Effect of Climate on Radial Growth of B.C. Coastal Conifers: 1996/99 Final Report

Report for the 36 month period May 1, 1996 to April 30, 1999

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UVTRL Report 99-03

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Report for the period May 1, 1996 to April 30, 1999

ABSTRACT

The potential for rapid climatic change in British Columbia over the next century mandates a need to understand the growth response of the provinces's forests to predicted climate conditions. The aim of this research programme was to provide answers to two questions: What is the radial growth response of individual tree species to climate in coastal British Columbia? , and; What impact will future climatic changes have on radial growth dynamics in coastal British Columbia? Our approach was to answer these questions within a hierarchal research methodology focussed initially on the collection of samples, secondly on the analysis and modelling of the inherent climate-growth relationships, and finally on the construction of predictive models capable of evaluating the impacts of future climatic changes.

Tree-ring chronologies were developed from increment cores (2500 trees, *ca.* 4800 cores) collected at 64 conifer stands on Vancouver Island and in the central coast region of British Columbia. The majority of these samples have been processed and over three-quarter of a million crossdated tree-ring measurements archived in our database. All of the tree ring series we examined contained a collective signal that permitted intra- and inter regional crossdating by species.

Dendrochronological analyses revealed the presence of persistent, region-wide, long-term intervals of enhanced and reduced radial growth. While these variations were shown to be associated with the interaction of tropical and extra-tropical forcing systems, close examination of the tree-ring chronologies showed that the productivity of forests in of coastal British Columbia undergoes abrupt regime shifts. In the case of Douglas-fir, these interactions were related to forcing mechanisms with 20-30 years and 50-60 years periodicities.

The climate-growth relationships of our tree-ring chronologies were examined using a principle component analysis to establish whether temperature or precipitation, or a combination thereof, were the predominant variables controlling their annual radial growth. Comparison of the regional response functions generated for trees on Vancouver Island and in the central Coast region shows that tree growth in this region is significantly linked to limited sets of climatic parameters. These site-specific analyses were combined using principal component analyses to summarize the various growth-response signals and extract the dominant modes of variability associated with each of the tree species examined. Based on these findings two simulation models capable of predicting radial growth under a given set of climatic conditions were produced. *TREE* (*Tree-ring Radial Expansion Estimator*) is an HTML-based model designed to display the impact of climate on the radial-growth behaviour of trees in the Vancouver Island montane biogeoclimatic zone. The model is user-friendly, educational and built upon authenticated growth-response data. The second simulation model uses an artificial neural network (ANN) to simulate the effects of climate change on tree growth by presenting it with a series of climatic scenarios. The ability of the ANN model to produce reasonably correct growth responses suggest it offers an innovative way to predict nonlinear growth responses to changing climates.

We expect that the findings of this research will ultimately be of value to practising foresters and the British Columbia forest community. Continuing refinements to TREE and to our ANN model will present foresters with the opportunity to consider the impact of future climatic changes on forest productivity and to evaluate these impacts within the context Annual Allowable Cut calculations.

INTRODUCTION

The climate of coastal British Columbia is regulated by the proximity of the Pacific Ocean, which imparts a maritime climate to this region through a complex suite of forcing processes (Hanawa 1995). Nevertheless, there is a growing recognition that the climate of this region is not static, and that shifts between climatic states have occurred not only repeatedly but often abruptly within the last millennium (Charles 1998). This longer term behaviour is largely a response to El Niño / Southern Oscillation (ENSO) related teleconnections and interdecadal climate variability driven by the Pacific Decadal Oscillation (PDO) (Hare 1996; Zhang *et al.* 1997). If future climate changes enhance these conditions as predicted, it is likely that there will significant changes to the climates of coastal British Columbia within the next century.

The potential for rapid climatic change in British Columbia mandates a need to understand the growth response of the provinces's forests to predicted climate conditions. General circulation models predict increases of 2 to 5 °C in mean summer and winter temperatures within this region (McBean and Thomas 1992). Given that much smaller temperature increases over the last 100 years appear to have had major impacts on the productivity of conifer forests in nearby Washington state (Graumlich *et al.* 1989), it is essential that forest managers in British Columbia understand how climate changes influences forest productivity.

Climate plays an important role in limiting tree growth in coastal British Columbia and dendro-climatological and ecological techniques provide a robust tool for assessing the potential impacts of climatic change. Mature conifers contain within their annual growth rings, a biological time series describing a response to a variety of site factors including, competition, tree and stand age, fire and other disturbances, and climate. Fritts (1976) has established a methodological framework that facilitates the use of statistical methods to factor out the climatic influences on radial growth. By comparing the annual variations in ring width to variations in monthly and seasonal climatic data, a descriptive climate-growth response model can be developed. These models can then be used to predict likely growth responses to different climate change scenarios

Research Purpose

The aim of this research programme was to examine the growth response of mature conifers in coastal British Columbia to climate. Based on the successful application of tree-ring studies by previous researchers in this setting (Parker *et al.* 1978, Robertson *et al.* 1990; Schweingruber *et al.* 1991), we chose a research methodology that utilized dendroclimatological techniques to answer two key questions:

- ❑ What is the radial growth response of individual tree species to climate in coastal British Columbia?
- ❑ What impact will future climatic changes have on radial growth dynamics in coastal British Columbia?

This approach is distinct from past studies of climate and radial growth in two important ways : (1) The emphasis on coastal tree-ring series is unprecedented in the literature (Blasing and Fritts 1976; Briffa and Jones 1992) and a comparison of coastal trees with interior trees by Wiles *et al*. (1996) has suggested that coastal chronologies are distinct. (2) The incorporation of multiple species from overlapping ranges allows multiple climate parameters to be reconstructed.

Research Objectives

Our research programme was designed to be completed within a three year period (1996-1999), and was intended to combine tree-ring studies of climatically-sensitive living trees in two regions of coastal British Columbia with the long record (*ca.* 10,000 years) of subfossil trees from Heal Lake on southern Vancouver Island. After the completion of the third field season (1998), we anticipated being in a position to summarize the various climate-response relationships and evaluate potential growth under different climate change scenarios.

This general research framework was stratified around several key objectives:

- to establish radial growth-response of selected conifers in coastal British Columbia to climate.
- to describe the radial-growth response of selected conifers under regionally different climates (Vancouver Island "vs" Central Coast).
- to describe the long-term growth behaviour of selected conifers in coastal British Columbia, with respect to any apparent pattern of periodic growth.
- to focus on establishing the growth rates and characteristics of Douglas-fir under historically different climatic regimes, including those similar to predictions under global warming scenarios.
- to develop a climate-response model capable of predicting effects of future climate change on the radial growth behaviour of selected coastal British Columbia conifers.

In order to accomplish these objectives, three University of Victoria graduate students (Ze'ev Gedalof [M.Sc. candidate, Geography Department]; Colin Laroque [Ph.D. candidate, Geography Department] and Qibin Zhang [Ph.D. candidate, Centre for Earth and Ocean Systems]) were allocated specific research tasks. These activities focussed on understanding the radial growth response of ***lowland forest sites*** dominated by stands of Douglas-fir trees (*Zhang*) and the radial growth response of ***high-elevation montane forest sites*** dominated by mountain hemlock, western hemlock, amabilis fir and yellow-cedar trees (*Gedalof* and *Laroque*).

RESEARCH METHODOLOGY

Our research program consisted of two essential components: the collection of an extensive sample of increment cores during the summer field season; and, a lengthy period of assessment and analysis at the University of Victoria Tree-Ring Laboratory, Department of Geography, University of Victoria. Numerous volunteers directly assisted with both facets of the research and the varied contributions of Kendrick Brown, Nicholas Cottone, Paul DelPrato, Chris Duquette, Dr.Greg Ettl, Kent Gustavson, Dave Lewis, Dawn Loewen, Jen Paul and Chris Wood are gratefully acknowledged.

Ring-Width Chronologies

Living tree ring-width chronologies were developed from increment cores collected at 64 conifer stands located on Vancouver Island and in the central coast region of British Columbia (Figure 1). While the majority of the field research activity associated with our research program took place on Vancouver Island in the summers of 1996, 1997, and 1998; comparative collections were made in the central coast region (Bella Coola area) in the summers of 1997 and 1998. Restricted access and a limited budget precluded the collection of a more comprehensive sample from the latter region.

Ring-width data for our montane sample sites comes from increment core samples (2 per tree) collected at mountain ridge or summit sites above 1000 m asl (Table 1, Appendix B). At all sites (with the exception of three), cores were obtained from a minimum of two species. Previous research has shown that the growth signal preserved in tree ring series varies between sites and species (Villalba *et al.* 1994), and records developed from different species at the same site provide considerably more information than investigations restricted to a single species (Colenutt and Luckman 1995). Permission to access all of the sites visited was granted by either the forest shareholder or BC Parks.

Ring-width data for the lowland sites comes from two sources. Living tree-ring chronologies were developed from increment core samples taken from Douglas-fir trees located at four sites on southern Vancouver Island (Table 1, Appendix 1) and at eleven sites in the Bella Coola area. The subfossil logs of Douglas-fir discovered on the bottom of Heal Lake on southern Vancouver Island provided ring-width data spanning the last 10,000 years (Zhang, 1996) and a narrow strip of wood was cut from each of the 700 logs for analysis.

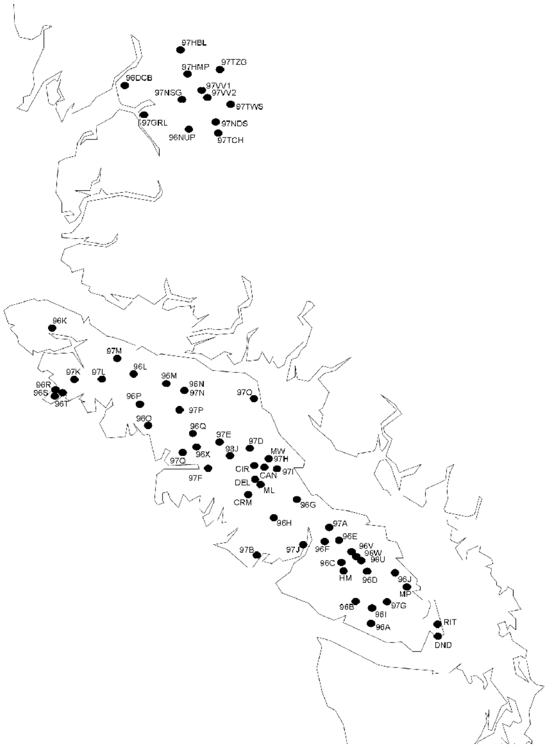


Figure 1. Sample sites in coastal BC.

Laboratory and Analytical Techniques

In order to facilitate ring-width measurement and to allow for crossdating, the increment core samples were first allowed to “air dry” and were then glued into slotted mounting boards. The samples were then polished with progressively finer sand paper (80 to 600) to highlight the boundaries between the annual rings. Following this, the majority of the samples were measured (to 0.01 mm) using a Windendro^{TM} tree-ring image processing system. A limited number of samples were measured at Pacific Foresty Centre (Victoria, B.C.) using either a Measu-Chron or Digimic tree-ring incremental measuring system.

Once all of the sample ring-widths were measured, they were visually crossdated with reference to a set of regional pointer years. Following this procedure, the samples from each site were collated and were checked for signal homogeneity using the COFECHA computer program (Holmes, 1983). Site- and species-specific living ring-width chronologies were then developed according to standard procedures (Fritts, 1976). The subfossil Douglas-fir samples from Heal Lake were treated in much the same way. While radiocarbon analysis indicate that the samples from Heal Lake span the 3rd to 9th millennia (Zhang 1996), through the use of use of skeleton plots (Stokes and Smiley 1968), 86 subfossil samples were crossdated into a master chronology that was verified with COFECHA.
The computer software program ARSTAN was used to remove age-related growth trends within each living

tree series and produce standardized indices of radial growth for the duration of each chronology (Grissino-Mayer *et al.*, 1993). In this instance, any age-related growth trends within the series were removed during the standardization by fitting either a negative exponential curve, a regression line of negative slope, or a horizontal line drawn through the mean of the series.

The relationship between the radial growth and climate was examined using the software program PRECON V5.17 (Fritts, 1998). The program calculates the principle components (PC) of the climate data and regresses the resultant PCs with the tree-ring data. The result is expressed in the form of a response function and the significance of the response coefficients is tested using a bootstrap method to overcome any autocorrelation problems within tree-ring chronologies. We used monthly climatic variables (mean monthly temperature and total monthly precipitation) over 18-month period (from previous year's May to October of the growth year) and the prior ring growth (acting as a proxy of the tree's health state) as independent variables to detect their significance in affecting the concurrent ring growth.

Two radial growth-response simulation models capable of predicting radial growth under a given set of climatic conditions were produced:

- The first model produced was **TREE** (***Tree-ring Radial Expansion Estimator***). This HTML-based model was constructed to display the impact of climate on the radial-growth behaviour of trees in the Vancouver Island montane biogeoclimatic zone. Tree-ring/climate relationships established during the course of this study are interactively used to indicate the resultant radial growth response. The model is user-friendly, educational and built upon authenticated growth-response data.

Tree-ring Radial Expansion Estimator

http://cgrg.geog.uvic.ca/tree.htm

- The second simulation model produced uses an artificial neural network (ANN) to simulate the effects of climate change on tree growth by presenting it with a series of climatic scenarios. This ANN model was developed using the software program *NeuroModeler* (Zhang, 1998) to provide additional insight into the non-linear response of tree growth to climate. The ability of the ANN model to produce reasonably correct growth responses was a result of a training exercise during which the connection weights were modified to minimize the differences between the actual and the modelled growth responses (Figure 2).

  The reliability of the ANN model for predicting growth-responses was assessed by validation on independent testing climate-growth data sets. The main advantages of the ANN technique over traditional dendroclimatic approaches are its ability to capture nonlinear climate-growth responses, and its non-reliance on assumed functional relationships for describing the observed data sets.

While the reliability of this simulation model is still under assessment, a manuscript describing its development is presently undergoing peer review (Zhang *et al.* 1999). A final presentation of the model is anticipated as a key component of Zhang's dissertation (2000). Nevertheless, our preliminary assessments indicate it offers an innovative way to predict nonlinear growth responses to changing climates, something not easily accomplished using more traditional approaches.

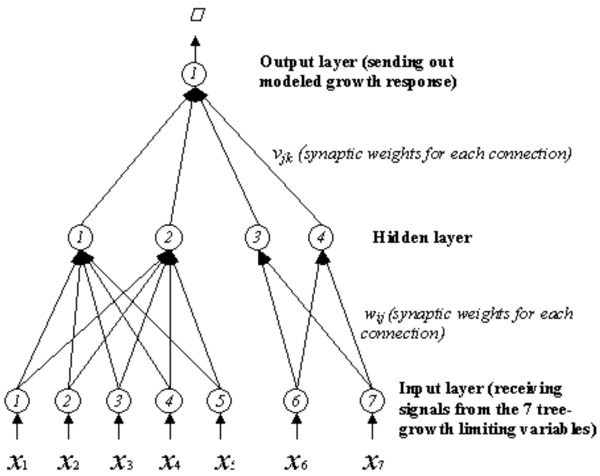


Figure 2. Architecture of the three-layer artificial neural network developed in this study for modelling nonlinear radial growth.

RESEARCH RESULTS

Dendrochronology

Almost 2500 trees were cored or sectioned during the tenure of this project, resulting in the collection of *ca.* 4800 increment cores for laboratory analysis. The majority of these samples have been processed and over three-quarter of a million crossdated tree-ring measurements are archived in our database.

Table 2 (Appendix B) presents a summary of the tree-ring statistics associated with our chronologies. These values are characteristic of climatically responsive trees, a finding corroborated by the high series correlation and mean sensitivity values at virtually all the sites examined.

All of the tree ring series we examined contained a collective signal that permitted intra- and inter regional crossdating by species. For instance in the case of lowland Douglas-fir, a comparison of the chronologies from southern Vancouver Island and the central coast region show a common growth response that resulted in suppressed during the late 1700s, late 1720s, late 1760s-early 1770s, late 1790s-early 1800s, late 1840s-1850s, late 1890s, late 1900s-early 1910s, and late 1920s-early 1930s (Figure 3). Similarly, common periods of enhanced growth during the 1690s-early 1700s, mid-1770s, late 1810s-early 1820s, 1860s, late 1930s-1940s, and 1980s suggest that Douglas-fir trees throughout coastal British Columbia are responding to some form of regional climate forcing.

These findings are reinforced by a correlation matrix analysis of 22 montane chronologies from Vancouver Island (Table 3, Appendix B). While the data within Table 3 show there is a significant spatial coherence between individual chronologies, a close examination of the data sets shows that this behaviour is species specific and becomes less significant the greater the distance between sites. Based on these types of observations, we recognize three broad sectors of similar montane tree growth behaviour on

Vancouver Island. These zones are illustrated in Figure 4 and provide the basis for the spatial classification incorporated within the TREE simulation model.

A notable finding of our analysis was the discovery of similar-aged stands of montane forests over broad areas of Vancouver Island. On northern Vancouver Island, and southward along the eastern and western coasts to approximately the Alberni Inlet and Campbell River respectively, most high-elevation trees are from 400 to 700 years old (Table 2 - Appendix A). The oldest montane stands (700 to 1200 years in age) we cored were found within the Vancouver Island Ranges northward from Strathcona Provincial Park. Far younger stands characterize mountain summits on the eastern and southern areas of the Island. With the exception of a few individual trees, most high-elevation stands in this area are less than 330 years in age.

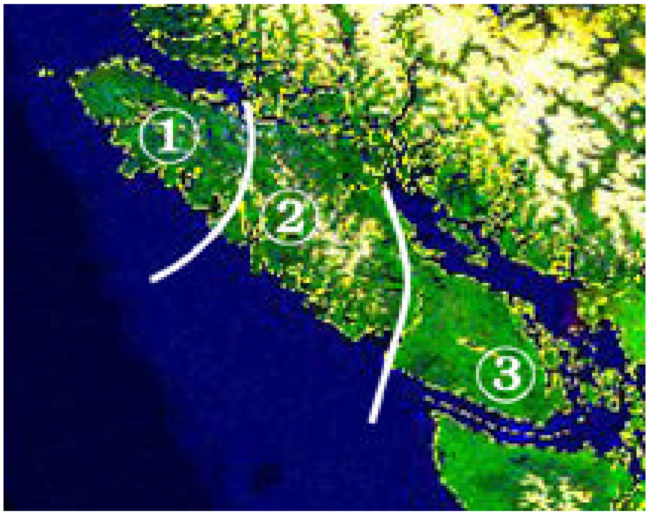


Figure 4. Division of Vancouver Island into sectors based on similar radial growth behaviour.

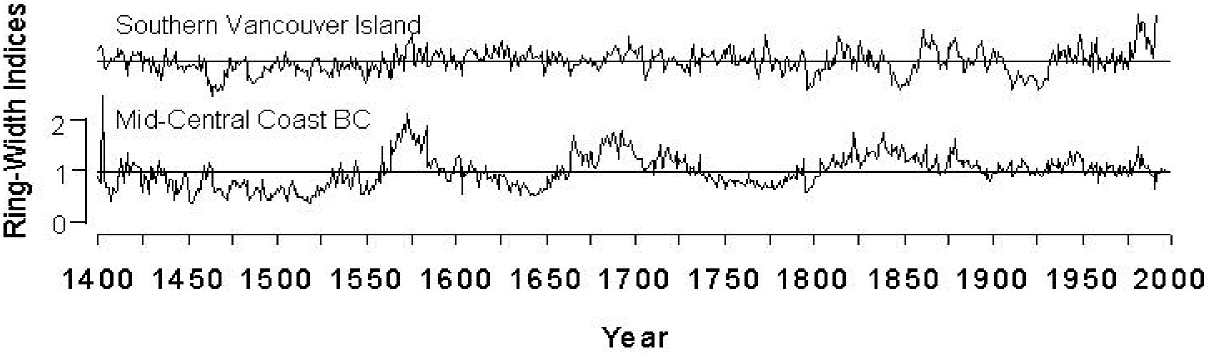


Figure 3. Comparison of standardized Douglas-fir radial growth trends in coastal British Columbia. Note that corollary intervals of enhanced and suppressed growth characterize both areas.

One of the most important biogeoclimatic boundaries on Vancouver Island is that defined by the change from stands dominated by western hemlock trees, to those characterized by mountain hemlock trees. While this change in forest structure is assumed to occur close to the 1000 m contour, our field data shows this is rarely the case and that this transitional zone actually has a very distinctive spatial characteristics. Our field data show that the transition to mountain hemlock dominated forests occurs at elevations well below 1000 m on the west side of Vancouver Island. In contrast, at sites located along the Vancouver Island Insular Mountain range divide, this transition occurs above the 1000 m contour. These spatial patterns reflect an ecophysiological response to precipitation variations on Vancouver Island. Given that the climatic changes forecasted for the Pacific Northwest include significant precipitation adjustments (Taylor and Taylor 1997), the discovery of an apparent depression of productive western hemlock stands on the west coast of Vancouver Island may serve to highlight a region vulnerable to climatic change.

Our dendrochronological research has added significantly to the understanding of the annual growth cycles of several coastal tree species. As shown by Figure 5, we have been able to document that at high-elevation locations on Vancouver Island, yellow-cedar radial growth production begins with the formation of earlywood cells by the beginning of mid-June. Earlywood cell construction appears to continue for between three to four weeks until mid-July, when our first observations of late-wood cells have been made. At most sites on Vancouver Island, latewood growth continues until mid-August when pollen formation begins. In contrast, the annual growth cycle of mountain hemlock begins with root growth, bud burst and shoot elongation in April and May. Increment core sampling over the past two field seasons has showed that radial growth commences by mid-June. Earlywood cells are produced for between three to four weeks, followed by an interval of latewood cell growth which only lasts for two to three weeks.

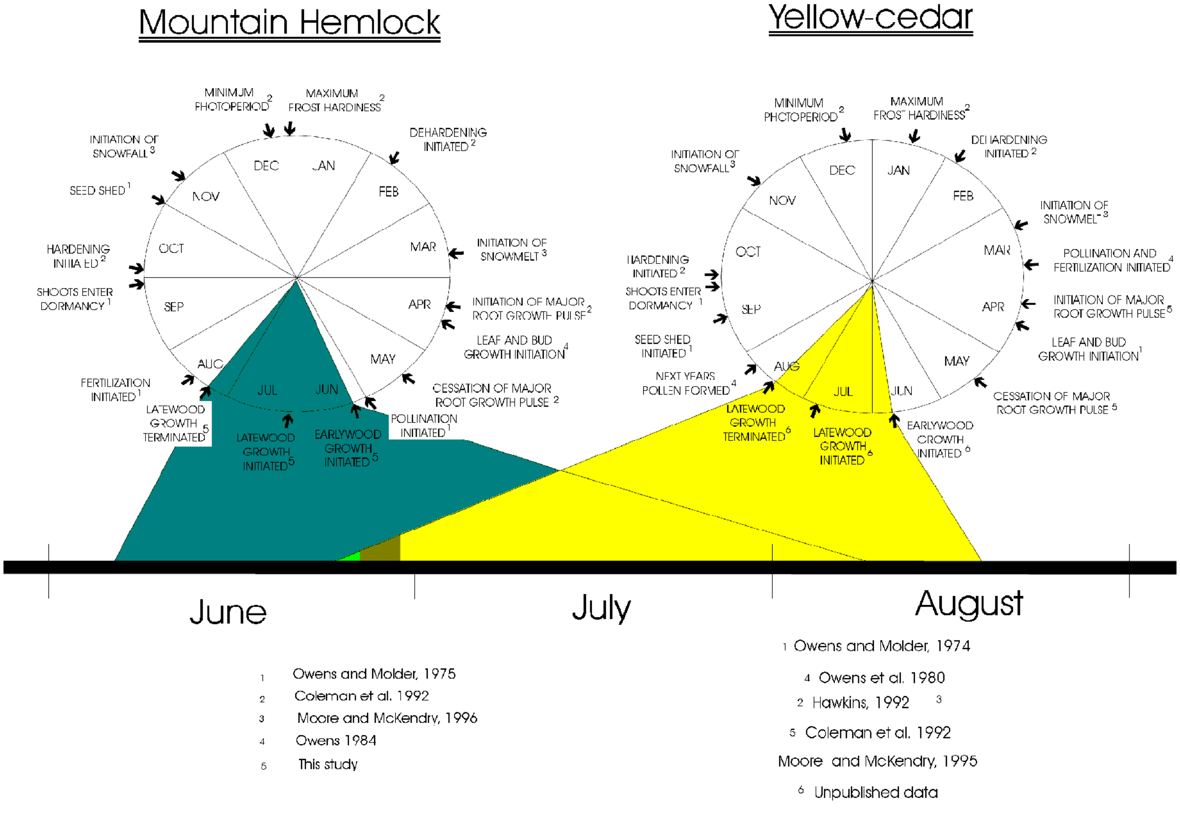


Figure 5. The yearly growth cycle of mountain hemlock and yellow-cedar trees growing at high-elevations on Vancouver Island.

Climate-Growth Relationships

The climate-growth relationships of our tree-ring chronologies were examined to establish whether temperature or precipitation, or a combination thereof, was the predominant variable controlling their annual radial growth. The relationship was expressed in the form of a response function. The significance of the response coefficients was tested using a bootstrap method to overcome any autocorrelation problems within tree-ring chronologies. Figure 6 portrays a typical outcome of the mountain hemlock response function product. In this instance, 77 percent of the annual ring-width variation is directly attributable to climate.

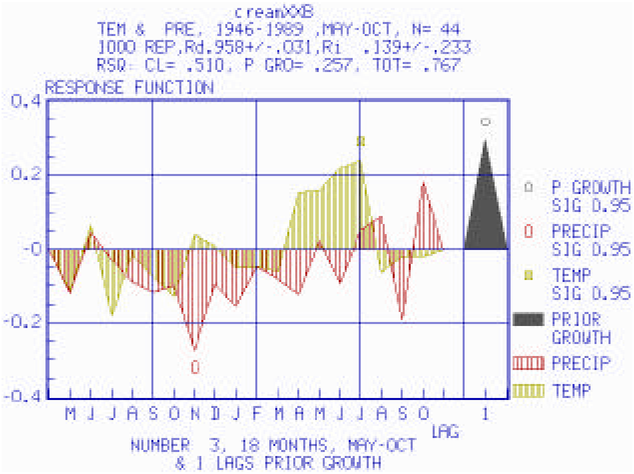


Figure 6. Response function output.

These site-specific analysis were combined using principal component analyses to summarize the various growth-response signals and extract the dominant modes of variability associated with each tree species. For instance, an analysis of the Bella Coola Douglas-fir chronologies showed that the first two PCs accounted for *ca.* 50 and 20 percent the total variance (Table 1). These findings provide a robust tool for understanding the regional climate-growth relationships of each of tree species.

Table 1. Principal components of Douglas-fir chronologies in the Bella Coola area.

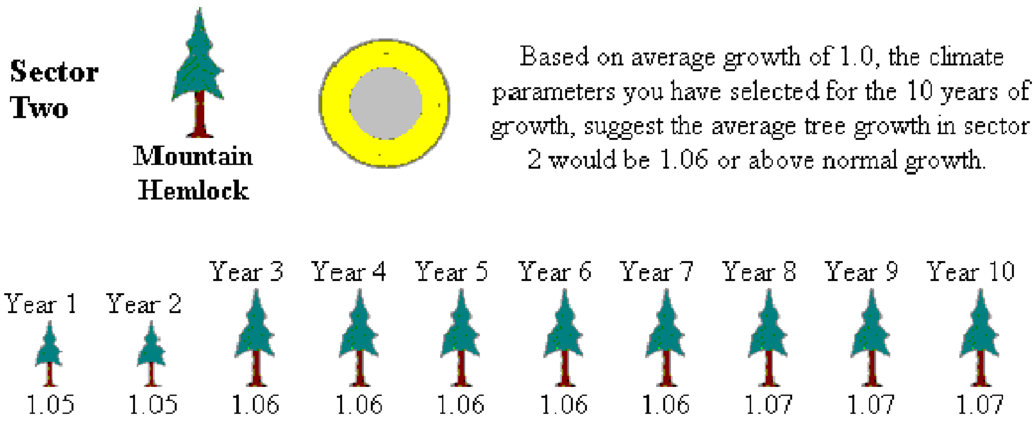
Principal component	Eigenvalue	Variance (%)	Cumulative variance (%)
1	4.54	50.48	50.48
2	1.86	20.63	71.11
3	0.80	8.84	79.95
4	0.75	8.30	88.25
5	0.33	3.70	91.95
6	0.29	3.20	95.15
7	0.18	2.01	97.16
8	0.16	1.83	98.99
9	0.09	1.01	100

NOTE: Eigenvalue is the sum of squares of the correlations between the component and the chronologies. Variance (%) refers to the percentage of total variance explained by the corresponding principal component.

Comparison of the regional response functions generated for trees on Vancouver Island and in the central Coast region shows that tree growth in this region is closely linked to climate. The response of each tree species was found to be reasonably consistent throughout the study area, suggesting that the long-term variations in radial growth we recorded are directly attributable to climate forcing by global-scale circulation changes (Gedalof and Smith 1999). Based on these findings, our research suggests that future climatic changes will impact disparate tree species differently in this region.

An Interactive Model of Radial Growth

The **TREE** model (**T**ree-ring **R**adial **E**xpansion **E**stimator, Version 1.0) was developed to predict future radial growth of high-elevation trees on Vancouver Island. TREE uses the response function outputs described above to identify the significant climatic parameters affecting growth in one of three stratified regions. After the selection of a particular species, users select the climatic parameter they wish to modify from list of applicable data. TREE evaluates the various inputs, computes the incremental growth response and presents this information in as HTML graphic (Figure 7).



Based on average growth of 1.0, the climate parameters you have selected for the 10 years of growth, suggest the average tree growth in sector 2 would be 1.06 or above normal growth.

Figure 7. An example of the output file produced by TREE which includes the predicted radial growth increments. Accompanying images indicate the relative change of each result in the computation of the data. Adjustments to the input parameters provide the user with the opportunity to evaluate the impact of various climatic change.

While TREE has considerable educational potential in its present form, we expect that TREE will ultimately be of practical value to practising foresters. Continuing refinements to TREE will present foresters with the opportunity to consider the impact of future climatic changes on forest productivity and to evaluate these impacts within the context Annual Allowable Cut (AAC) calculations.

DISCUSSION

This report summarizes our investigations of the impact of climate on the radial growth of BC coastal conifers which sought to address two key questions: What is the radial growth response of individual tree species to climate in coastal British Columbia?; and, what impact will future climatic changes have on radial growth dynamics in coastal British Columbia? Our approach was to answer these questions within a hierarchal research methodology focussed initially on the collection of samples, secondly on the analysis and modelling of the inherent climate-growth relationships, and finally on the construction of predictive models capable evaluating the impacts of future climatic changes.

Within the context of our research program, we identified five key objectives for study. While priority was given to data collection and analysis in the first two years of the research program, our attention in the final year of the program was directed to explaining the climate-growth relationships we discovered and in the development of two predictive models. Measurable success was made in completing objectives 1 to 4 and considerable progress has been made towards achieving objective 5.

Objective Milestones

Objective 1: To establish the radial growth-response of selected conifers in coastal British Columbia.

- over the tenure of the research almost 2500 trees were cored (*ca.* 4800 increment cores) in coastal British Columbia.
- 64 cross-dated site chronologies have been developed for 12 low-elevation and 52 high-elevation sites.
- conifers growing at all the sites examined were shown to be sensitive to historical climatic changes.

Objective 2: To describe the radial-growth response of selected conifers under regionally different climates (Vancouver Island "vs" Central Coast).

- our research has added significantly to the understanding the annual growth cycles of several montane tree species.
- our field collections on Vancouver Island and in the central coast region of British Columbia (Bella Coola area) revealed regional similarities in the radial growth response of conifers.
- detailed analysis of montane forests on Vancouver Island revealed subregional characteristics, exemplified by radial growth trends and forest structure.

Objective 3: To describe the long-term growth behaviour of selected conifers in coastal British Columbia, with respect to an apparent pattern of periodic growth.

- our climate-response modelling indicates that species-specific radial growth trends relate to distinct seasonal, annual and longer-term climate variations.
- persistent, region-wide, long-term intervals of enhanced and reduced radial growth in mature coastal conifers were identified.
- Douglas-fir productivity in coastal British Columbia shows intervals of reduced and enhanced growth related to forcing mechanisms with 20-30 years and 50-60 years periodicities
- productivity in the montane forests of coastal British Columbia undergoes abrupt disturbances in

response to large-scale climate forcing mechanisms.

- longer term radial growth variations in coastal British Columbia are associated with the interaction of tropical and extra-tropical forcing systems.

Objective 4: To focus on establishing the growth rates and characteristics of Douglas-fir under historically different climatic regimes, including those similar to predictions under global warming scenarios.

- comparisons of Douglas-fir chronologies from southern Vancouver Island and the central coast region demonstrated that they while they do share some common attributes, notable differences in their radial growth behaviour is apparent.
- the climate-growth responses recorded by these chronologies show that local growth conditions (*e.g.* preconditioning) introduce important localized growth response patterns of different regions.
- three floating tree-ring chronologies, representing the growth response of Douglas-fir to climate in the 3rd, 4th and 5th millennia, have been developed using 86 cross-dated subfossil samples from Heal Lake, southern Vancouver Island.
- consideration of these ancient tree-ring chronologies and the reexamination of a related two-millennium chronology (Zhang 1996) suggests that climatic variations have influenced Douglas-fir growth trends throughout the Holocene.
- comparison of ring-width trends through the Holocene shows that the last 5000 years have been the most stable on record.

Objective 5: To develop a climate-response model capable of predicting effects of future climate change on the radial growth behaviour of selected coastal British Columbia conifers

- a beta version of TREE was produced to predict the radial growth of high-elevation trees on Vancouver Island using different climatic scenarios.
- an artificial neural network (ANN) model was constructed which appears capable of predicting radial growth Douglas-fir under a given set of climatic conditions.

Application of Results

While many of our results will be more formally summarized in University of Victoria doctoral dissertations produced by Laroque (March, 2001) and Zhang (December, 2000), and in a M.Sc, thesis to be presented by Gedalof (June, 1999); we have endeavoured to illustrate the findings of our studies throughout the tenure of our FRBC award. A listing of these extension activity follows:

Refereed papers

Smith, D.J.; and Laroque, C.P., 1998. Mountain hemlock growth dynamics on Vancouver Island. *Northwest Science* 72 (Special Issue 2): 67-70.

Smith, D.J.; and Laroque, C.P., 1998. High-elevation dendroclimatic records from Vancouver Island. *Proceedings of the Workshop on Decoding Canada's Environmental Past: Climate Variations and Biodiversity Change during the Last Millennium, Ottawa, January 1997*. Edited by: D.C. MacIver and R.E. Meyer. Downsview: Atmospheric Enviroment Service. p. 33-44.

Laroque, C.P.; and Smith, D.J., 1999. Tree-ring analysis of yellow-cedar (*Chamaecyparis nootkatensis*) on Vancouver Island, British Columbia. *Canadian Journal of Forest Research*. 29:115-123.

Gedalof, Z.; and Smith, D.J. 1999. Interannual climate variability in the Northeast Pacific interpreted from the annual growth rings of mountain hemlock. *Proceedings of the Workshop on Decoding Canada's Environmental Past: Adaption Lessons Based on Changing Trends and Extremes in Climate and Biodiversity, Victoria. January, 1999*. Edited by: D.C. MacIver and R.E. Meyer. Downsview: Atmospheric Environment Service (*in press*).

Zhang, Q.; Hebda, R.; Zhang, Q-J.; Alfaro, R., 1999. Modeling tree-ring growth responses to climatic variables using artificial neural networks. *Forest Science* (submitted March 1999).

Laroque, C.P.; Lewis, D.; and Smith, D.J. 1999. Habitat implications of subalpine meadow tree invasion for the endangered Vancouver Island marmot, British Columbia. *Conservation Biology* (in preparation for June, 1999 submission)

Graduate Theses/Dissertations (completed)

Gedalof, Z. 1999. Low frequency climate variability in the Northeast Pacific interpreted from the annual-growth rings of mountain hemlock. Unpublished M.Sc. University of Victoria.

Scientific presentations

Presentation at the 1996 Annual Meeting of the Canadian Association of Geographers, Saskatoon, Saskatchewan, entitled - Dendrochronological analysis of Yellow-cedar from timberline sites on Vancouver Island. (Laroque and Smith).

Presentation at 1996 International American Institute for Global Change Workshop: Assessment of Present, Past and Future Climate Variability in the Americas from Treeline Environments, Jasper Alberta, entitled - Dendrochronological Studies on Vancouver Island. (Smith)

Presentation at 1997 Annual Meeting, Western Division, Canadian Association of Geographers, Prince George, British Columbia, entitled - Tree invasion and regeneration patterns in endangered Vancouver Island marmot habitat. (Lewis, Laroque and Smith)

Presentation at the Canadian Forest Service ‘Workshop on Structure, Process and Diversity in Secessional Forests of Coastal B.C, February 1998, entitled - Mountain Hemlock Dynamics on Vancouver Island (Smith and Laroque).

Presentation at 1998 Annual Meeting, Western Division, Canadian Association of Geographers, Richmond. March 1998 entitled - Reconstruction of Little Ice Age climates on Vancouver Island: an index to glaciological responses in the southern Canadian Cordillera? (Laroque, Zhang, Smith and Hebda)

Presentation at 1998 Annual Meeting, Western Division, Canadian Association of Geographers, Kwantlen University College, Richmond entitled - In Pursuit of the Decadal Oscillation: a dendroclimatic approach (Gedalof and Smith).

Presentation at 1999 Workshop on Decoding Canada's Environmental Past: Adaption Lessons Based on Changing Trends and Extremes in Climate and Biodiversity, Victoria. January, 1999 entitled - Interannual climate variability in the Northeast Pacific interpreted from the annual growth rings of mountain hemlock. (Gedalof and Smith)

Presentation at 1999 Workshop on Decoding Canada's Environmental Past: Adaption Lessons Based

on Changing Trends and Extremes in Climate and Biodiversity, Victoria. January, 1999 entitled - Little Ice Age climate trends at treeline in Strathcona Provincial Park, Vancouver Island: insights from glaciers and trees. (Lewis and Smith)

- Presentation at 1999 Annual Center for Earth and Ocean Sciences Research Workshop, University of Victoria, - Modeling tree-ring climatic relationships using artificial neural networks. (Zhang and Hebda)
- Presentation at 1999 Annual Meeting of the Western Division, Canadian Association of Geographers. Kelowna, British Columbia, March 1999 entitled - Low-frequency climate variability in the northeast Pacific interpreted from the annual growth rings of mountain hemlock. (Gedalof and Smith)
- Presentation at 1999 Annual Meeting of the Western Division, Canadian Association of Geographers. Kelowna, British Columbia, March 1999 entitled - Understanding tree time: dendroclimatological baby steps in the Pacific Northwest. (Laroque and Smith)
- Presentation at 1999 Annual Meeting of the Canadian Association of Geographers. Lethbridge, Alberta. June, 1999 entitled - Dendroclimatology on the Outer Shores. (Smith and Gedalof)
- Presentation at 1999 Annual Meeting of the Canadian Association of Geographers. Lethbridge, Alberta. June, 1999 entitled - Applied dendroclimatology: Estimating radial growth trends under changing climates at high elevational sites on Vancouver Island, British Columbia. (Laroque and Smith)
- Presentation at 1999 Joint Meeting of the Canadian Quaternary Association and the Canadian Geomorphology Research Group. Calgary, Alberta. August, 1999 entitled - Little Ice Age climates and glacier regimes in coastal British Columbia: evidence from moraines and tree-rings. (Smith, Gedalof, Laroque and Lewis)

Public presentations

- Featured story on the nationally televised Weather Network (Channel 23, Shaw Cable) describing some of the preliminary findings of our FRBC-sponsored research programme, September 24th 1997.
- Presentation at the Annual Meeting of the Ecological and Monitoring Network (Vancouver Island), Victoria, British Columbia, entitled - Reconnaissance Tree-Ring studies at CFB Esquimalt. (Smith and Lewis)
- Presentation to the Public Colloquium Series, University of Victoria, Department of Geography, February 7th, 1997 describing some findings, entitled - What to do with 35,000 straws. (Laroque)
- Featured story on the community broadcast channel in Victoria (Channel 11, Shaw Cable) describing some of the preliminary findings of our research.
- Featured story in the University of Victoria newspaper The Ring (October, 1997) entitled - Research Deciphers Stories Told by Trees, describing some of our preliminary findings.
- Featured story in the University of Victoria campus student newspaper The Martlet (October 24, 1997) entitled Tree Rings Tell Age-old Climate Tales, describing the preliminary findings of the research.
- Presentation at Simon Fraser University (October 1997) entitled -The LIA: Dendrochronological Evidence from Vancouver Island (Smith).
- Presentation to the Victoria Garden Club on November 5, 1997 describing preliminary findings.
- Featured story in the Victoria Times-Colonist (December 15, 1997) entitled - Rapid Tree Growth

Predicted, describing some of our preliminary findings.

- \# Presentation to the Public Colloquium Series, University of Victoria, Department of Geography, January 16th, 1998 describing some findings, entitled - Battle for the subalpine: Marmot vs Trees. (Laroque)

Research Reports

- \# *Dendrochronology of Vancouver Island marmot habitat (Interim Report).* Prepared for: Vancouver Island Marmot Recovery Team. University of Victoria Tree-Ring Laboratory Report 96-02. (Laroque and Lewis)
- \# *Reconnaissance tree-ring studies at CFB Esquimalt*. Prepared for: Trudi Chatwin, Fisheries and Wildlife, Ministry of Environment, Lands and Parks, Nanaimo B.C. University of Victoria Tree-Ring Laboratory Report 96-04. (Smith and Lewis)
- \# Report to B.C. provincial park personnel responsible for Strathcona Provincial Park, Vancouver Island, where sampling was undertaken in 1997. (Smith)
- \# Report to B.C. provincial park personnel responsible for Tweedsmuir Provincial Park, central coast region of British Columbia, where sampling was undertaken in the summer of 1997. (Smith)
- \# T*ree invasion in subalpine Vancouver Island marmot habitat - Final report.* University of Victoria Tree-Ring Laboratory Report 98-01. Department of Geography, University of Victoria. (Laroque)
- \# *Dendrochronology and dendroclimatology using shore pine from Brooks Peninsula, Vancouver Island, British Columbia*. University of Victoria Tree-Ring Laboratory Report 98-02. (Smith, Nelson and Ferby)
- \# *Chronological Dating of Bat Roosting Sites on Standing Snags, Northern Vancouver Island*. University of Victoria Tree-Ring Laboratory Report 99-02. (Laroque and Kellner).

End Users

The FRBC-sponsored research undertaken under the tenure of this award has been of interest to a number of individuals, Provincial and Federal Forest Ministry personnel, and private forest companies. Collaborative linkages and contacts include those with:

- \# *Canfor Forest Products Ltd.*, Englewood Logging Division (Woss). The Operational Foresters contacted and consulted about preliminary project findings were Pat Bryant

- \# *Carleton University*, Department of Electronics. Collaborative research linkages were established with to evaluate the potential of artificial neural networks (ANN) for modeling Douglas-fir growth-response scenarios.

- \# *Coastal Montane Working Group* (CMWG). Collaborative research linkages have been established with the CMWG long-term biodiversity monitoring site at Mt.Cain. The CMWG is a research collective linking the activities of BC Environment, BC Forest Service, Royal BC Museum, the coastal forest industry and BC Universities. Related activities include collaboration with M. Kellner (M.Sc. candidate, Department of Biological Sciences, Simon Fraser University) designed to evaluate the use of standing snags by bats as roosting sites.

- *Ecological Monitoring and Assessment Network* (EMAN). Collaborative research linkages have been established with the B.C. Ministry of Environment, Lands and Parks) to evaluate the long-term dendrochronological behaviour of Douglas-fir within the Smithsonian bio-diversity monitoring site at CFB Esquimalt.

- *Inter-American Inter American Institute for Global Change*. Collaborative linkages made with 13 researchers from Argentina, Boliva, Canada, Chile, Mexico and the United States to work on a program designed to provide an 'Assessment of Present, Past and Future Climate Variability in the Americas from Treeline Environments'.

- *Pacific Forestry Centre*. Collaborative research linkages have been established with Forestry Canada (Victoria, B.C.)

- *Vancouver Island Marmot Recovery Team* (VIMRT). Collaborative research linkages have been established to evaluate the long-term behaviour of montane trees in critical marmot habitat areas on Vancouver Island. Our findings will be presented at a forthcoming (June, 1999) 'Vancouver Island Marmot Conservation Workshop' (Nanaimo, B.C.) sponsored by Environment Canada, Canadian Wildlife Service, B.C. Ministry of Environment, Lands and Parks, Royal British Columbia Museum and the VIMRT

- Collaboration with a team of 15 climatologists, dendrochronologists, fisheries biologists, geochemists, geomorphologists, hydrologists, sedimentologists, and soil scientists from various governments and universities assembled to document the impact of long-term temporal and spatial patterns of precipitation and temperature on sediment production and delivery in coastal British Columbia.

SUMMARY AND CONCLUSIONS

If climatic change in the Pacific Northwest occurs as predicted by climate modellers over the next century, it could have a profound impact on the long-term productivity and sustainability of the forest industry in British Columbia. While there is considerable uncertainty as to the ultimate effect of climatic change in many of British Columbia's forest regions (Taylor and Taylor 1997), the contribution of coastal forests to the provincial economy motivated an analysis of the potential impact of climate change.

Meaningful evaluations of the impacts of climate change on the coniferous forests of coastal British Columbia will rely upon two things. The first requirement is a comprehensive understanding of the consequences of past changes on forest productivity. The second requirement is for a robust predictive model capable of dealing with the spatial complexities of the region's forest cover.

Our aim was to study the effect of past climatic changes on coastal forests using tree-rings and to incorporate these insights into predictive models capable of quantifying future responses under different climate change scenarios. We approached this task by drawing together a collaborative cluster of researchers to undertake a research program designed to answer two key questions: What is the radial growth response of individual tree species to climate in coastal British Columbia? , and; What impact will future climatic changes have on radial growth dynamics in coastal British Columbia? Answers to these questions necessitated the coordination of a research program requiring extensive fieldwork, laboratory analysis and innovative computer modelling.

Dendrochronological analyses of 4800 increment cores collected from 2500 trees found at 64 sites in coastal British Columbia revealed the presence of persistent, region-wide, long-term intervals of enhanced and reduced radial growth. These variations were shown to be related to year-to-year changes in climate and associated with the interaction of tropical and extra-tropical climate forcing systems (Gedalof 1999; Gedalof and Smith 1999). These climate-growth relationships were analysed to establish the predominant variable(s) controlling their annual radial growth. These site-specific analyses were subsequently summarized to extract the dominant modes of variability associated with each of the tree species examined. Based on these findings, we were able to successfully establish the radial growth response of several tree species to climate in coastal British Columbia.

Using the data and information provided by our analyses, two radial growth-response simulation models capable of predicting radial growth under a given set of climatic conditions were produced. The first model is *TREE* (*Tree-ring Radial Expansion Estimator*), an HTML-based model designed to display the impact of climate on the radial-growth behaviour of trees in the Vancouver Island montane biogeoclimatic zone. The second simulation model uses an artificial neural network (ANN) to simulate the effects of climate change on tree growth by presenting it with a series of climatic scenarios. While continuing refinements to TREE and ANN will improve their predictive capabilities, they already offer insight into what the impact of future climatic changes will be on the radial growth dynamics of conifers in coastal British Columbia.

Conclusions

The research completed during our three-year FRBC program has demonstrated that conifers growing in coastal British Columbia contain useful dendrochronological records. We successfully described the climate-growth dynamics of several conifer species and interpreted these findings to build computer models capable of describing the impact of future climate changes. While the applicability of our radial growth forecast models will ultimately depend upon the ability of climate modellers to predict future climates, we expect these findings will be of practical value to the British Columbia coastal forest community as it explores the potential consequences of future climatic changes.

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APPENDIX A: Disbursements November 1, 1998 to April 30, 1999

Copy of University of Victoria: Statement of Project Receipts and Disbursements (November 1, 1998 to April 30, 1999)

APPENDIX B: Summary Tables

Table 1. - Study site information for the 64 conifer stands included within this study.

Tree species sampled codes refer to: WH = western hemlock, YC = yellow-cedar, MH = mountain hemlock, DF = douglas-fir, WRC = western red cedar, PC = shore pine.

No.	**Name**	**Site Code**	**Tree Species Sampled**					**Site Description (Latitude, longitude, average elevation, NTS map sheet, UTM coordinate)**
			WH	**YC**	**MH**	**DF**	**WRC**	
1	Mount Cain	96N / 97N	x	x	x			50° 13' 55" N, 126° 19' 30" W, 1100m asl, 92 L/1, 907670
2	Mount Becher	97I		x	x			49° 39' 30" N, 125° 12' 40" W, 1120 m asl, 92 F/11, 407023
3	Green Mountain	96V / 96C	x	x	x			49° 03' 20" N, 124° 20' 25" W, 1200m asl, 92 F/1, 021344
4	Mount MacIntosh	96K		x	x			50° 40' 10" N, 127° 51' 20" W, 696m asl, 92L/12, 808133
5	Castle Mountain	97M		x	x			50° 28' 10" N, 127° 03' 00" W, 1100m asl, 92 L/1, 907670
6	Butterfly / Wolf Ridge	96T / 96S		x	x			50° 11' 10" N, 127° 43' 05" W, 610m asl, 92 L/4, 899595 50° 11' 00" N, 127° 44' 20" W, 518m asl, 92 L/4, 916603
7	Colonial Creek	97K		x	x			50° 17' 30" N, 127° 33' 20" W, 915 m asl, 92 L/5, 031722
8	Bulldog Ridge	97L		x	x			50° 17' 50" N, 127° 14' 00" W, 870m asl, 92 L/6, 259731
9	Mrs. Wade Mountain	96L		x	x			50° 21' 30" N, 126° 53' 05" W, 1097m asl, 92 L/7, 503804
10	Mount Elliot	96M		x	x			50° 17' 50" N, 126° 29' 55" W, 1433m asl, 92L/8, 780744
11	Mount Menzies	97O		x	x			50° 12' 15" N, 125° 28' 10" W, 915m asl, 92 K/3, 232643
12	Apple Tree Hill	96P		x	x			50° 08' 00" N, 126° 46' 55" W, 1036m asl, 92 L/2, 582550

13	Maquilla Peak	97P		x	x			50° 07' 55" N, 126° 21' 45" W, 1220m asl, 92 L/1, 891563
14	Silver Spoon Saddle	96O		x	x			49° 58' 30" N, 126° 40' 45" W, 900m asl, 92 E/15, 664386
15	South Sheena Creek	96Q		x	x			49° 55' 45" N, 126° 09' 55" W, 1158m asl, 92 E/16, 032348
16	Nesook Creek	97Q	x	x				49° 46' 45" N, 126° 16' 50" W, 610m asl, 92 E/16, 964166
17	Mount Upana	96X		x	x			49° 49' 10" N, 126° 07' 20" W, 1025m asl, 92 E/16, 073225
18	Mount Heber	97		x	x			49° 53' 50" N, 125° 55' 50" W, 1375m asl, 92 F/13, 898312
19	Lupine Mountain	97D		x	x			49° 49' 15" N, 125° 31' 00" W, 1300m asl, 92 F/13, 189215
20	Mount Washington	94MW / 97H		x	x			49° 44' 35" N, 125° 17' 30" W, 1400m asl, 92 F/11, 350130
21	Hanging Valley Creek	97F		x	x			49° 40' 10" N, 125° 58' 30" W, 1130m asl, 92 F/12, 855061
22	Circlet Lake	93CIR			x			49° 41' 30" N, 125° 23' 30" W, 1260m asl, 92 F/11, 280070
23	Milla Lake	94ML		x	x			49° 33' 20" N, 125° 23' 00" W, 1380m asl, 92 F/11, 265924
24	Cream Lake	95CRM			x			49° 29' 00" N, 125° 31' 00" W, 1280m asl, 92 F/5, 166846
25	Mount Apps	96G		x	x			49° 26' 30" N, 124° 57' 55" W, 1200m asl, 92 F/7, 578779
26	Mount Porter	96H		x	x			49° 18' 30" N, 125° 13' 45" W, 1140m asl, 92 F/6, 380645
27	Mount Arrowsmith	94MA / 97A	x	x	x			49° 16' 15" N, 124° 37' 30" W, 1120m asl, 92 F/7, 818585
28	Mount Redford	97B	x	x				49° 01' 30" N, 125° 24' 40" W, 680m asl, 92 F/3, 239333
29	Pirate Peak	97J		x	x			49° 06' 20" N, 124° 52' 55" W, 1010m asl, 92 F/2, 625407

30	Douglas Peak	96F		x	x			49° 08' 10" N, 124° 38' 45" W, 1365m asl, 92 F/2, 802432
31	Mount Moriarty	96	x	x	x			49° 08' 30" N, 124° 28' 00" W, 1400m asl, 92 F/1, 932440
32	Wapiti Ridge	96C	x	x	x			48° 59' 40" N, 124° 26' 20" W, 1040m asl, 92 C/16, 948277
33	Haley Lake	96U	x		x			49° 00' 30" N, 124° 18' 45" W, 1320m asl, 92 F/1, 043293
34	Heather Mountain	94HM		x	x			48° 57' 37" N, 124° 27' 23" W, 1135m asl, 92 C/16, 936232
35	Mount Franklyn	96D			x	x		48° 54' 40" N, 124° 11' 00" W, 1060m asl, 92 C/16, 118163
36	Mount Brenton	96J		x	x			48° 54' 00" N, 123° 50' 50" W, 1305m asl, 92 B/13, 380166
37	Mount Prevost	95MP				x		48° 49' 50" N, 123° 43' 50" W, 780m asl, 92 B/13, 441089
38	T-A-D Ridge	96B	x	x	x			48° 41' 40" N, 124° 16' 40" W, 980m asl, 92 C/9, 062941
39	Mount Modeste	96I	x	x	x			48° 38' 20" N, 124° 06' 20" W, 1100m asl, 92 C/9, 183875
40	San Juan Ridge	96A	x	x	x			48° 31' 15" N, 124° 07' 50" W, 1000m asl, 92 C/9, 16374
41	Hump Lake	97HMP			x			52° 27' 30" N, 126° 13' 05" W, 1325m asl, 93 D/8, 898159
42	Gurr Lake	97GRL			x			52° 17' 45" N, 126° 53' 40" W, 1300m asl, 93 D/7, 436953
43	Nusatum Pass	96NUP			x			52° 13' 55" N, 126° 19' 05" W, 1035m asl, 92 D/1, 835894
44	Dean Channel Bluff	96DCB		x	x			52° 31' 05" N, 127° 12' 20" W, 1085m asl, 92 D/11, 219194
45	Rocky Point	96DND				x		48° 23' 20" 123° 29' 30" W, 40m asl, 92 B/5, 577517
46	Rithet’s Bog	96RIT					PC	48° 29' 30" N, 123° 29' 50" W, 325m asl, 93 D/8, 898159
47	Circlet Lake	93CIR			x			49° 41' 30" N, 125° 29' 30" W, 1260m asl, 92 F/11, 280070

48	Delight Lake	93DEL			x			49° 35' 30" N, 125° 26' 00" W, 1400m asl, 92 F/11, 232973
49	Cruickshank Canyon	93CAN			x			49° 41' 45" N, 125° 21' 45" W, 1200m asl, 92 F/11, 296072
50	Koksilah Valley	97KS1				x		00° 00' 00" N, 000° 00' 00" W, m asl, 92 B/13,
51	Victoria watershed N	97VWN				x		48° 34' 00" N, 123° 42' 00" W, m asl, 92 B/12,
52	Victoria watershed S	97VWS				x		48° 34' 00" N, 123° 42' 00" W, m asl, 92 B/12,
53	Heal Lake	97HLL				x		48° 32' 00" N, 123° 28' 00" W, 126m asl, 92 B/11,
54	Heckman Pass top	97HP1				x		52° 26' 48" N, 125° 52' 00" W, 1060m asl, 93 C/5,
55	Heckman Pass middle	97HP2				x		52° 25' 12" N, 125° 52' 30" W, 820m asl, 93 C/5,
56	Hobs Lake	97HBL				x		52° 46' 00" N, 126° 26' 00" W, 850m asl, 93 D/16,
57	Nordschow Creek	97NDS				x		52° 17' 42" N, 126° 05' 30" W, 650m asl, 93 D/8,
58	Valley View Trail High	97VV1				x		52° 27' 30" N, 126° 13' 00" W, 650m asl, 93 D/8,
59	Valley View Trail Low	97VV2				x		52° 26' 12" N, 126° 11' 30" W, 250m asl, 93 D/8,
60	Talchako Creek	97TCH				x		52° 15' 12" N, 126° 01' 42" W, 300m asl, 93 D/8,
61	Tweedsmuir Lodge	97TWS				x		52° 24' 24" N, 125° 55' 00" W, 260m asl, 93 C/5,
62	Noosgulch River	97NSG				x		52° 26' 36" N, 126° 22' 48" W, 250m asl, 93 D/8,
63	Kleena Kleene	97KLK				x		51° 56' 00" N, 124° 47' 00" W, 900m asl, 92 N/15,
64	Dean River	97DNR				x		52° 45' 24" N, 126° 32' 00" W, 300m asl, 93 D/15,

Table 2. Tree-ring chronology statistics. The extent of each chronology in years is described as a range. Series correlation describes the climatic strength of a chronology by averaging the internal correlations of all the cores in the series. Mean sensitivity is a measure of between-ring variability and positive values are characteristic of climatically responsive chronologies. Autocorrelation measures the correlation between successive increments, and positive values suggest growth is conditioned by factors in preceding growth years. [Site codes are as follows: 000 = western hemlock, 100 = yellow-cedar, 200 = mountain hemlock, 300 = Douglas-fir, 400 = subalpine fir, 700 = western red cedar]

	Overall Chronology Statistics				
	***n* = Trees (cores)**	**Range (years AD)**	**Series correlation**	**Mean sensitivity**	**Auto-correlation**
San Juan Ridge 000	19 (27)	1708-1996	0.502	0.235	0.852
Mount Modeste 000	8 (14)	1738-1996	0.354	0.208	0.728
Wapiti Ridge 000	13 (24)	1791-1996	0.592	0.292	0.865
TAD Ridge 000	17 (28)	1648-1996	0.4	0.225	0.801
Mount Moriarty 000	19 (33)	1760-1996	0.477	0.231	0.797
Mount Redford 000	13 (25)	1469-1997	0.447	0.264	0.781
Mount Arrowsmith 000	8 (15)	1705-1997	0.512	0.215	0.796
Green Mountain 000	17 (32)	1696-1997	0.5	0.232	0.805
Mount Cain 000	15 (24)	1320-1997	0.328	0.218	0.788
Milla Lake 100	22 (24)	798-1994	0.3	0.282	0.692
Mount Arrowsmith 100	44 (61)	1105-1994	0.433	0.238	0.72
Mount Cain 100	42 (44)	1205-1994	0.453	0.257	0.619
Heather Mountain 100	15 (25)	1497-1994	0.437	0.269	0.728
Mount Washington 100	48 (91)	1702-1994	0.469	0.209	0.806
San Juan Ridge 100	13 (20)	1533-1996	0.421	0.258	0.758
Wapiti Ridge 100	17 (27)	1809-1996	0.487	0.261	0.67
Mount Apps 100	18 (32)	1145-1996	0.45	0.236	0.82
Douglas Peak 100	19 (36)	1752-1996	0.552	0.254	0.725
San Juan Ridge 200	15 (23)	1490-1996	0.424	0.239	0.835
TAD Ridge 200	18 (32)	1699-1996	0.495	0.23	0.735

Mount Moriarty 200	20 (36)	1738-1997	0.617	0.287	0.731
Douglas Peak 200	20 (38)	1708-1996	0.578	0.225	0.826
Wapiti Ridge 200	21 (38)	1784-1996	0.627	0.236	0.754
Mount Franklyn 200	17 (28)	1751-1996	0.506	0.249	0.797
Mount Washington 200	19 (37)	1504-1997	0.558	0.277	0.732
Mount Apps 200	16 (30)	1552-1996	0.518	0.298	0.694
Mount Porter 200	20 (36)	1747-1996	0.537	0.227	0.72
Pirate Peak 200	20 (38)	1777-1997	0.531	0.258	0.716
Mount Becher 200	18 (32)	1668-1997	0.55	0.284	0.759
Haley Lake 200	21 (41)	1876-1996	0.509	0.237	0.687
Gemini Peak 200	18 (29)	1757-1996	0.548	0.284	0.65
Green Mountain 200	20 (38)	1749-1996	0.565	0.298	0.595
Cream Lake 200	23 (39)	1412-1995	0.608	0.27	0.666
Mount Franklyn 300	17 (32)	1724-1997	0.576	0.213	0.822
Mount Prevost 300	25 (35)	1757-1996	0.548	0.269	0.721
Heckman Pass top 300	17 (17)	1875-1996	0.535	0.218	0.735
Heckman Pass Mid 300	17 (17)	1839-1996	0.606	0.214	0.772
Hobs Lake 300	15 (15)	1777-1996	0.582	0.207	0.771
Nordschow Creek 300	29(29)	1568-1996	0.511	0.188	0.859
Valley View High 300	22 (22)	1733-1996	0.556	0.234	0.759
Valley View Low 300	17 (17)	1697-1996	0.604	0.261	0.75
Talchako Creek 300	20 (20)	1648-1996	0.574	0.193	0.774
Tweedsmuir Lodge 300	16 (16)	1697-1996	0.474	0.199	0.798
Noosgulch River 300	16 (16)	1704-1996	0.576	0.228	0.862
Kleena Kleene 300	7 (7)	1750-1995	0.563	0.21	0.829
Dean River 300	6 (6)	1850-1995	0.434	0.201	0.812
Haley Ridge 400	35 (35)	1922-1996	0.474	0.243	0.412
Nesook Creek 700	13 (23)	1616-1997	0.474	0.178	0.789
Mount Redford 700	9 (18)	1672-1997	0.501	0.189	0.86

Table 3. Correlation matrix illustrating the between species relationships (1800-1996) and between site relationships (1800-1996). (Note 99% significance value = 0.167).

	San Juan 000	Wapiti 000	Moriart 000	Milla 100	Arrow 100	Cain 100	Heathe 100	Wash 100	San Jua 100	Wapiti 100	San Jua 200	TAD 200	Moriart 200	Douglas 200	Wapiti 200	Frankly 200	Haley 200	Gemini 200	Green 200	Cream 200	Frankyl 300	Provost 300
San Juan 000	1.000																					
Wapiti 000	0.584	1.000																				
Moriarty 000	0.472	0.571	1.000																			
Milla 100	0.006	0.086	0.107	1.000																		
Arrow 100	0.029	0.083	-0.035	0.696	1.000																	
Cain 100	0.101	0.065	0.102	0.613	0.613	1.000																
Heather 100	0.129	-0.019	0.119	0.385	0.465	0.460	1.000															
Wash 100	0.006	0.115	0.007	0.693	0.787	0.637	0.375	1.000														
San Juan 100	0.234	0.114	0.074	0.291	0.309	0.362	0.410	0.303	1.000													
Wapiti 100	0.033	0.249	0.182	0.356	0.363	0.220	0.235	0.373	0.435	1.000												
San Juan 200	0.391	0.162	0.203	-0.070	-0.026	-0.036	0.314	-0.176	0.075	-0.081	1.000											
TAD 200	0.162	0.319	0.317	0.069	0.133	0.057	0.112	0.090	-0.140	0.078	0.377	1.000										
Moriarty 200	0.091	0.104	0.158	0.300	0.448	0.394	0.410	0.424	0.060	0.118	0.188	0.275	1.000									
Douglas 200	0.147	0.268	0.257	0.308	0.451	0.298	0.259	0.347	0.019	0.156	0.209	0.656	0.551	1.000								
Wapiti 200	0.124	0.224	0.270	0.155	0.279	0.156	0.175	0.247	-0.144	0.059	0.287	0.697	0.541	0.735	1.000							
Franklyn 200	0.061	0.214	0.193	-0.007	0.170	-0.090	-0.004	0.053	-0.120	0.138	0.192	0.761	0.281	0.645	0.708	1.000						
Haley 200	0.237	0.202	0.222	0.260	0.156	0.175	0.371	0.081	0.026	0.023	0.380	0.345	0.565	0.312	0.429	0.277	1.000					
Gemini 200	0.159	0.111	0.156	0.418	0.454	0.469	0.522	0.329	0.234	0.123	0.355	0.177	0.677	0.346	0.266	0.051	0.688	1.000				
Green 200	0.163	0.111	0.171	0.292	0.398	0.283	0.449	0.256	0.017	0.109	0.385	0.348	0.816	0.552	0.506	0.349	0.651	0.724	1.000			
Cream 200	0.181	0.055	0.209	0.404	0.432	0.347	0.564	0.255	0.167	0.079	0.485	0.421	0.648	0.584	0.505	0.322	0.601	0.667	0.711	1.000		
Frankyln 300	0.220	0.417	0.328	-0.050	-0.040	0.029	0.077	-0.032	0.070	0.223	0.198	0.461	0.018	0.331	0.228	0.392	0.243	0.016	0.067	0.104	1.000	
Provost 300	0.060	0.183	0.205	0.082	-0.057	0.018	0.085	0.004	0.068	0.183	0.186	0.274	-0.018	0.060	0.139	0.229	0.181	-0.034	0.042	0.066	0.326	1

Note: Series labels indicated: 000 - Western Hemlock; 100 - Yellow-cedar; 200 - Mountain Hemlock; 300 - Douglas-fir