Growth rates remained low throughout the 1930s but rise again in the 1940s. From the 1950s to 1961 growth rates slowly increased. This interval is followed by reduced growth rates until 1974, after which growth rates recovered until 1984. Since 1984, below-average growth has occurred at the Mount Washington site.

Although the majority of samples from Mount Washington were collected from a stand located at 1350 m, a few trees were sampled along the crest of the mountain at ca. 1500 m. This latter sample proved to have the weakest common signal within any of the trees sampled at Mount Washington, and only two cores from this group are included in the site chronology. This observation suggests that yellow cedar has a limit of normal growth on the slope, and that across altitudinal ranges of less than 150 m, microenvironmental or ridgeline conditions could outweigh the influence of macro-scale parameters on annual growth trends (cf. Villalba *et al.* 1994).

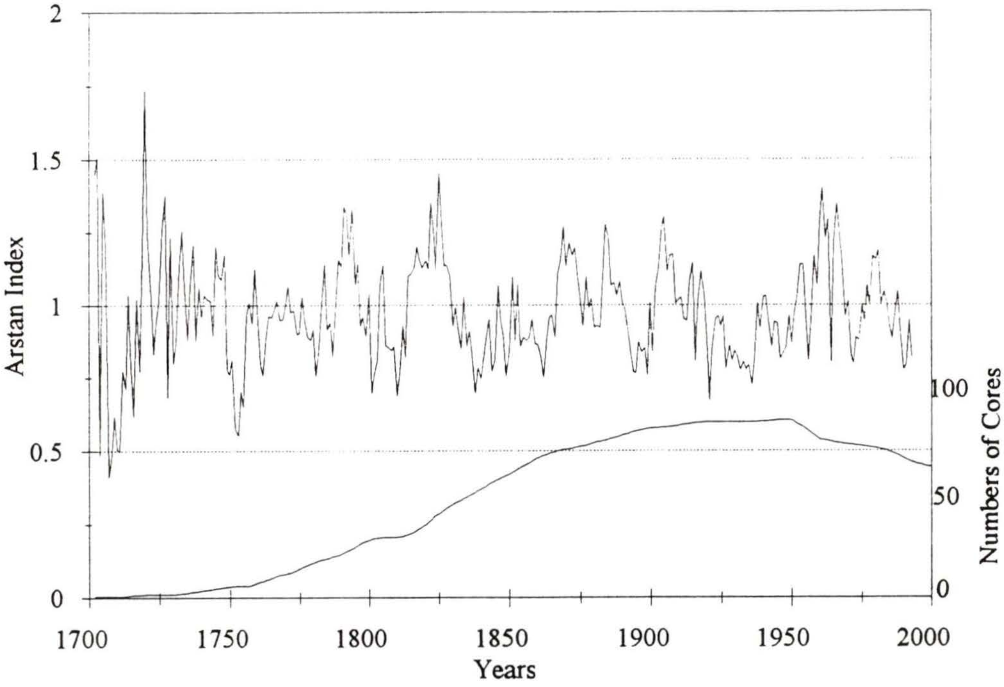


Figure 5.2 - The Mount Washington master chronology and the number of cores in the final index.

5.3.3 Milla Lake

The yellow-cedar trees sampled at Milla Lake were found on the steepest and highest slope examined. Analysis of the ring-width trends at the site resulted in the development of a chronology that extends from 798 to 1994 A.D. The sampling depth at the Milla Lake site resulted in 24 cores overlapping in the chronology in 1900, with only a single tree providing records in the interval from 798 to 1200 (Figure 5.3).

The yellow-cedar master chronology developed for Milla Lake is similar in appearance to that developed elsewhere (Figure 5.3). Above average growth occurred in the 1940s, 1910s, 1880s, 1840s, 1820s, 1790s, 1770s and early 1720s. Reduced rates of growth characterize the 1970s, 1950s, 1920s, 1860s, 1840s, 1800s, 1740s and 1660s. Like the situation at Mount Cain, intervals of increased growth distinguish the 1550s, the 1510s, the 1350s, the early 1330s, the 1260s, and the mid 1220s. After the mid 1120s growth rates decline to reach to a period of markedly reduced growth in 1165 and subsequently rapidly increase, as a period of enhanced growth distinguished the early 1170s. The initial section of the ring record from 1200-798, is driven by the increment records of a single tree which shows other intervals of enhanced growth in the 1020s, the 970s and the 940s.

At Milla Lake mature yellow-cedars with normal boles grew at 1635 m, well above the krummholtz zone at the other four study sites. The large range of ages in this stand and its position likely explain the relatively weak intra-site correlation signal detected. Dendrochronological assessments at the site are complicated by Little Ice Age glacial activity. Smith and Laroque (1996) suggest that Moving Glacier was very close to the trees sampled in this study as recently as 1931. Nevertheless, it is assumed that the Little Ice Age glacier activity never directly influenced the trees sampled. Instead, it seems likely that both systems were responding to the same climate forcing mechanisms (possibly reduced temperature and/or increased snowfall), leading to both reduced tree-ring growth and to the accumulation of ice.

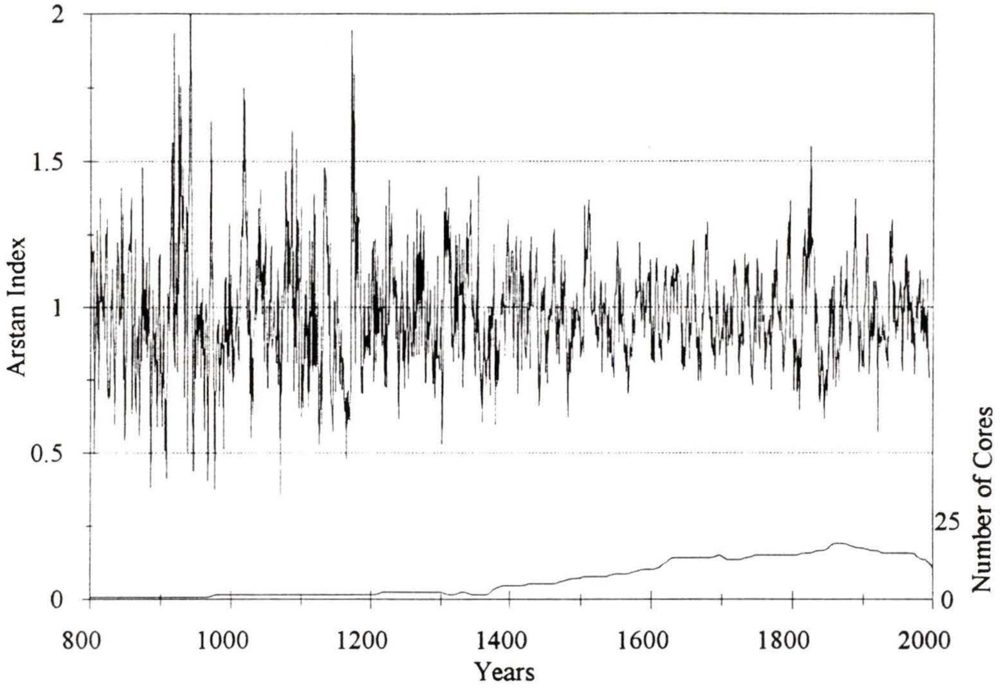


Figure 5.3 - The Milla Lake master chronology and the number of cores in the final index.

5.3.4 Mount Arrowsmith

Sampling at Mount Arrowsmith produced a cross-dated chronology extending from 1105 to 1994 A.D. The final chronology consists of 77 cores, with the majority describing only the last 150 years of the chronology (Figure 5.4). From 1750 to 1450 the record is derived from only 10 cores, while a single core provides a record to 1105.

The growth chronology of trees at Mount Arrowsmith is very similar to that at Milla Lake, Mount Cain, and Mount Washington in the interval from 1700 to 1994 (Figure 5.4). Growth trends in the 1700s were highly variable and it was not until the 1800s that a lengthy interval of reduced growth is recorded. Higher rates of growth occur in the early 1900s, but this trend is interrupted by short intervals of reduced growth.

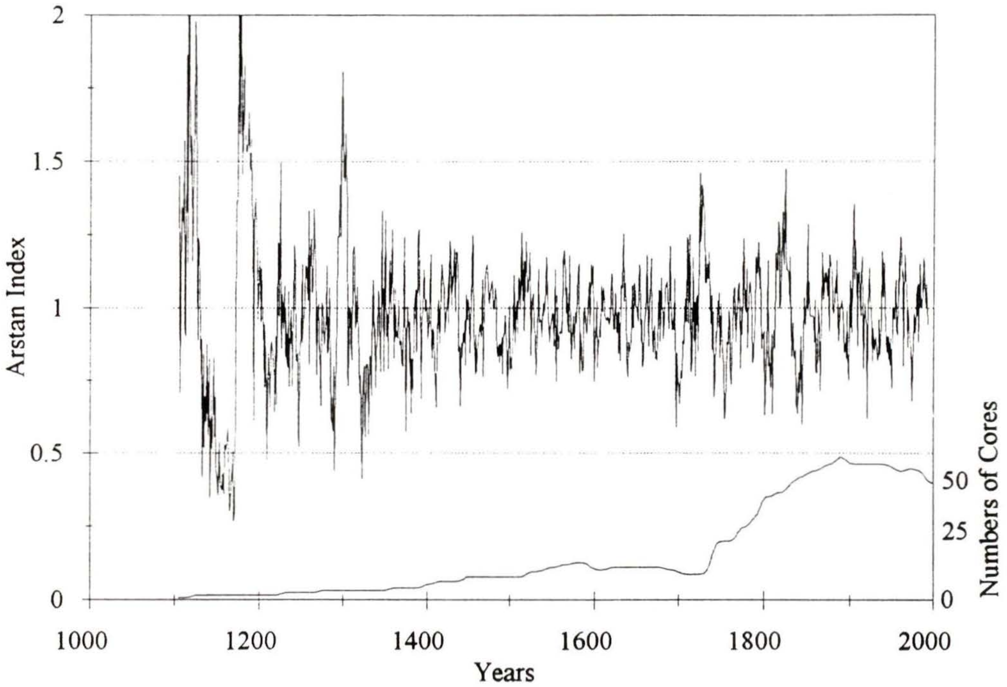


Figure 5.4 - The Mount Arrowsmith master chronology and the number of cores in the final index.

From 1360 to 1700, the chronology records an interval with little variation in the annual increments of growth. An exception over this interval is increased growth in the 1510s. Prior to this interval, enhanced growth characterized the 1350s, the early 1300s, the 1260s, and the 1225s. A period of anomalous growth between 1124-1172 is noteworthy. While recorded by only a single tree, growth in the mid 1120s declines until the lowest point in the chronology is reached in 1165. Recovery from this event is rapid and by 1172 the growth pattern suddenly shows the second highest growth in the whole chronology.

Sampling at Mount Arrowsmith was largely restricted to trees positioned on sloping sites with good drainage. Nevertheless, a few of the largest and oldest trees sampled occurred in obvious depressions where they may have benefited from extra moisture or available nutrients. This group of trees retained a growth signal common to the majority of trees sampled at the Mount Arrowsmith site.

5.3.5 Heather Mountain

Twenty-five of the 30 cores collected at Heather Mountain were incorporated into the site chronology which covers the period from 1497 to 1994 A.D. (Figure 5.5). As with the larger samples from the main study sites, the greatest sampling depth occurs within the last century and only a single core describes growth trends prior to 1600.

The Heather Mountain chronology between 1700 and 1994 is very similar in appearance to those developed at the other four sites (Figure 5.5). Common low growth periods occur in the mid 1750s, early 1810s, early 1840s, early 1860s, late 1880s, early 1920s, early 1950s, and mid 1970s. Synchronous above-average growth occurs in the mid 1790s, early 1810s, mid 1850s, late 1870s, late 1910s, late 1940s, mid 1960s and the mid 1980s. Prior to 1700, the chronology has three peaks in the growth index but the low numbers of cores describe a section of the chronology that may not be as reliable. High rates of growth occurred in the late 1640s, the early 1590s, and the late 1530s. Noteworthy is the interval of enhanced growth in the 1530s, as it is the only one that corresponds to high rates of growth at Mount Cain, Mount Arrowsmith and Milla Lake.

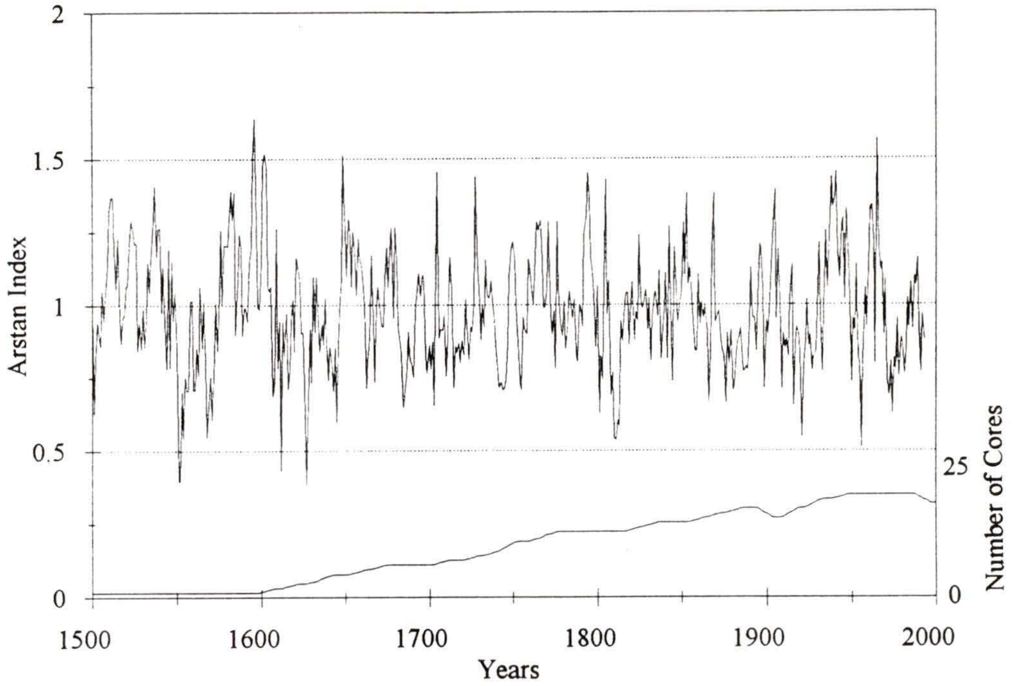


Figure 5.5 - The Heather Mountain master chronology and the number of cores in the final index.

Sampling at Heather Mountain revealed that useful yellow-cedar chronologies could be produced from sites with small samples sizes (n=30) and extremely wet subsurface conditions. This chronology is similar to that developed elsewhere and its growth signal differs only in terms of magnitude. For instance, when regional growth rates are high, the annual increment of growth at Heather Mountain seems to be even greater. When the rate of growth is low elsewhere, the growth rate at Heather Mountain seems lower and for a longer interval of time. This growth behaviour is likely related to the amount of water present at the site (i.e., high/low water levels persist for a greater length of time which creates the exaggeration and lag effects described above.)

5.4 Regional Chronology

A correlation matrix was constructed from the five site chronologies to test for similarity using a 195 year time period (1800-1994) common to all five sites (Table 5.3). There appears to be a significant correlation in growth behaviour of yellow-cedar at the three primary study sites (mean $r^2=0.47$). While Milla Lake correlates in a similar range with the primary sites, Heather Mountain shows a weaker correlation to the group.

Following this analysis a master regional chronology was constructed using COFECHA. Table 5.4 shows the relationship between the individual site chronologies and the regional master chronology. The correlations were performed in 50 year segments, with correlations higher than 0.3281 significant at the 99% confidence limit. The range of correlations was from 0.47 to 0.92, with a mean correlation of the group being 0.75. The highest correlations were for the 50 year period from 1900 to 1949, while the lowest were for the initial segment from 1800 to 1849. As all sites were strongly correlated, the regional master chronology was considered acceptable. ARSTAN was used to detrend the COFECHA outputs and an index of the regional master chronology was produced (Figure 5.6). The regional index eliminates the anomalous growth variations specific to individual sites. It shows high amplitude fluctuations from 800 to approximately 1200 A.D., possibly due to the low number of cores representing this interval. From 1200 to 1500 high rates of ring growth were recorded. The mid 1500s to the late 1700s are characterized by smaller annual ring-width increments. Following this interval more frequent oscillations, with higher magnitudes, are experienced throughout the last 200 years.

Table 5.3 - Correlation matrix (r^2-values) of the five site master chronologies.

	Mount Cain	Mount Washington	Milla Lake	Mount Arrowsmith	Heather Mountain
Mount Cain	1	---	---	---	---
Mount Washington	0.41	1	---	---	---
Milla Lake	0.37	0.47	1	---	---
Mount Arrowsmith	0.37	0.62	0.49	1	---
Heather Mountain	0.21	0.13	0.15	0.22	1

Table 5.4 - Correlation of individual sites with the regional master chronology (values above 0.32 are significant at the 99% confidence interval).

	1800-1849	1825-1874	1850-1899	1875-1924	1900-1949	1925-1974	1950-1994
Mount Cain	0.49	0.78	0.75	0.88	0.92	0.80	0.77
Mount Washington	0.67	0.68	0.74	0.88	0.86	0.80	0.75
Milla Lake	0.67	0.64	0.47	0.74	0.83	0.84	0.73
Mount Arrowsmith	0.79	0.82	0.76	0.83	0.87	0.81	0.79
Heather Mountain	0.67	0.69	0.66	0.81	0.82	0.72	0.55

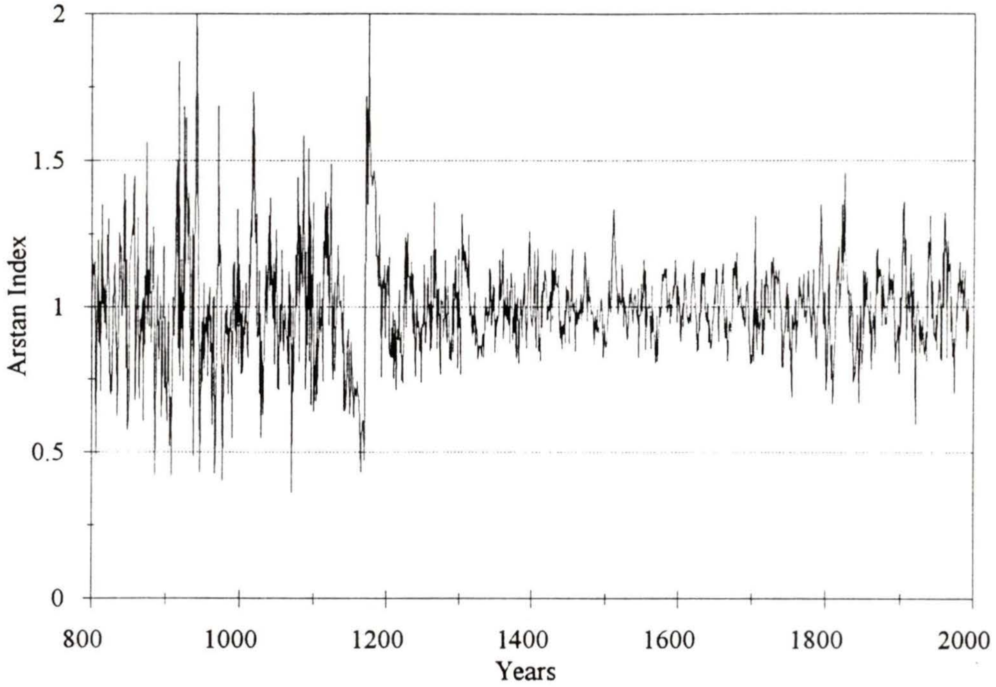


Figure 5.6 - The regional master chronology.

6.0 Dendroclimatology of Yellow-cedar

The purpose of this chapter is to examine the dendroclimatological capabilities of yellow-cedar. The chapter begins with an assessment of the growth signal found within the yellow-cedar chronologies. Next a climatic model is presented which provides a proxy record of climate for the duration of the regional chronology. The chapter concludes with an analysis designed to verify the dendroclimatological reliability of the yellow-cedar signal.

6.1 Response Functions

The five site chronologies and one regional chronology were evaluated using a response function analysis to identify and quantify the role played by climate in tree growth. Each site chronology was analyzed using the PRECON program and mean monthly temperature and precipitation values from the Nanaimo climate station (1902-1991). Initially it was anticipated that climatic data from the nearest long-term station would be used in each analysis. However, for a variety of reasons, this proved either to be impossible or inappropriate. For instance, the Mount Cain chronology was initially considered against the climate data from the Sayward (1973-1982) AES station. However, the data from both this station and the Campbell River AES (1939-1990) station proved too short to ensure statistical reliability. Similarly, it became apparent that the areal representativeness of long-term station data from a number of locations was questionable.

Average annual air temperature records for Nanaimo, Port Alberni and Comox show a strong similarity from 1945 to 1990 (Figure 6.1). The Nanaimo temperature values generally lie between those recorded at Comox and Port Alberni. The temperature values from Port Alberni are generally lower than those recorded at the other two stations. This is particularly apparent from the 1930s to the 1960s and may be due to relocation of the climate station. The Nanaimo station recorded air temperatures continuously at one location from 1901 until 1968. Although the station was relocated in 1968, it shows trends that are consistent with the other two stations in the region. Consequently the Nanaimo temperature record was considered representative of regional trends.

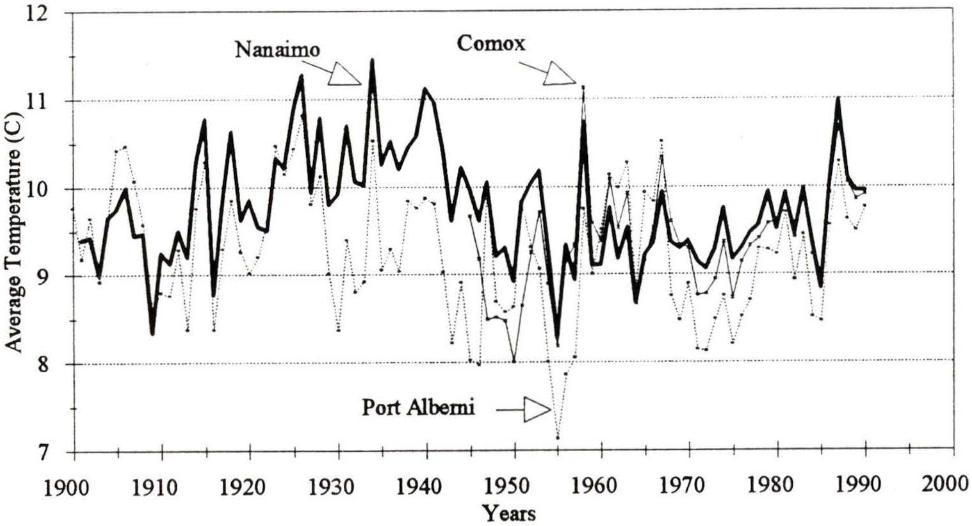


Figure 6.1 - Yearly temperature averages over time for three locations on Vancouver Island.

Annual precipitation at Port Alberni was substantially higher than at Comox, or Nanaimo (Figure 6.2). Port Alberni's location on the windward side of the Insular Mountain range resulted in substantial orographic precipitation. Consequently, it was felt that the Port Alberni data provided a poor representation of the precipitation values at the high elevational sites. Precipitation trends from Comox and Nanaimo are remarkably similar. While the Comox precipitation record is relatively short (1945-1990), the Nanaimo record begins in 1901. Though neither station provides any direct insight into the character of precipitation at treeline, the length of the Nanaimo data warranted its use in the response function analysis.

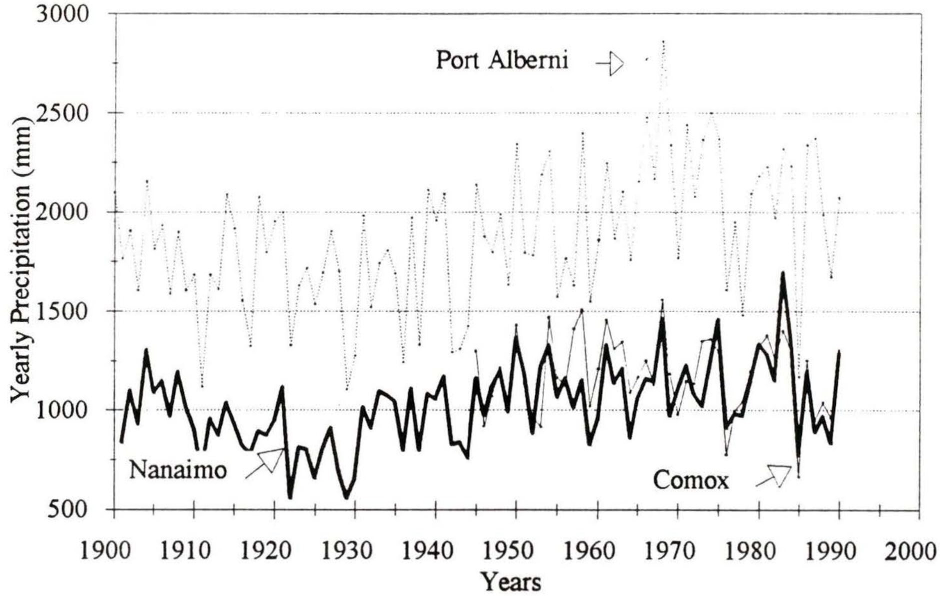


Figure 6.2 - Yearly precipitation averages over time for three locations on Vancouver Island.

The Nanaimo station data (1901-1990) were used in all the PRECON calculations. Application of this relatively long data set eliminated statistical effects that would have resulted from the use of climate records collected at shorter term stations. The station was felt to be more representative of environmental conditions at most of the study sites than the very wet Port Alberni data set. A lingering concern is that the Nanaimo station is positioned near sea level and describes climatic conditions distinct from those at higher elevations on Vancouver Island (cf. Weiss 1995).

6.2 Site Responses

Figures 6.2a to 6.2f show the growth response of the various tree-ring chronologies to the temperature and precipitation data from the Nanaimo station and to one year's prior growth. Each figure illustrates the amount of variation in tree-ring width explained by either temperature or precipitation, over a 15-month period extending from June of the previous year to August of the growth year. This interval was chosen to capture the annual growth signal of high-elevation trees, which is often heavily influenced by growth in the previous year (Colenutt and Luckman 1991).

6.2.1 Mount Cain

Sixty-two percent of the variance in tree growth at Mount Cain was attributed to climate and prior growth (Table 6.1). Three climate variables were significant; tree growth was positively related to July air temperature, negatively related to the previous August temperature, and negatively related to July precipitation (Figures 6.3a). The positive relationship to July temperature is likely related to increased growing season temperatures that increase photosynthesis (Fritts 1976). The negative relationship to previous August temperature could be a major factor in the current year's growth because of its effect on the storage of photosynthate needed to initiate growth in the following year. The higher than normal temperatures could trigger a physiological shutdown of growth in the trees (Taiz and Zeiger 1991). The significant negative July precipitation signal at Mount Cain probably represents the effects of late-lying snowpacks or increased cloudiness, both of which would dampen the growth potential of the tree.

Table 6.1 - Percentage of total variation in growth related to climate, prior growth and total variance for five sites and the regional master chronology.

Site	Climate Signal	Prior Growth	Total Variance
Mount Cain	31	31	62
Mount Washington	27	39	66
Mount Arrowsmith	30	23	53
Heather Mountain	26	32	58
Milla Lake	28	30	58
Regional Master	31	30	61

6.2.2 Mount Washington

The results of the PRECON analysis at Mount Washington were disappointing, even though the analysis indicated that climate and prior growth explained 66% of the variance in annual growth at the site. Five of the 30 climate variables tested were found to be significant at the 95% confidence interval (Figure 6.3b).

Air temperature in August of the growth and preceding year negatively influenced development, as did previous October precipitation and current June precipitation. February precipitation in the growth year positively affected growth. July temperature of the growing season, a variable identified at most of the other sites, was not significantly related to growth, suggesting that local site factors influence the response function relationships at Mount Washington or that the climate set was inappropriate.

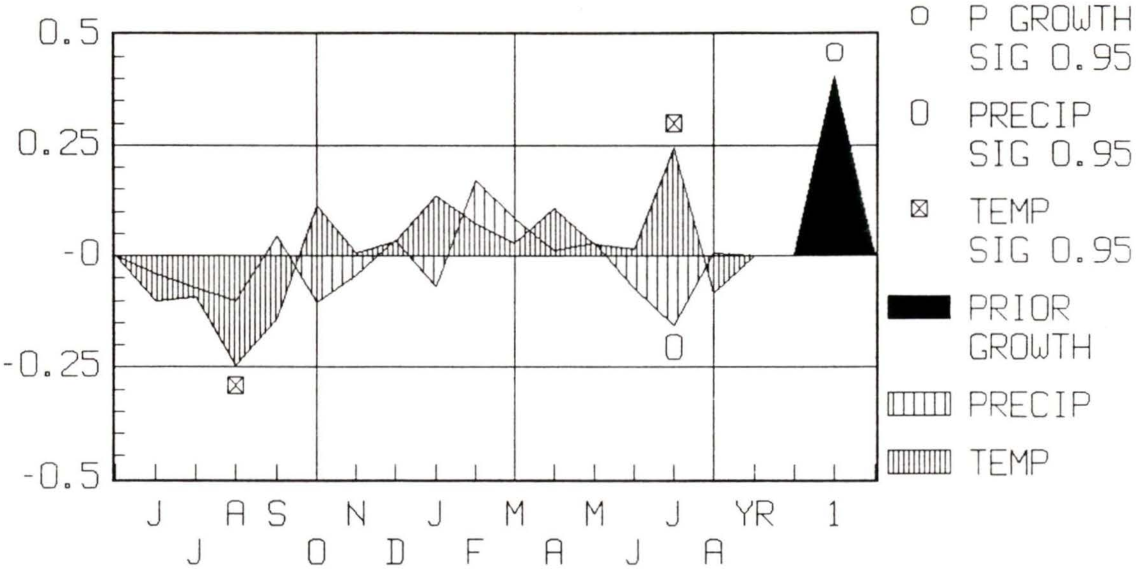


Figure 6.3a- Mount Cain response function. Variables that are significant at the 95% confidence interval are indicated by a square or circle above (if positive) or below (if negative) the zero line.

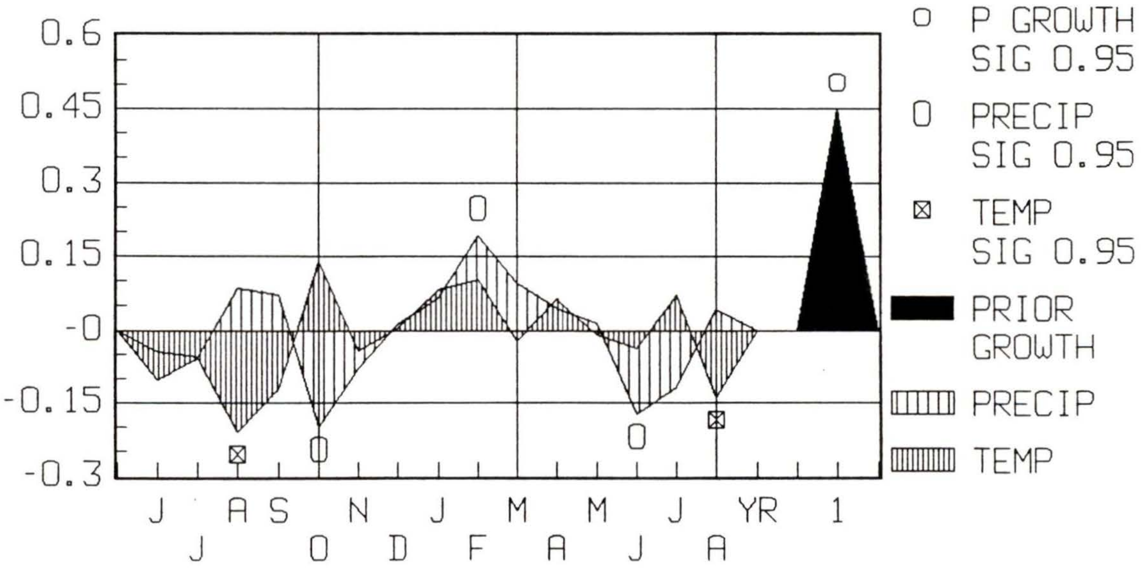


Figure 6.3b- Mount Washington response function.

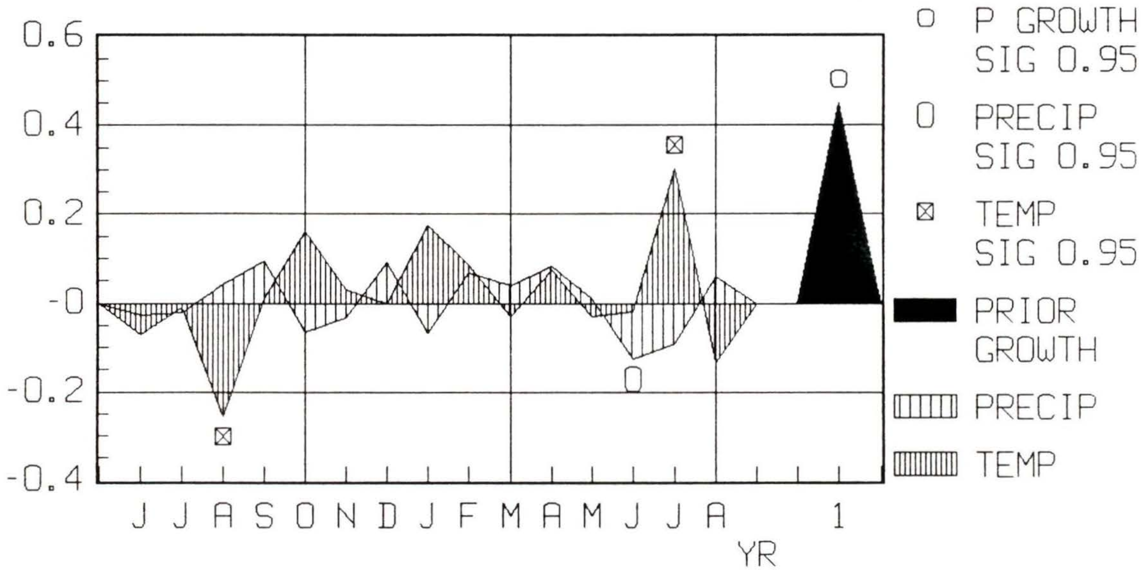


Figure 6.3c- Milla Lake response function.

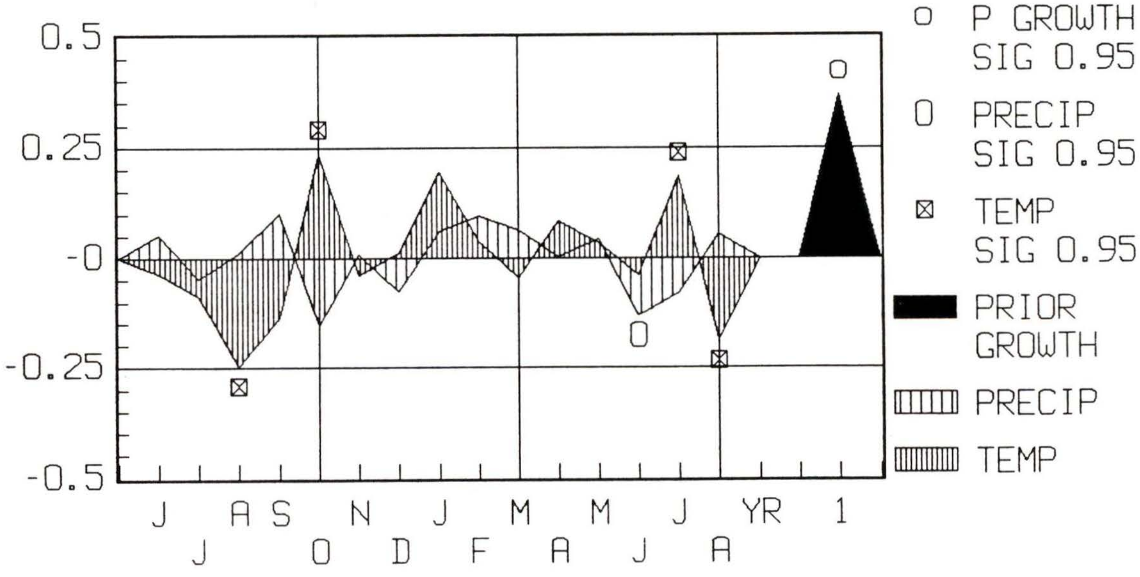


Figure 6.3d- Mount Arrowsmith response function.

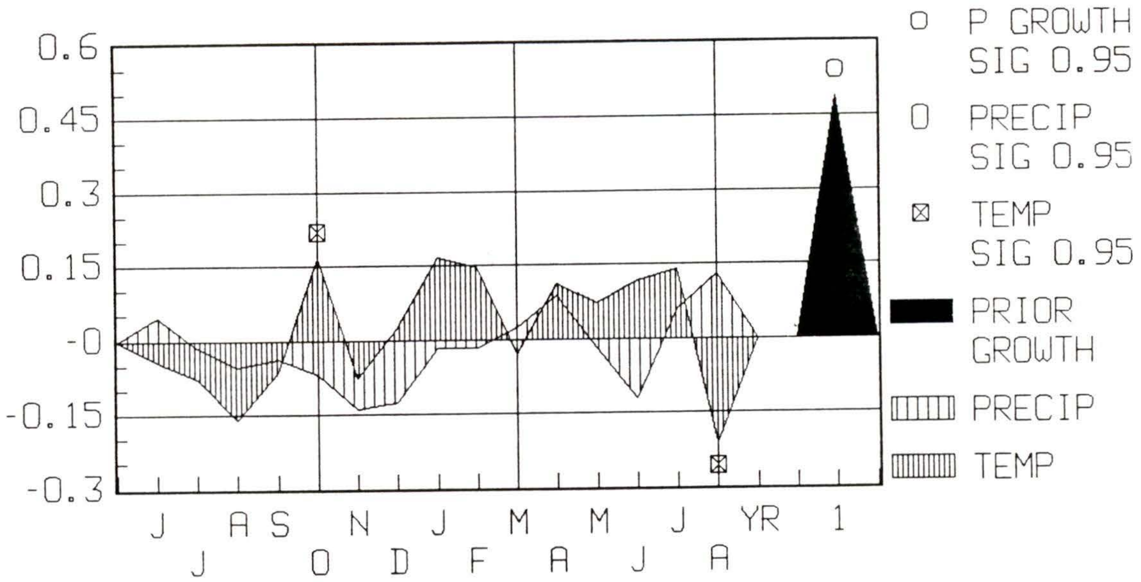


Figure 6.3e- Heather Mountain response function.

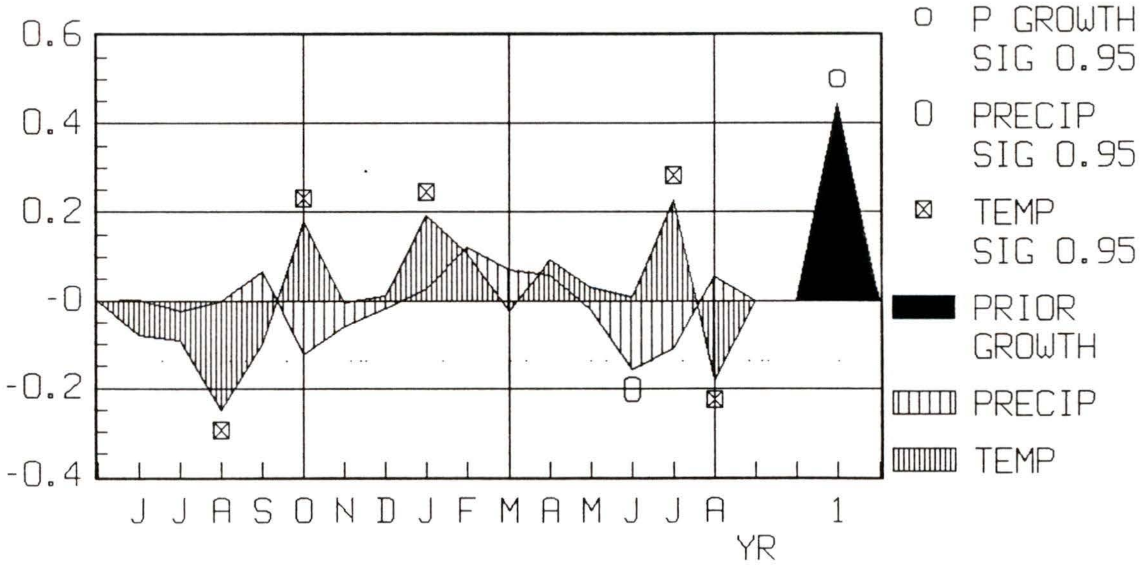


Figure 6.3f- Regional response function.

6.2.3 Milla Lake

Climate in the growth year explained 28% of the radial growth at Milla Lake, while 30% was explained by growing conditions in the preceding year (Table 6.1). August temperatures in the preceding year had a negative influence and July temperature in the growth year had a positive influence on growth. June precipitation of the growth year had a negative effect on growth (Figure 6.3c).

The strong positive relationship to July temperature indicates that growing season temperatures are limiting at this elevation. The negative precipitation signal in June probably represent the influence of late-lying snowpacks or increased cloudiness which hampers growth.

6.2.4 Mount Arrowsmith

The growth response of yellow-cedar at Mount Arrowsmith appears closely linked to air temperature, which accounts for the majority of the explained climatic variance (Table 6.1). Two variables were positively significant: temperature in the previous October and temperature in July of the growth year (Figure 6.3d). Two variables were negatively significant: temperature in the previous August and temperature in August of the growth year. One precipitation factor was significant, a negative response to the June variable (Figure 6.3d).

Variance explained from the Mount Arrowsmith site was lower than that at the other four sites (53%). This may be because Mount Arrowsmith is more directly influenced by moist Pacific air masses, whereas the other locations are in the rainshadow of the Vancouver Island ranges and experience much drier conditions. Warmer October temperatures may act to prolong the photosynthetic season by reducing snow accumulation throughout the fall period. However, this relationship is difficult to verify because upper and lower elevational conditions can be very different.

6.2.5 Heather Mountain

Two temperature variables were shown to influence the annual growth of yellow-cedar at the Heather Mountain site. In addition to a positive correlation of growth with the previous October temperature (Figure 6.3e), a significant negative relationship with temperature in August of the growth year was identified. No significant correlations with precipitation were found.

Heather Mountain had the lowest reported variance percentage due to climate at 26%, with 32% of the growth related to conditions in the preceding year. At all the sites growth was significantly related to growth in the previous year, but Heather Mountain was the only site with a significant relationship to growth in the second and third previous year. A delayed influence of precipitation from previous years would help explain the high percentage of growth in prior years and also explain longer temporal trends in the high/low growth rates in the Heather Mountain chronology. Tree growth at the Heather Mountain site may also be influenced by the ability of the bog system to maintain a water supply (Jozsa 1988b).

The response function analysis at Heather Mountain suggested that air temperature in the October preceding growth and August of the growth year affect radial growth. As with Mount Arrowsmith, increased fall temperatures appear to prolong the photosynthetic period, thereby positively influencing next year's growth. In August, if temperatures remain high, the available moisture in the bog decreases and radial growth could slow in response to a moisture stress. This pattern seems common throughout the sites.

6.2.6 Regional Master

A multiple regression analysis of growth trends within the regional yellow-cedar chronology identified six climatic variables as significant to growth. Five different temperature variables significantly influence growth: previous October (positive); January (positive), July (positive); and lower than normal temperatures in the previous and current August (Figure 6.3f). June precipitation of the growth year had a significant negative impact on growth (Figure 6.3f). Overall 61% of the growth variance within yellow-cedar was attributed to climate and prior growth (Table 6.1).

The regional PRECON assessment of yellow-cedar represents the strongest growth signals at all of the sites studied. Of the six variables identified as significant regionally, all were significant or nearly significant at each of the five sites. The common negative response to previous August and current August temperature is assumed to reflect limitations imposed by soil moisture deficits (Jozsa 1988a).

Presumably, higher than normal October temperatures affect ring growth in the following year by permitting the storage of photosynthate which then becomes available for growth in the following year (Fritts 1976).

The relationship of winter temperatures and tree growth in the following summer seems likely to be related to the seasonal snowpack. Moore and McKendry (1995) have shown that warm air masses in the winter have the ability to drastically reduce winter snowpack accumulations on Vancouver Island, which would in turn probably lengthen the growing season and accentuate radial growth.

The negative correlation to June precipitation is interpreted as a response to lingering snowpacks or excessive cloud cover. Either condition would presumably reduce the growth-ring increment, by not providing moisture for the growth cycle, by hindering tree photosynthetic energy outputs due to a reduction in available incoming solar radiation, or by hindering root efficiency due to cool soil temperatures.

The positive relationship between summer temperature and increased growth is one of the best understood relationships in dendroclimatology (Fritts 1976). Summer temperature increases induce physiological processes within the tree leading to an increase in the availability of photosynthetic energy needed to promote the growth response in earlywood cells (Berry and Bjorkman 1980).

6.3 Development of a Proxy Climatic Record

A proxy record of previous August temperature was created by REC. Whereas additional variables registered as significant, they were not included in the reconstruction. Previous August temperature was the highest and most consistently significant variable affecting ring-width growth (Table 6.2). In this analysis, the previous August temperature was regressed against the corresponding growth increment to predict August temperatures over the dendrochronological record.

Figure 6.4 displays the predicted August temperature versus the actual August temperature from the Nanaimo AES station. The predicted mean air temperature has an average value (17.66° C) close to the actual recorded mean temperature (17.61° C). In only a few cases does the predicted temperature deviate by more than a degree from the actual temperature.

6.4 Verification

Figure 6.4 is a visual representation of the validity of the predictor relationship between yellow-cedar proxy data and the actual August temperature. The software program VFR was used to provide a statistical summary of the goodness-of-fit of the predicted versus the actual August temperature fluctuations (Table 6.3). In this case the calibration period selected was from 1946 to 1990, or half of the length of the climate data from the Nanaimo station. The verification of the calibration was conducted for the time span from 1902 to 1945, the other half of the data. In this way the two sets of tests do not cover similar time periods and an unbiased comparison of the goodness-of-fit between the two lines can be made.

Table 6.2 - Percentage of previous August temperature and its rank in a list of variables at each site.

Site	Percentage of temperature signal	Rank of previous August temperature in a list of the sites strongest variables
Mount Cain	25	1st
Mount Washington	16	1st
Milla Lake	25	2nd
Mount Arrowsmith	25	1st
Heather Mountain	16	2nd
Region	25	1st

Table 6.3 - Results from calibration and verification statistical tests (* = significant at the 95% confidence interval).

	Mean		Standard Deviation	
	Actual	Estimated	Actual	Estimated
CALIBRATION:	17.47	17.66	1.19	0.32
VERIFICATION:	17.79	17.63	1.09	0.25

CALIBRATION: comparison between ACTUAL and ESTIMATED

	Value obtained	Value of 95% confidence
Correlation	0.1646	>= .2482
Correlation (p = .975)	0.1646	>= .2950
Reduction of error	- 0.0099	>= .0616
T-value	0.3284	>= 1.680
Sign-products	19	<= 16
Negative first diff	15 *	<= 15
Degrees of freedom	43	

VERIFICATION: comparison between ACTUAL and ESTIMATED

	Value obtained	Value of 95% confidence
Correlation	0.3941 *	>= .2509
Correlation (p = .975)	0.3941 *	>= .2980
Reduction of error	0.1787 *	>= .0630
T-value	2.2000 *	>= 1.680
Sign-products	15 *	<= 16
Negative first diff	23	<= 15
Degrees of freedom	42	

Since six out of twelve of the verification tests signalled a significant predictive model for August temperature, a full hindcast (projection back through time) of August temperature was constructed (Figure 6.5).

Figure 6.6 shows the predicted air temperature variations as deviations from the mean proxy temperature (°C). It suggests that the relative magnitude of the air temperature fluctuations greatly decreased from the 1450s to the 1750s compared to before and after this period. The exception in this time period is the one large peak in the 1530s. Before this time period and again after, larger fluctuations away from mean values seem to have occurred. Large positive temperature deviations occur in the 1200s, and a negative and positive deviation occurs in the 1300s. A strong positive deviation in temperature is evident at the end of the 1700s, with the 1800s having two strong fluctuations, one negative and one positive. During the 1900s, three general deviations occur, two negative and one positive but the magnitudes are once again more suppressed.

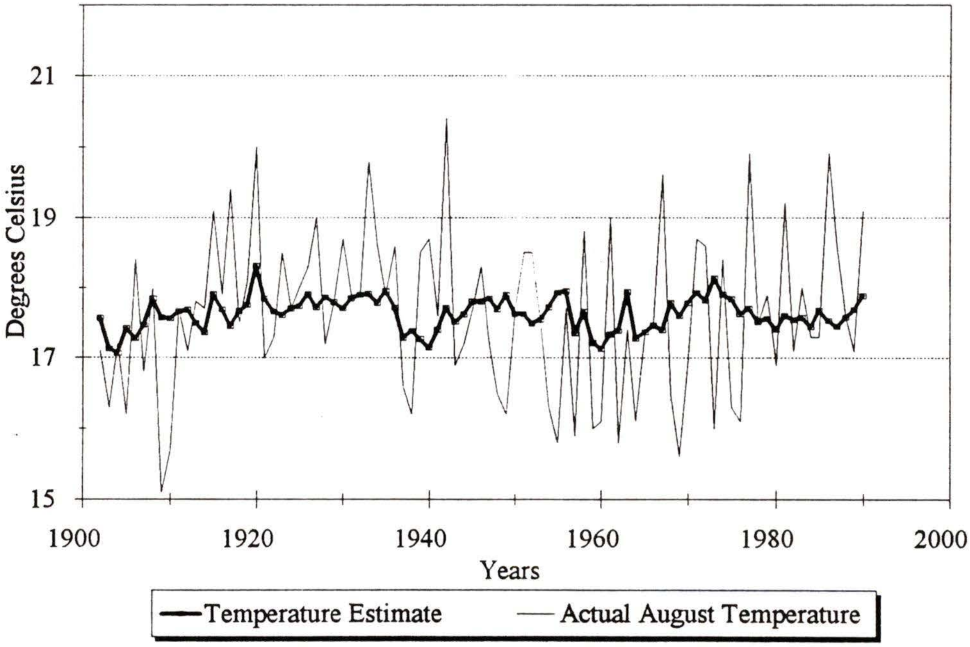


Figure 6.4 - Predicted versus actual August temperatures.

6. 5 Discussion

The regional yellow-cedar chronology appears to contain a record of short-term variations in August temperatures. It shows that August temperatures generally increase and decrease by as much as 0.3° C over the 800 year interval (Figure 6.7).

Fifteen distinct warm intervals and 15 distinct cool intervals occur within the 800 year interval shown in Figure 6.7, giving an average cyclicity of about 54 years between phase swings. Long-term cool Augusts occurred in the early 1300s, and the mid 1400s, with another interval of cooler-than-normal temperatures occurring in the 1540s. Short-term cooling occurred in the early and late 1600s, the mid 1700s, two in the 1800s, with the last cool event occurring in the 1960s. Warm periods occurred during the early 1200s, the mid 1300s, the early 1500s, and the early and late 1700s. A minor warm interval occurred at the beginning of the 1800s with a large event apparent in the 1870s. The last major period of warmth occurred in the late 1930s and early 1940s.

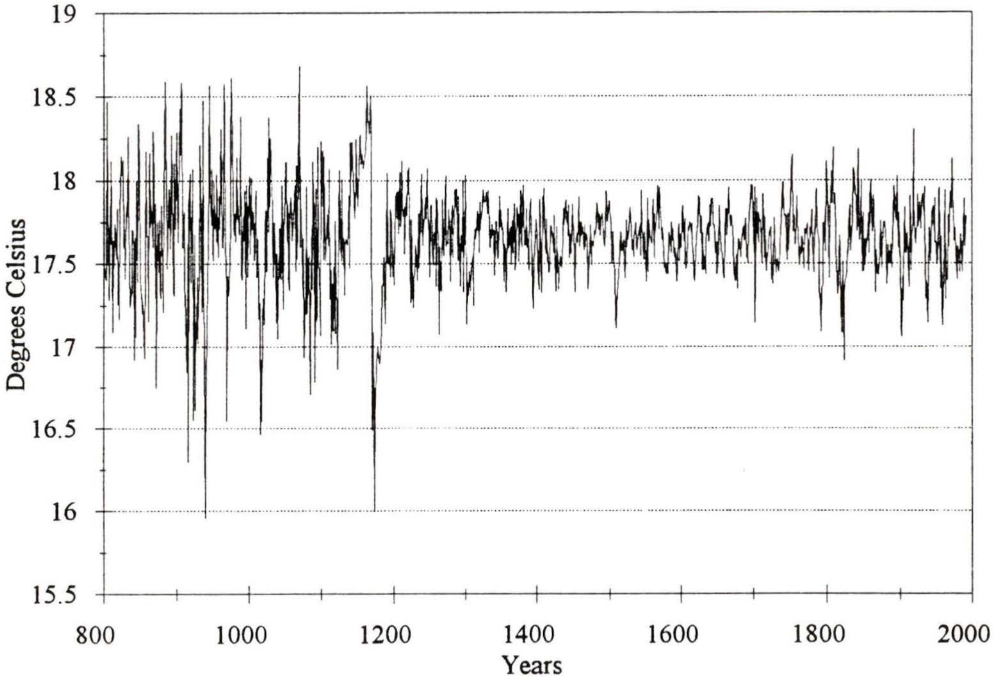


Figure 6.5 - Predicted August temperature from yellow-cedar regional chronology.

The 54 year cyclicity within the yellow-cedar chronology is twice that distinguished in the Pacific northwest by Briffa *et al.* (1992). In their study, statistically significant temperature deviations were identified with 27 and 32 year cycles.

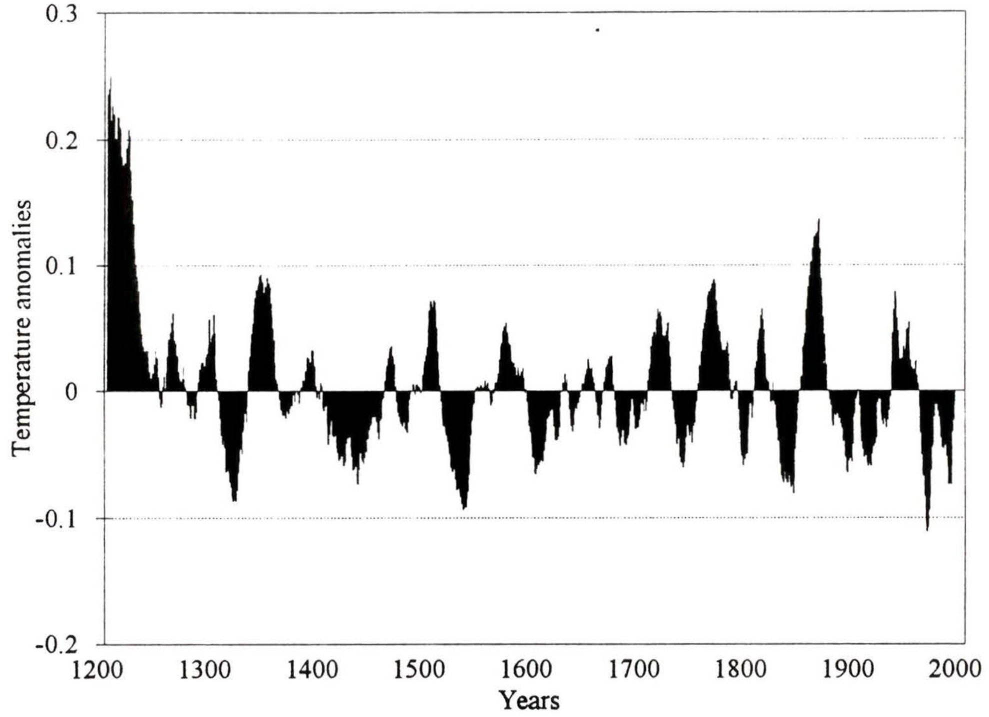


Figure 6.6 - Temperature deviations from the predicted mean on Vancouver Island.

Briffa *et al.* (1992) reconstructed summer temperatures from 1750 to 1982. Similarities to above average temperature reconstruction occurred in the 1780s, 1860s and 1940s. Below average temperature deviations are similar in the 1770s, 1790s, 1840s, and the 1890s. It must be noted that their constructions were based on six month reconstructions over large areas of the Pacific northwest, whereas this study focused on only August reconstructions in only the Vancouver Island region.

The longer term variations inherent within the proxy air temperature data appear similar to those that occurred at a global scale. A generalized cool period throughout

North America in the 1500s, 1600s and 1700s (Lamb 1982) can be seen in the yellow-cedar reconstruction. During this time period it is hypothesized that the general westerly wind pattern moved further south on the west coast of North America resulting in increased precipitation along coastal areas (Lamb 1982). The early 1800s were characterized by cool temperatures and marked variability in summer temperature as Europe and North America emerged from the "Little Ice Age" (Lamb 1982). This trend seems consistent with the predictions from the yellow-cedar data in Figure 6.6. Lastly, a warm dry period in North America known as the "Dirty Thirties" (Lamb 1982) is evident in the yellow-cedar proxy temperature record.

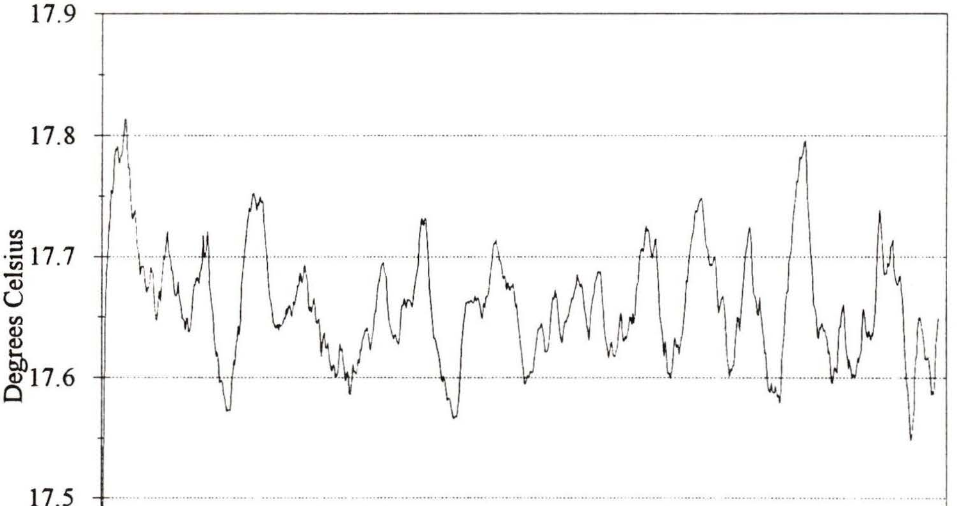


Figure 6.7 - Predicted 30 year moving average of August temperatures.

7.0 Inter-species Comparison

Chapter 7 compares the results of this research program to the findings of Schweingruber *et al.* (1991) and Smith (1995b) for mountain hemlock at similar high-elevation sites on Vancouver Island. There are no comparable yellow-cedar chronologies from the Pacific Northwest (Luckman and Innes 1990; Grissino-Mayer *et al.* 1992). Therefore, mountain hemlock, a common associate of yellow-cedar within the subalpine parkland zone on Vancouver Island (Pojar and MacKinnon 1994), provides the only opportunity to assess the climatic growth response of yellow-cedar in this setting.

7.1 Chronological Comparisons

7.1.1 Milla Lake comparisons

Investigations by Smith (1995b) at Milla Lake in 1994 provide an opportunity to directly compare the growth trends of yellow-cedar and mountain hemlock from the same stand of trees. The mountain hemlock chronology is made up of 30 cores from 20 trees, and encompasses an interval from 1374 to 1994.

The Milla Lake hemlock data had an overall series intercorrelation of 0.519, a mean sensitivity at 0.251 and an autocorrelation value of 0.676. The hemlock chronology shows high variablity in the 1400s, where few cores exist (Figure 7.1). The 1500s are marked by a decline in ring-width indices, a trend which continued until the mid 1600s. Ring-width growth increments are larger in the early 1700s before decreasing through the remainder of the 1700s. Then the ring-width increments widen up to the 1840s, and subsequently narrow again until the 1870s. The ring-widths widen from the late 1800s throughout the early 1900s, until the late 1940s where growth in ring-widths peak. From this point until the end of the chronology, ring-width growth narrows.

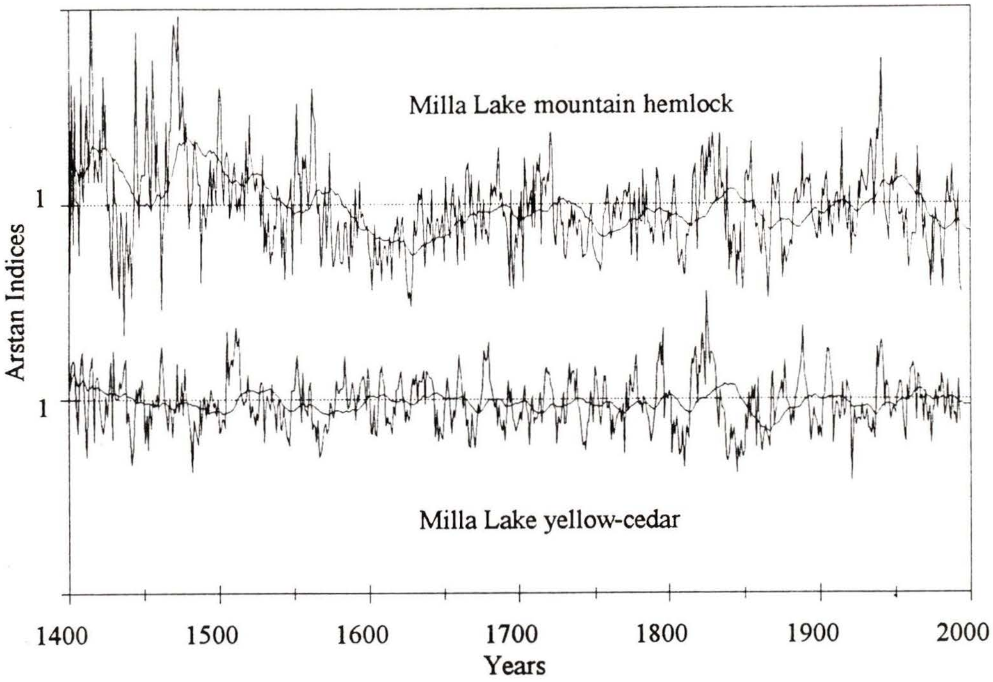


Figure 7.1 - Comparison of a mountain hemlock chronology to a yellow-cedar chronology at Milla Lake. A 30 year running mean is shown on the chronologies.

In a direct comparison the two species show many similarities. Peaks in growth are seen in the mid 1940s, the late 1880s, the mid 1820s, the mid 1720s, the early 1690s, and the 1550s. Times of reduced growth rates correspond in the early 1920s, the early 1860s, the late 1830s, the early 1750s, the mid 1620s, the mid 1560s, and the late 1490s. These periods of similar growth increments lead to the supposition that both tree species are responding to the local climate and not to unique physiological characteristics.

7.1.2 Mount Arrowsmith comparison

A single mountain hemlock chronology compiled by Briffa *et al.* (1992) provides the only ring-width data from another high elevation dendrochronological investigation on Vancouver Island. This chronology is made up of 28 cores from 14 trees located on the west side of Mount Arrowsmith at 1020 m asl. The chronology extends from 1629 to 1983 and has a series intercorrelation of 0.52, a mean sensitivity value of 0.125 and an autocorrelation value of 0.842.

The mountain hemlock chronology at Mount Arrowsmith has many distinctive growth signals (Figure 7.2). Enlarged ring-growth characterizes the 1660s but is followed by narrow increments until the 1690s. After a slight increase in ring-growth around 1700, the amount of annual growth decreases until the 1730s. Small growth increments characterize the mid 1700s, until 1770, when wider rings are produced. The first half of the 1800s is marked by reduced growth, with wide rings produced in the late 1850s. At the beginning of the 1900s wider rings in the growth chronology are followed by lower growth rates throughout the mid 1900s. In the 1940s, 1950s and 1960s, the chronology shows higher growth rates but by the 1970s ring growth is once again narrow.

There is some similarity between yellow-cedar and mountain hemlock growth in chronologies from Mount Arrowsmith. Corresponding increases in ring growth in the chronologies are found in the 1960s, the 1940s, in the early 1900s, the mid 1850s, the 1790s, and the late 1730s. Matching narrow rings in the data are exhibited during the mid 1970s, the early 1930s, the early 1800s, the mid 1750s, the late 1740s, and the early 1700s.

Differences in the chronologies could be associated with elevation, as the yellow-cedar samples were collected at a site approximately 300 metres higher than the mountain hemlock site. As was found with the Mount Washington samples in this study, and as indicated by other studies (Villalba *et al.*, 1994), a critical elevation threshold can change characteristics in growth sequences.

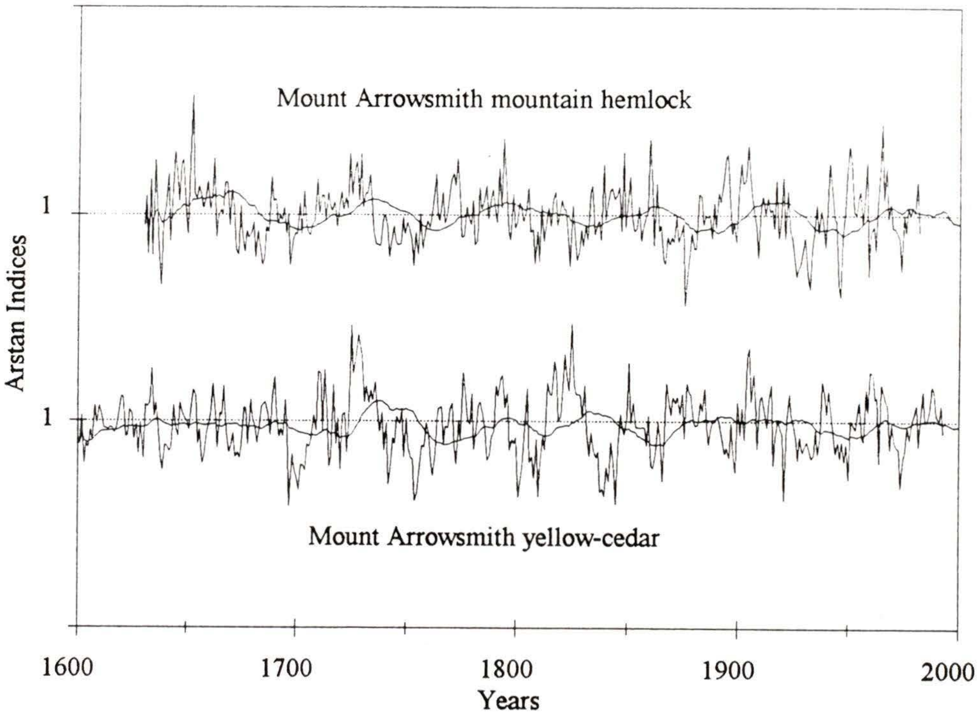


Figure 7.2 - Comparison of a mountain hemlock ring-width chronology to a yellow-cedar chronology at Mount Arrowsmith. A 30 year running mean is shown on the chronologies.

7.2 Vancouver Island regional comparisons

Smith (1995b) presents a mountain hemlock chronology from Strathcona Provincial Park and this chronology is compared to the regional yellow-cedar chronology developed for this study. The two regional assessments have one site (Milla Lake) in common and both chronologies are limited to high elevation stands. The hemlock sites are all from an area in the eastern section of Strathcona Provincial Park. The four hemlock chronologies were derived from sites located between 1200 and 1450 m asl, somewhat higher in elevation than the yellow-cedar sites.

The hemlock regional chronology extends from 1500 to 1994 (Figure 7.3). The chronology shows periods of reduced growth throughout the early 1500s, but increases in growth increments in the 1560s and again in the late 1590s. In general the 1600s and the 1700s show reduced growth, with the only exception being slightly larger ring widths in the 1630s and 1720s. The early 1800s were an interval of increased ring growth before the annual rings began to narrow from the 1830s until the late 1890s. Following this interval, the average ring-width increment began to increase, until a minor decrease in the growth increment occurs in the 1920s. From this point ring growth widens until the 1940s and then slowly decreases until the 1970s; rings then enlarge until 1994.

Both chronologies have similar growth trends from the mid 1650s to 1994 (r^2 = 0.27). The interval was limited by the depth of samples in the mountain hemlock chronology before 1650. Common growth intervals between the two chronologies occur for 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. Increased growth occurs simultaneously in the chronologies in the mid 1960s, the early 1900s, the late 1880s, the mid 1850s, the mid 1820s, the late 1790s, and the early 1700s. These similarities were an important discovery as it emphasized that the climate signal captured was not unique to yellow-cedar.

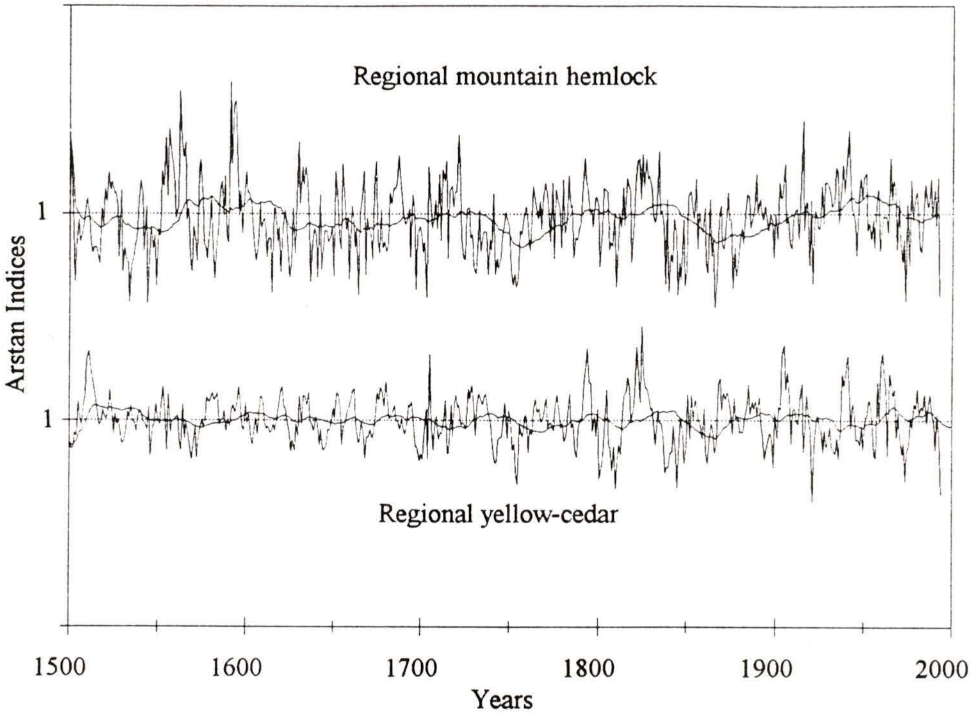


Figure 7.3 - Comparison of a Vancouver Island mountain hemlock regional chronology to the Vancouver Island regional yellow-cedar chronology. A 30 year running mean is shown on the chronologies.

Even though the two tree species have similar growth patterns the growth response of mountain hemlock is more extreme. Specifically during narrow growth periods the response of mountain hemlock is to grow narrower than yellow-cedar. This response seems to indicate that mountain hemlock reacts to the same climatic conditions as yellow-cedar, but in a different manner due to inherent biological differences between the species. Yellow-cedar has a slightly lower average mean sensitivity (0.245) than mountain hemlock (0.263), but more importantly a higher overall autocorrelation (0.713) than the hemlock (0.610) (Table 7.1).

The fact that these two species react in differing ways to the same climatic shifts, indicates that the same climate parameters may affect trees differentially in this biogeoclimatic zone. Mountain hemlock for instance is known to exhibit significantly reduced growth in a given year if the spring snowpack is large (Graumlich and Brubaker 1986; Smith 1995b). Although yellow-cedar is probably affected by spring snowpack levels, tests showed a very weak correlation between growth and spring snowpack (r = -0.32) compared to significant results from mountain hemlock (Graumlich and Brubaker 1986; Smith 1995b). The propensity of the trees to react slightly differently is useful but only if the exact climatic parameters affecting each species can be determined. If two tree species can be shown to react differently to the same climate, it may be possible to more precisely characterize the nature of past climatic change.

Table 7.1 - Ranked mean sensitivity and autocorrelation of mountain hemlock and yellow-cedar tree-ring chronologies on Vancouver Island.

Species	Mean Sensitivity	Auto-correlation	Source Area
Mountain hemlock	0.281	0.593	Delight Lake
Yellow-cedar	0.269	0.728	Heather Mountain
Mountain hemlock	0.265	0.646	Canyon
Yellow-cedar	0.257	0.619	Mount Cain
Mountain hemlock	0.255	0.526	Circlet Lake
Yellow-cedar	0.252	0.692	Milla Lake
Mountain hemlock	0.251	0.676	Milla Lake
Yellow-cedar	0.238	0.720	Mount Arrowsmith
Yellow-cedar	0.209	0.806	Mount Washington

8.0 Summary and Conclusions

8.1 Summary

Five high elevation sites were selected in this study to capture a growth signal of yellow-cedar at treeline. The five sites were Mount Cain, Mount Washington, Milla Lake, Mount Arrowsmith, and Heather Mountain. At each of the three primary sites (Cain, Washington and Arrowsmith), 100 cores were collected from 50 trees. At Milla Lake, 50 cores were sampled from 25 trees, at Heather Mountain, 30 cores were taken from 15 trees. Ring-widths for each of the 380 cores were measured to the nearest one hundredth of a millimetre using the WinDendro™ system. Individual site chronologies were built using the software program COFECHA for each of the five locations. The chronologies were then detrended by the program ARSTAN and, using this information, a regional chronology combining the five sites was constructed for Vancouver Island. Master site chronologies all indicate similar upper elevational dendrochronological signals. Series inter-correlations were in the range of 0.300 to 0.469, autocorrelation within the groups ranged from 0.619 to 0.806, and mean sensitivity readings ranged from 0.209 to 0.269

The yellow-cedar site chronologies were used for a dendroclimatological investigation. Response functions were calculated for each site with the software program PRECON, using climatic data from the Nanaimo AES station. The five site response functions described similar climatic parameters involved in yellow-cedar growth. Five temperature variables and one precipitation variable were significantly related to the regional chronology. Upper elevational yellow-cedar growth is significantly related to prior August and October temperatures and those of the current year's January, July and August temperatures as well as June precipitation. At all sites climate and prior growth explain two thirds of the variance in yellow-cedar growth. The climate factor that accounted for the highest percentage of growth was a negative relationship to previous August's temperature. A proxy climatic reconstruction was made with previous August growth using the program REC, which was then verified, both visually and using the program VFY. The proxy climatic values were then presented as visual deviations from the mean proxy temperature, and as a 30 year running mean of temperature. This analysis showed average temperature amplitudes on a 30 year running mean varying by up to one third of a degree Celsius over the last 800 years.

Comparisons with mountain hemlock chronologies from the same stand of trees at Milla Lake, from the same area close to Mount Arrowsmith, and from the same mid-Island regions as the yellow-cedar sites, indicate that yellow-cedar and mountain hemlock ring-widths are similarly influenced by climate in high elevational areas of Vancouver Island.

8.2 Conclusions

The answer to the initial question, "Is yellow-cedar sensitive to climatic fluctuations?" is yes. The species shows a common growth signal, not only between trees from the same stand but also in trees from five different sites in the Insular mountains of Vancouver Island. The growth ring-records of the trees are sensitive to climate but are also heavily autocorrelated with the prior year's growth. These characteristics demonstrate that yellow-cedar is suitable for dendroclimatological reconstruction, but is probably limited to the detection of low-resolution trends.

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Appendix A

Mount Cain - Sample numbers, elevations and measured years.

Core Number	Sample Elevation	Measured Years	Core Number	Sample Elevation	Measured Years
94250A-	1460	243	94264A-	1405	237
94250B-	1460	207	94264B-	1405	524
94251A-	1460	232	94265A-	1400	325
94251B-	1460	412	94265B-	1400	215
94252A-	1460	405	94266A-	1400	271
94252B-	1460	466	94266B-	1400	193
94253A-	1450	369	94267A-	1400	98
94253B-	1450	497	94267B-	1400	259
94254A-	1435	502	94268A-	1395	483
94254B-	1435	331	94268B-	1395	312
94255A-	1440	332	94269A-	1395	528
94255B-	1440	469	94269B-	1395	436
94256A-	1435	369	94270A-	1395	287
94256B-	1435	451	94270B-	1395	335
94257A-	1435	268	94271A-	1390	428
94257B-	1435	435	94271B-	1390	334
94258A-	1425	647	94272A-	1385	380
94258B-	1425	205	94272B-	1385	490
94259A-	1430	451	94273A-	1387	277
94259B-	1430	508	94273B-	1387	176
94260A-	1420	630	94274A-	1380	586
94260B-	1420	381	94274B-	1380	492
94261A-	1420	56	94275A-	1390	159
94261B-	1420	284	94275B-	1390	165
94262A-	1420	556	94276A-	1380	393
94262B-	1420	580	94276B-	1380	370
94263A-	1410	289	94277A-	1397	460
94263B-	1410	199	94277B-	1397	391

94278A-	1380	636
94278B-	1380	609
94279A-	1370	398
94279B-	1370	246
94280A-	1370	679
94280B-	1370	634
94281A-	1370	634
94281B-	1370	697
94282A-	1370	753
94282B-	1370	776
94283A-	1360	275
94283B-	1360	86
94284A-	1360	536
94284B-	1360	562
94285A-	1370	378
94285B-	1370	423
94286A-	1370	575
94286B-	1370	550
94287A-	1370	454
94287B-	1370	441
94288A-	1370	233
94288B-	1370	466
94289A-	1360	341
94289B-	1360	566
94290A-	1375	519
94290B-	1375	546
94291A-	1358	135
94291B-	1358	79
94292A-	1375	468
94292B-	1375	467
94293A-	1360	385
94293B-	1360	283
94294A-	1375	592
94294B-	1375	462
94295A-	1360	319
94295B-	1360	711
94296A-	1358	720
94296B-	1358	702
94297A-	1360	558
94297B-	1360	424
94298A-	1360	535
94298B-	1360	789
94299A-	1355	400
94299B-	1355	377

Average Elevation = 1393 m asl
Average Core Age = 418 years

Appendix B

Mount Washington - Sample numbers, elevations and measured years.

Core Number	Sample Elevation	Measured Years	Core Number	Sample Elevation	Measured Years
94200A-	1570	156	94214A-	1205	153
94200B-	1570	158	94214B-	1205	165
94201A-	1500	178	94215A-	1205	171
94201B-	1500	212	94215B-	1205	157
94202A-	1500	195	94216A-	1205	161
94202B-	1500	207	94216B-	1205	145
94203A-	1500	176	94217A-	1210	130
94203B-	1500	168	94217B-	1210	165
94204A-	1500	165	94218A-	1210	121
94204B-	1500	174	94218B-	1210	164
94205A-	1440	189	94219A-	1210	161
94205B-	1440	183	94219B-	1210	154
94206A-	1425	250	94220A-	1210	132
94206B-	1425	292	94220B-	1210	103
94207A-	1420	182	94221A-	1205	92
94207B-	1420	156	94221B-	1205	87
94208A-	1243	132	94222A-	1205	201
94208B-	1243	122	94222B-	1205	218
94209A-	1225	237	94223A-	1205	218
94209B-	1225	235	94223B-	1205	167
94210A-	1220	236	94224A-	1210	199
94210B-	1220	224	94224B-	1210	206
94211A-	1215	99	94225A-	1210	143
94211B-	1215	173	94225B-	1210	114
94212A-	1210	90	94226A-	1225	249
94212B-	1210	70	94226B-	1225	218
94213A-	1210	110	94227A-	1225	179
94213B-	1210	104	94227B-	1225	201

Core Number	Sample Elevation	Measured Years
94228A-	1220	261
94228B-	1220	213
94229A-	1225	160
94229B-	1225	181
94230A-	1220	261
94230B-	1220	205
94231A-	1218	125
94231B-	1218	238
94232A-	1225	225
94232B-	1225	235
94233A-	1220	170
94233B-	1220	159
94234A-	1230	203
94234B-	1230	221
94235A-	1230	197
94235B-	1230	202
94236A-	1232	177
94236B-	1232	145
94237A-	1225	179
94237B-	1225	168
94238A-	1210	174
94238B-	1210	200
94239A-	1220	185
94239B-	1220	161
94240A-	1220	227
94240B-	1220	181
94241A-	1230	137
94241B-	1230	118
94242A-	1240	153
94242B-	1240	149
94243A-	1230	153
94243B-	1230	155
94244A-	1240	99
94244B-	1240	152
94245A-	1240	148
94245B-	1240	117
94246A-	1230	179
94246B-	1230	185
94247A-	1240	175
94247B-	1240	124
94248A-	1420	174
94248B-	1420	192
94249A-	1420	219
94249B-	1420	208

Average Elevation = 1270 m asl
Average Core Age = 173 years

Appendix C

Milla Lake - Sample numbers, elevations and measured years.

Core Number	Sample Elevation	Measured Years
94350A	1600	21
94350B	1600	633
94351A	1600	355
94351B	1600	440
94352A	1600	156
94352B	1600	171
94353A	1605	170
94353B	1605	171
94354A	1605	430
94354B	1605	248
94355A	1605	372
94355B	1605	433
94356A	1610	297
94356B	1610	291
94357A	1610	458
94357B	1610	767
94358A	1610	618
94358B	1610	506
94359A	1610	1003
94359C	1610	1194
94360A	1595	183
94360B	1595	259
94361A	1590	298
94361B	1590	389
94362A	1590	526
94362B	1590	558
94363A	1592	166
94363B	1592	224
94364A	1590	485
94364B	1590	445
94365A	1590	199
94365B	1590	258
94366A	1590	244
94366B	1590	381
94367A	1592	191
94367B	1592	577
94368A	1592	483
94368B	1592	476
94369A	1592	649
94369B	1592	572
94370A	1620	224
94370B	1620	251
94371A	1630	374
94371B	1630	376
94372A	1630	301
94372B	1630	98
94373A	1595	235
94373B	1595	169
94374A	1600	259
94374B	1600	291

Average Elevation = 1602 m asl
Average Core Age = 378 years

Appendix D

Mount Arrowsmith - Sample numbers, elevations and measured years.

Core Number	Sample Elevation	Measured Years	Core Number	Sample Elevation	Measured Years
94300A-	1290	263	94314A-	1258	204
94300B-	1290	232	94314B-	1258	204
94301A-	1288	573	94315A-	1255	219
94301B-	1288	425	94315B-	1255	164
94302A-	1280	227	94316A-	1260	202
94302B-	1280	197	94316B-	1260	244
94303A-	1288	440	94317A-	1220	257
94303B-	1288	486	94317B-	1220	269
94304A-	1280	367	94318A-	1260	223
94304B-	1280	383	94318B-	1260	247
94305A-	1275	115	94319A-	1220	224
94305B-	1275	130	94319B-	1220	214
94306A-	1280	494	94320A-	1250	260
94306B-	1280	503	94320B-	1250	258
94307A-	1260	69	94321A-	1210	167
94307B-	1260	172	94321B-	1210	171
94308A-	1275	145	94322A-	1248	216
94308B-	1275	266	94322B-	1248	232
94309A-	1270	587	94323A-	1210	217
94309B-	1270	644	94323B-	1210	254
94310A-	1262	456	94324A-	1240	253
94310B-	1262	448	94324B-	1240	245
94311A-	1260	453	94325A-	1198	276
94311B-	1260	566	94325B-	1198	272
94312A-	1258	255	94326A-	1220	261
94312B-	1258	239	94326B-	1220	172
94313A-	1258	149	94327A-	1180	605
94313B-	1258	200	94327B-	1180	167

Core Number	Sample Elevation	Measured Years
94328A-	1220	273
94328B-	1220	268
94329A-	1168	877
94329B-	1168	890
94330A-	1210	230
94330B-	1210	257
94331A-	1180	200
94331B-	1180	159
94332A-	1210	230
94332B-	1210	208
94333A-	1180	174
94333B-	1180	119
94334A-	1190	164
94334B-	1190	258
94335A-	1190	144
94335B-	1190	201
94336A-	1200	267
94336B-	1200	197
94337A-	1188	32
94337B-	1188	56
94338A-	1198	256
94338B-	1198	162
94339A-	1178	486
94339B-	1178	123
94340A-	1198	193
94340B-	1198	203
94341A-	1180	446
94341B-	1180	512
94342A-	1185	771
94342B-	1185	727
94343A-	1180	446
94343B-	1180	460
94344A-	1195	256
94344B-	1195	233
94345A-	1180	355
94345B-	1180	425
94346A-	1195	247
94346B-	1195	264
94347A-	1175	417
94347B-	1175	115
94348A-	1178	483
94348B-	1178	574
94349A-	1175	468
94349B-	1175	553

Average Elevation = 1224 m asl
Average Core Age = 306 years

Appendix E

Heather Mountain - Sample numbers, elevations and measured years.

Core Number	Sample Elevation	Measured Years
94375A	1135	158
94375B	1135	236
94376A	1135	116
94376B	1135	132
94377A	1135	130
94377B	1135	70
94378A	1135	80
94378B	1135	84
94379A	1135	493
94379B	1135	466
94380A	1135	297
94380B	1135	326
94381A	1135	186
94381B	1135	178
94382A	1135	275
94382B	1135	228
94383A	1135	389
94383B	1135	310
94384A	1135	83
94384B	1135	251
94385A	1135	260
94385B	1135	178
94386A	1135	360
94386B	1135	377
94387A	1135	68
94387B	1135	254
94389A	1135	50
94389B	1135	103
94390A	1135	359
94390B	1135	324

Average Elevation = 1135 m asl
Average Core Age = 227 years

VITA

Surname: Laroque	Given Names: Colin Peter

Place of Birth: Saskatoon, Saskatchewan, Canada

Educational Institutions Attended:

University of Victoria	1993 to 1995
University of Saskatchewan	1988 to 1993

Degrees Awarded:

B. Sc. (Honours)	University of Saskatchewan	1993

Honours and Awards:

-1993 Griffith Taylor Prize in Geography
-1993 R.C.G.S Undergraduate Project Bursary
-1992 Alumni Challenge Undergraduate Scholarship
-1991 R.C.G.S Undergraduate Project Bursary

(All held at the University of Saskatchewan)

Publications:

Papers:

Smith, D.J., and Laroque, C.P., 1996. Dendroglaciological of a Little Ice Age glacial advance at Moving Glacier, Vancouver Island, British Columbia. Géographie physique et Quaternaire. (in press).

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