Forest Renewal BC Research Program

Final Report

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FOREST RENEWAL BC

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FINAL REPORT

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Title of Project: Impact of changing disturbance regimes and patch size on stand structure of Interior and Coastal high-elevation forests.

Project Leaders: R. PARISH[1] and J.A. ANTOS[2]
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Project Duration: April 1, 1996 to March 31, 2001

Abstract
The high-elevation forests of British Columbia are rapidly becoming an important source of both wood products and recreational areas. Knowledge of the effects of disturbance on high-elevation forests expands the basis for sound management decisions and provides a rationale to support empirical studies of forest management options. This project examined of stand structure in two Interior and two coastal high elevation forests. We analyzed the size, age, and spatial distributions of populations of tree species on the four sites to examine the relative importance of different scale and intensity in controlling stand. We found that the importance of patch dynamics varied greatly among areas.

The two Interior forests showed a strong contrast in the scale, frequency and type of disturbance. The forest at Adams Lake showed no evidence of major disturbance in the past 400 years and individual tree death appeared to be the main process of gap formation. In contrast, the forest at Damfino Creek originated about 330 years ago. The presence of a single cohort of pine dating from *c.* 1660 suggests that a fire destroyed the previous forest. Outbreaks of the defoliator, two-year cycle spruce budworm (*Choristoneura biennis*) has had major impacts on tree growth, mortality and gap processes.

Information about the dynamics and disturbance history of the high-elevation forests at Mount Cain and Mount Elphinstone, on the Coast, is still being analyzed. Preliminary results suggest that the forest are very old (>1000 years) and their dynamics appear to be largely controlled by small-scale events.

Introduction
The dynamics of natural forest stands are often complex. Stand composition and structure are not only molded by environmental conditions such as climate, geology and physiography, but are also strongly influenced by disturbance. Disturbances often are pivotal in controlling the structure of stands within the context set by various environmental factors. Disturbance is not a simple factor, but a variety of phenomena that can destroy or damage plants, often releasing resources and altering microenvironments. Disturbances vary not only in kind, but in spatial scale, frequency, and intensity.

In British Columbia, a variety of disturbances, including fire, wind, landslides, insects and diseases, have had major impacts on natural forests. All of these types of disturbances can vary greatly in intensity, frequency, and spatial scale both among and within forest regions. High-elevation forests in the southern half of the province are affected by all these disturbances to varying degrees, but the relative importance of different types, size, frequencies and intensities of disturbances varies considerably. Although the critical role of disturbance in structuring forests is clear, we have little information beyond broad generalizations on how disturbances actually affect high-elevation forests in the province.

Studies of the response of tree populations to disturbance at various spatial scales has lead to a greatly increased understanding of natural forests in many parts of the world (e.g. Runkle 1982; Veblen *et al.* 1992). Although Watt (1947) first recognized the importance of patch dynamics, only in the last few years has the importance of small-scale processes been adequately appreciated (Pickett and White 1985). Meticulous reconstructions of stand history from the examination of live trees and dead wood has yielded numerous insights into processes controlling stand structure (Henry and Swan 1974; Deal *et al.* 1991; Johnson *et al.* 1994). Detailed age and size structure of trees in conjunction with data on spatial pattern have uncovered past disturbances and identified the relative roles of both small and large, intense disturbances (e.g. Stewart 1986; Johnson and Fryer 1989; Lusk and Ogden 1992). In general, patch dynamics is fundamentally important in canopy tree replacement in forests with no or only infrequent, intense, large-scale disturbances (e.g. Denslow 1987; Runkle 1990), including wet conifer forests of western North America (Spies and Franklin 1989; Lertzman and Krebs 1991; Lertzman 1992). Patch dynamics is considered less important in forests with frequent, high-intensity disturbances (e.g. many boreal and Rocky Mountain forests, Johnson and Fryer 1989) because the initial post-disturbance cohort is often destroyed before small-scale disturbances can become important.

Published data on detailed age structures of forest stands in British Columbia are scant, and only in the past decade has information been published on the relative importance of patch dynamics versus large-scale phenomena (Lertzman and Krebs 1991, Lertzman 1992). Studies of fire history in the Canadian Rockies and southeast British Columbia indicate that large fires are frequent, generally stand replacing, and that most trees come from the post-fire cohort (Johnson and Fryer 1989, Johnson *et al.* 1990, Johnson and Larsen 1991). Parish et al. (1999), however, found the re-establishment phase lasted 80 years in the high elevation forests at Sicamous Creek. Moreover, forests in the wet Interior tend to be uneven-aged because an initiating disturbance is followed by long periods when disturbances, such as insects or windstorms, control tree regeneration.

Information about the dynamics and disturbance history of the high-elevation forests west of the crest of the Coast Mountains is scant, and there is little information that can be extrapolated from elsewhere. Studies of root rot effects in mountain hemlock forests in Oregon (Dickman and Cook 1989) are of little help because the edaphic factors are unique. High-elevation forests near the coast are generally very wet and their dynamics appear to be largely controlled by small-scale events because major disturbances are probably infrequent.

In this project, we reconstruct the history and dynamics of four high elevation, old-growth forests; 1) to determine the size structure, age structure, tree spatial pattern, and distribution of coarse woody; 2) to compare the structure and dynamics of these stands in terms of habitat differences and disturbance histories; and, 3) to examine the comparative dynamics of the different tree species in these stands in relation to type, size and intensity of disturbance.

Methods

Obtaining age data from large numbers of trees, especially if the trees have large diameters or are old and small can be slow, difficult, and expensive. Moreover, information from buried scars or other growth anomalies can be difficult to ascertain. Therefore, we are using an approach that has been successfully used elsewhere (Stewart 1986, Lusk and Ogden 1992) involving the use of stands scheduled for clear-cut logging. All site data, tree locations and sizes, and samples of small trees for aging are obtained prior to logging, whereas age samples are obtained from stumps of large trees following logging.

We have selected four subalpine forest sites: two coastal (Mt. Elphinstone and Mt. Cain) and two in the Interior (Adams Lake and Damfino Creek). We have followed the same basic protocol at all sites. In each stand, we located 4 plots each 50X50 m in size for intensive sampling. Plots were selected to be as representative as possible of the stand as a whole. Within each plot, we recorded basic site and vegetation information. All trees ≥1.3 m in height and ≥4 cm in diameter at breast height in each plot were mapped by determining their distance and bearing from reference points. By having exact tree locations we can use spatial analyses based on exact position. For each tree we obtained its species, diameter at breast height, estimated total height, estimated height to lowest live branch, and condition. Snags were mapped along with live trees. All downed logs in the plots were measured, assigned to a decay class, and the diameter at both ends determined. Logs in decay classes 1 to 3 were mapped. In one 20 m diameter round subplot per main plot, saplings ≥1.3 m tall and <4 cm diameter were mapped. We used transects in the Interior sites to collect seedlings (trees <1.3 m tall). Seedlings were collected from 100m long transects until a total of 500 seedlings per interior site had been collected. On the coastal sites, Mt. Elphinstone and Mt. Cain, we used eight 5X5m quadrats, two per 50X50 m plot to collect seedling and microsite data.

All mapped trees too small to be of commercial value (<17.5 cm dbh) were cut at the base, or as close to the base as possible, and discs labeled and saved. Discs from sound portions of CWD were collected where possible. Large trees are tagged near the base and discs collected after commercial logging. Contractors mapped trees at Damfino Creek, Adams Lake and Mt. Elphinstone and felled non commercial trees and cut collected and transported discs from all sites. Drs. Parish and Antos mapped and measured trees at Mt. Cain with the assistance of University of Victoria students.

We have completed the examination of annual rings on the discs from all sites. University of Victoria students, Kevin Conley, Michael Conway, Brandy Small and Nathan Goudie conducted this work at Dr. Rene Alfaro's laboratory at Pacific Forestry Centre. Brandy Small has continued the work on contract. Rings were not only counted to determine tree age, but also to determine patterns of growth to delineate periods of release and other major growth changes. After sanding, rings on each disc were examined under a dissecting microscope attached to a computer, on which ring widths were recorded. Using this methodology we efficiently obtain a large amount of information on the detailed growth patterns of trees in the stands. Sections were also searched for any unusual features, such as scars, and these were dated where possible.

RESULTS
Seedlings

To examine the age structure and growth of small trees (advanced regeneration) in the Interior, Kevin Conley obtained ages for the *c.* 1000 seedlings <1.3 m tall (500 from each sites). Many seedlings were old and growing slowly, although spruce was growing more rapidly than subalpine fir. Subalpine fir only 1 m tall averaged 86 and 97 years old at the two sites and 1 m tall spruce averaged about 63 and 67 years old. Age structures indicated that recruitment of both species was fairly continuous. Although these trees were growing slowly, they appear to have considerable potential to release following canopy opening.

University of Victoria co-op student, Carla Davidson, collected *c.* 1000 seedlings <1.3 m tall at the Mt. Elphinstone site. Amabilis fir regenerated abundantly on the forest floor mainly in humus and was the most common seedling <1 m tall. The average amabilis fir seedling was 10.4 cm tall and 15 years old. The average 1-m tall fir was 111 years old. Both mountain and western hemlock preferred dead wood and mountain hemlocks were the most common seedling >1 m tall. The average hemlock seedling was 10.6 cm tall and 10 years old. The average 1 m tall mountain hemlock was 67 years old whereas 1 m tall western hemlock seedlings were rare. Hemlock seedlings grew faster than fir especially under closed canopy conditions, although in deep shade hemlocks lose epinastic control and become 'bushy' (Oliver and Larson 1990). Yellow cedar was the least abundant seedling and showed no clear substrate preference probably because of the low sample size. Yellow cedar seedlings formed two distinct size classes: one class was small seedlings which averaged 3.0 cm tall and 3 years of age whereas the second class averaged 97.2 cm tall and 71years old. Members of this class may have been of vegetative origin from layered yellow cedar.

Diameter and age structure
Interior Sites

We have done preliminary analysis on the diameter and spatial structure data for Coastal sites and have completed the analysis of the age data from the Interior sites. The forests at both Interior sites were dominated by subalpine fir, which comprised 95.6% of the stems (≥1.3 m tall and ≥4 cm dbh) at Adams Lake and 92.8% at Damfino Creek. Engelmann spruce was a minor component of both stands (4.4% at Adams Lake and 5.8% at Damfino Creek). The Damfino Creek stand also contained some lodgepole pine (1.4%), most of which were dead or dying. Dead standing trees accounted for about 12% of the stems at both Interior locations.

The forest at Adams Lake showed no evidence of a major disturbance. The oldest tree, a spruce, was 462 years old but the majority of trees ≥1.3 m tall were 130 - 150 years old (Fig. 1). Spruce had a bimodal age distribution and showed peak abundance in the 140-150 year age class with a second peak from 190-220 years ago. Release patterns suggested that this forest experienced many small scale disturbances so that the forest may be older than the age of the oldest tree.

The forest at Damfino Creek probably arose after a fire in the 1660s. A single cohort of pine, *c.* 340 years old, suggests this origin. Both spruce and fir dated from this time period (Fig. 2). There were five fir that dated prior to 1660 suggesting that the fire skipped patches, leaving living small fir, probably in the many wet depressions throughout the forest. Fir and spruce at Damfino Creek were simultaneously subject to periodic growth reductions compared to lodgepole pine. Two-year cycle spruce budworm (*Choristoneura biennis*) was active in the area from *c.* 1944 to 1956 (Unger 1984). Analysis of host and nonhost chronologies suggest that budworm has influence the dynamics of the stand for at least the past 200 years.

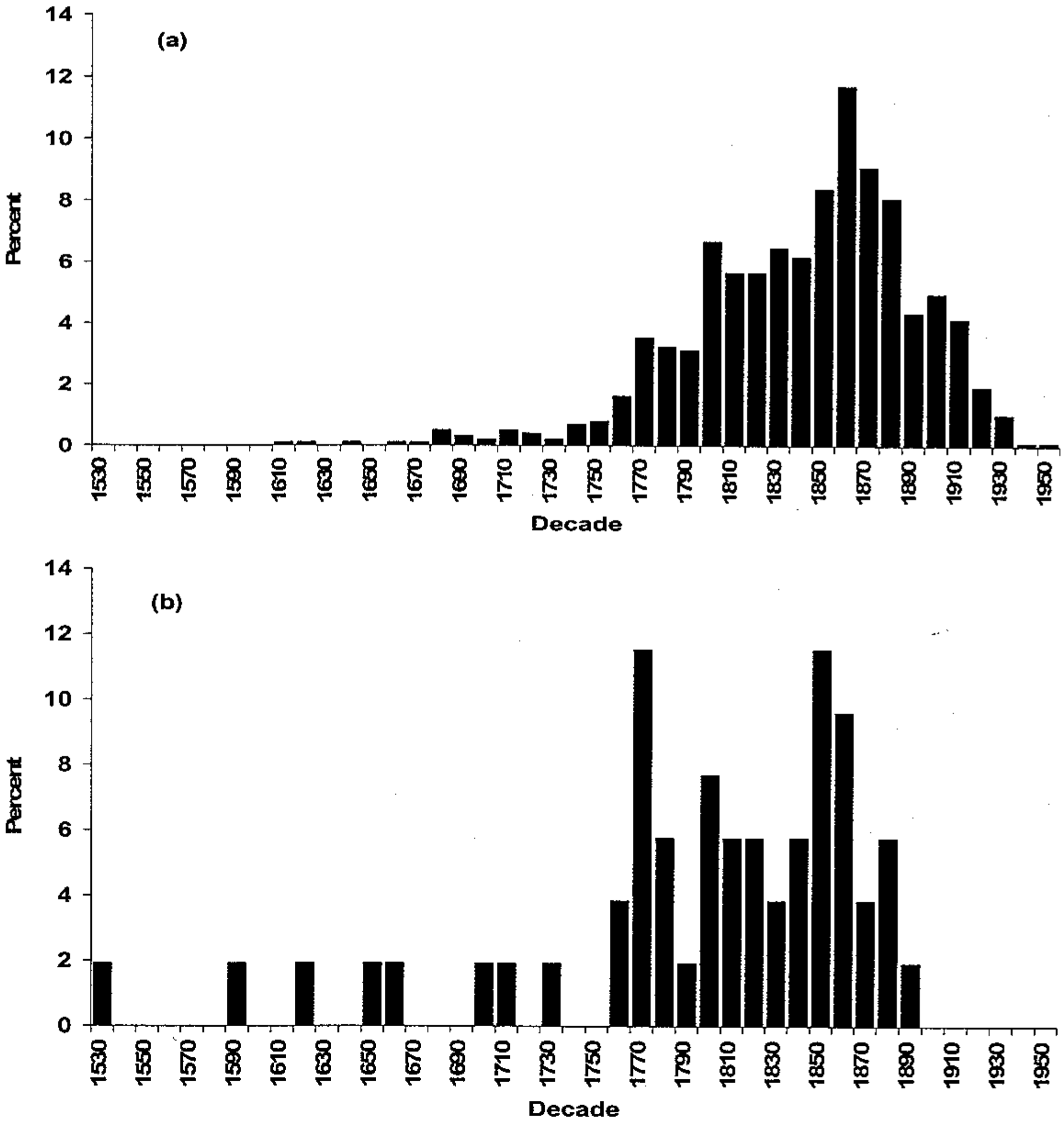


Fig. 1 Age class distribution of (a) subalpine fir and (b) Engelmann spruce ≥1.3 tall and ≥4 cm dbh at the Adams Lake site.

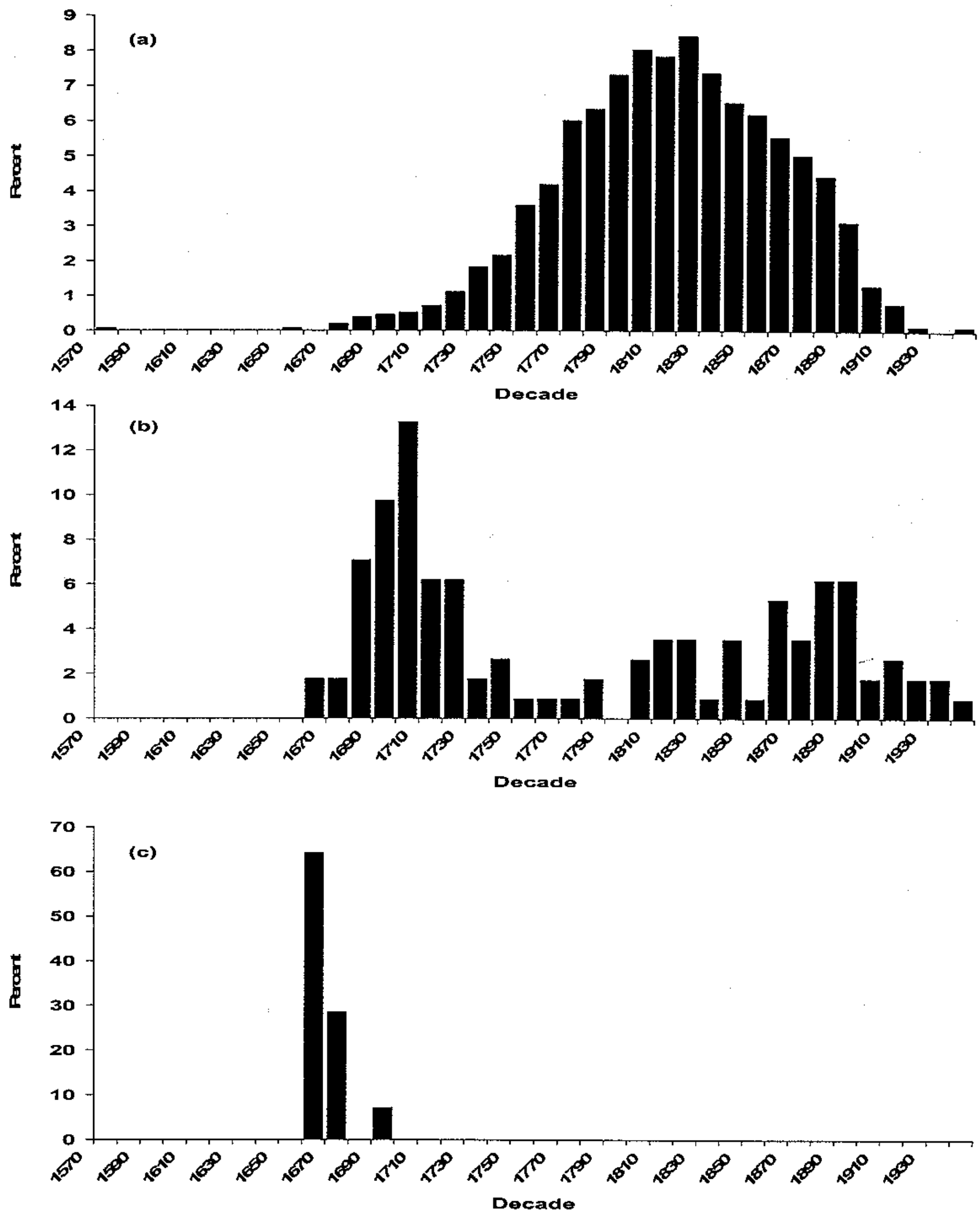


Fig.2. Age class distribution of (a) subalpine fir, (b) Engelmann spruce and (c) lodgepole pine ≥1.3 m tall and ≥4 c. dbh at the Damfino Creek site.

We used the tree ring data to construct *c*. 300 year-old subalpine fir and Engelmann spruce chronologies for the Adams Lake site and *c*. 300 year-old spruce, fir and pine chronologies for the Damfino Creek site (Fig. 3). These chronologies were archived with the World Data Center for Paleoclimatology and NOAA Paleoclimatology Program. The Adams Lake and Damfino Creek spruce and fir chronologies showed some parallel trends. There is a period of unfavourable radial growth in the early 1700s and throughout much of the 1800s, followed by improved growth in the 1900s until the 1950s when growth decreased. Favourable radial growth resumed in the 1970s and has decreased recently. Pine radial growth, on the other hand, showed good radial increment in the early 1700s followed by decreased growth in the mid 1700s. The pronounced reduction in growth at Damfino Creek during the mid 1800s is absent as is the growth reduction in the 1940s -50s. This differential growth is probably due to budworm.

We used the monthly climate data (homogenized temperature and rehabilitated precipitation data) available from the Historical Canadian Climate Data Base version 2 to relate spruce and fir growth patterns with climate. We performed response function analysis using the commercial software program, PRECON 5.17B, developed by Dr. Hal Fritts of the University of Arizona Tree-Ring Lab. For Adams Lake, we selected climate data from Vavenby, which is available from 1913 to 1998. Residual chronologies in which the effects of prior growth have been removed (pre-whitening) were developed for spruce and fir using the ARSTAN program. The response function coefficient (RFC) was significantly positive for the relationship of current June and July temperatures to fir growth and current May, June and July temperatures for spruce growth and negative for the impact of previous July and August temperatures on both species. Precipitation in the current October was significantly associated with good spruce radial increment. These results are comparable to those from other areas (e.g., in the Rocky Mountains, Colenutt and Luckman 1991; and in the Cascades, Peterson and Peterson 1994). Unlike Peterson and Peterson (1994) neither total monthly snow nor total winter snowfall (November to April) were significant probably because our snow measurements were from the low elevation Vavenby station and not directly on site.

For Damfino Creek, we selected temperature and precipitation data from McCulloch. Rehabilitated precipitation data are available from 1924 to 1994 but homogenised temperature data were not. We used temperature data from 1936 to 1994 available from Environment Canada (1994). Examination of residual from regression on surrounding climate stations suggests that there are no obvious inhomogeneities. Response function analysis of monthly climate and tree radial increment showed a significant positive RFC for the relationship of spruce radial increment with current June maximum and July minimum temperatures and a negative relationship to previous August and September temperatures. Fir had a significant positive response to current March maximum temperatures and a negative response to previous August temperatures. Pine showed no response to temperatures in the previous year but responded positively to current July temperatures. All three species responded positively to precipitation in the previous October.

Spatial analysis using Ripley's *K* showed that subalpine fir at Adams Lake were clumped over short distances, usually <6 m, and randomly distributed at distances from 6-30 m. When subalpine fir were divided into size classes, all classes were randomly distributed at all spatial scales. This suggests the clumps of trees are multi-sized which agrees with our observations on the site. Spatial analysis of the Damfino Creek subalpine fir showed some clumping over short distance which was due to a aggregation of subcanopy trees. Canopy trees were randomly distributed.

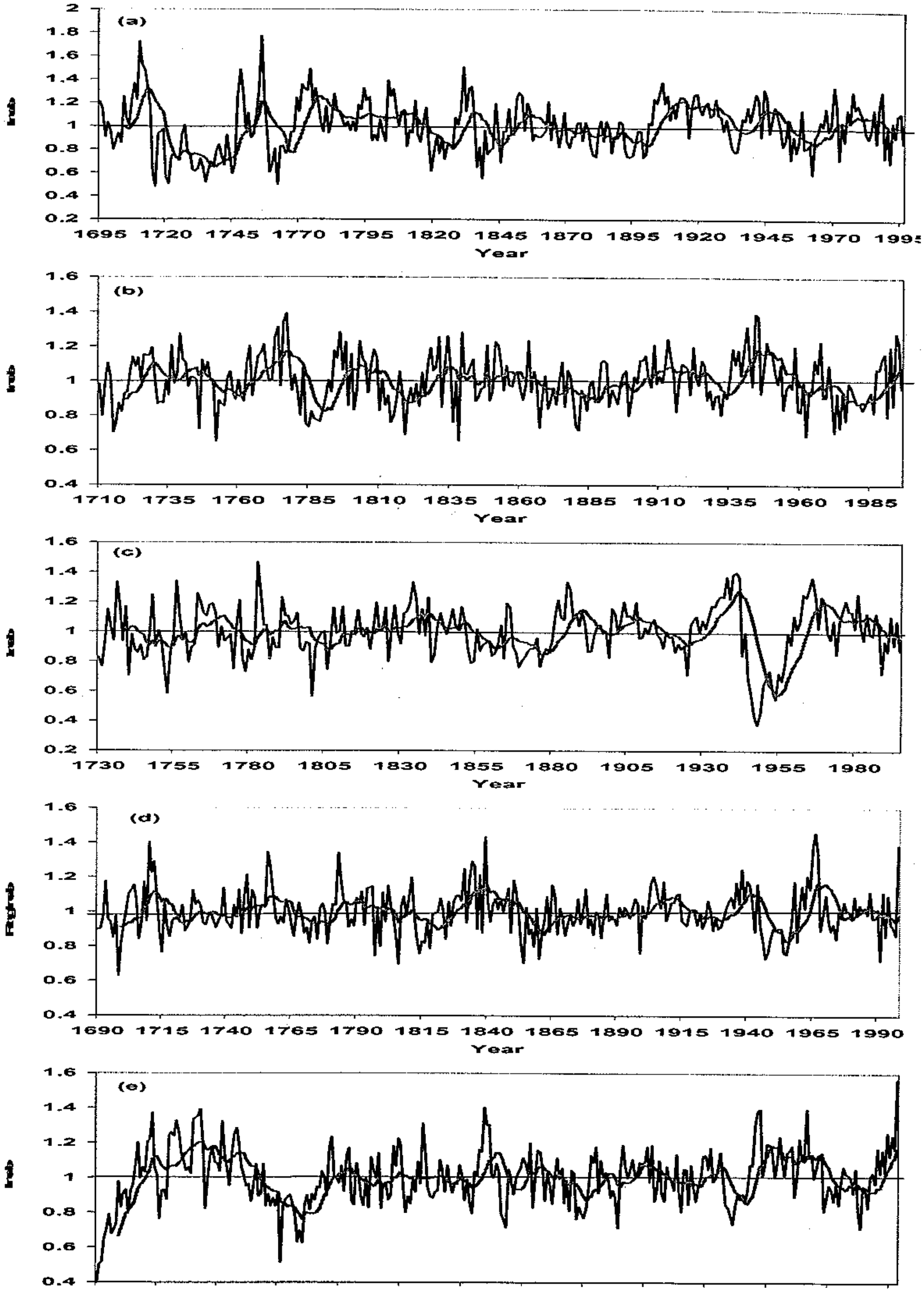


Fig. 3.. Tree-ring chronologies showing a 10-year running average from (a) subalpine fir and, (b) Engelmann spruce at Adams Lake, and (c) subalpine fir, (d) Engelmann spruce and (e) lodgepole pine at Damfino Creek.

Damfino Creek had more downed wood (268.1 m^3 per ha) than Adams Lake (149.3 m^3 per ha). The distribution of size and decay classes of downed wood was also different between the two sites (Fig. 3): Adams Lake had no pieces in decay class 5 whereas Damfino Creek had a 35% (94.0 m^3 per ha) in that class. Data collected by the BC Forest Service on downed woody debris in Interior subalpine forest indicate a range from 16.0 to 268.1 m^3 per ha.

(a)

(b)

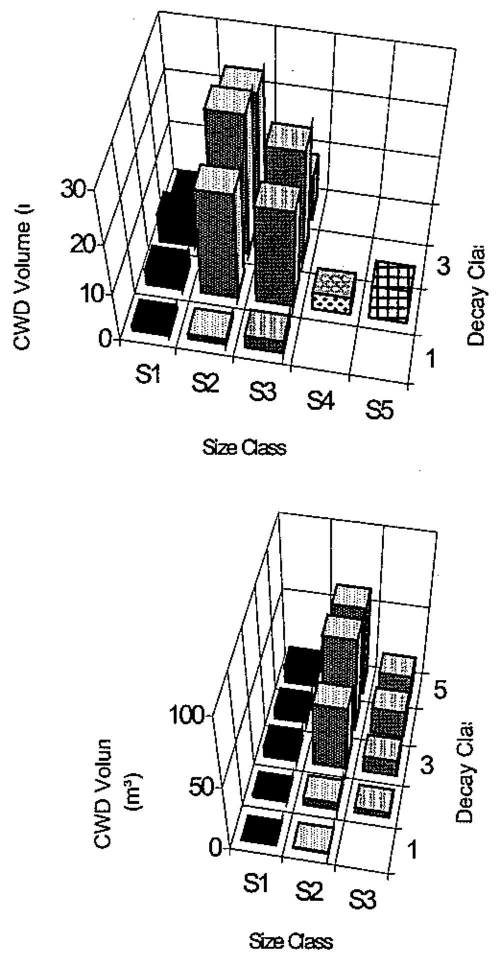


Fig. 4. Coarse wood debris volumes by decay and size class for (a) Adams Lake and (b) Damfino Creek. Size class S1 is 7.5 -20 cm, size class S2 is 20-40 cm, size class S3 is 40-60 cm, size class S4 is 60-80 cm and size class S5 is 80 cm bottom diameter.

Coastal site

The coastal sites at Mt. Elphinstone and Mt. Cain provided some contrasts and similarities. Amabilis fir, mountain hemlock and yellow cedar and western hemlock dominated the coastal forests. Amabilis fir and western hemlock were more abundant at Mt. Cain than at Mt. Elphinstone (Table 1). Dead standing trees ≥1.3 m tall were a small component (4.3%) of the Mt. Elphinstone forest but comprise 12.4% of stems at Mt. Cain.). The coastal forests at contained some very old trees. At Mt. Cain, one yellow cedar dated back to 550 AD and it had a rotten pith that would indicate it established before that time. Several yellow cedars and mountain hemlocks at both sites were over 900 years old.

The diameter distributions of the three dominant species at Mt. Elphinstone showed the typical 'J' shape with the smallest size class (4-15 cm dbh) the most abundant. Nearly half the amabilis fir and over half of the yellow cedar were in the smallest size class. In contrast, at Mt. Cain, only amabilis fir and western hemlock had a 'J' shaped size class distribution. Mountain hemlock showed a bimodal distribution with the smallest size class the largest and a distinct peak in the 70 cm class. On both sites, mountain hemlocks and yellow cedars attained diameters over 1 m at breast height.

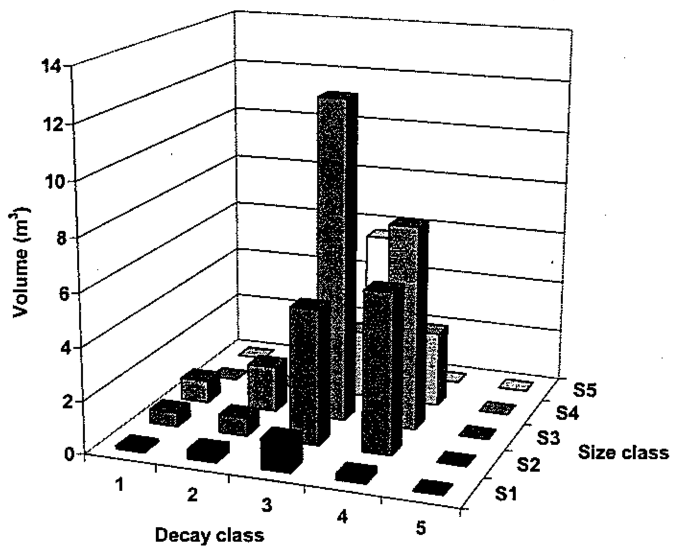
Table 1. Percent composition of tree species at two coastal sites

Species	Mt. Elphinstone (%)	Mt. Cain (%)
Abies amabilis	34	60
Chamaecyparis nootkaensis	30	12
Tsuga mertensiana	33	11
Tsuga heterophylla	2.5	17
Pinus monticola	<1	0

There was less downed wood (47.9 m^3 ha^{-1}) at Mt. Elphinstone than at Mt. Cain (242.7 m^3 ha^{-1}). At Mt. Elphinstone the majority of downed wood was in decay class 3 but at Mt. Cain it was fairly evenly distributed among decay classes 2 to 4 (Fig. 5).

We use Ripley's *K* to analyze spatial patterns of the size classes at Mt. Elphinstone. Canopy trees were randomly distributed and subcanopy trees were aggregated. Intraspecies aggregation was significant in all three of the dominant tree species. Aggregation was usually significant in the <7.5 cm dbh class and subcanopy individuals between 7.5-17.5 cm dbh were randomly distributed. This implies that density dependent mortality occurred in the smallest size class. In the canopy, yellow cedar was positively associated with amabilis fir and western hemlock was negatively associated with amabilis fir. All other interspecies interactions were random.

Mount Elphinstone



Mount Cain

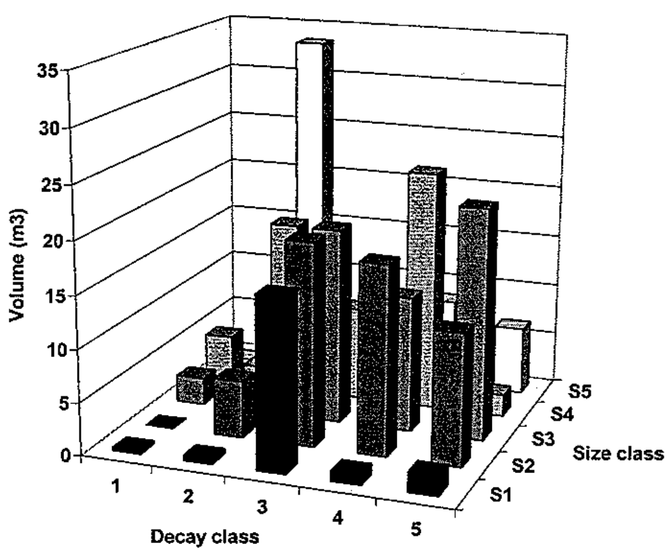


Fig. 5. Coarse wood debris volumes by decay and size class for Mt. Elphinstone and Mt. Cain. Size class 1 is 7.5 -20 cm, size class 2 is >20-40 cm, size class 3 is >40-60 cm, size class 4 is >60-80 cm and size class 5 is >80 cm bottom diameter.

Brandy Small investigated the effect of weather patterns on the growth of yellow cedar at Mt. Elphinstone. She used the records of mean monthly temperature and total monthly precipitation from 1960 to 1993 measured at Hollyburn Ridge, a station located at 930 m elevation and *c.* 25 km south-east of the site (Environment Canada 1994). Hollyburn Ridge has the longest continuously measured climate record at subalpine elevations on the.southern coast. She used the program SAS PROC ARIMA (SAS Institute 1993) to calculation cross correlation coefficients between tree ring index and climate variables. Both temperature and precipitation had a significant effect on growth of yellow cedar. June temperature and previous August had a positive effect on growth but rainfall in the June of the current year negatively impacted growth (Fig. 6).

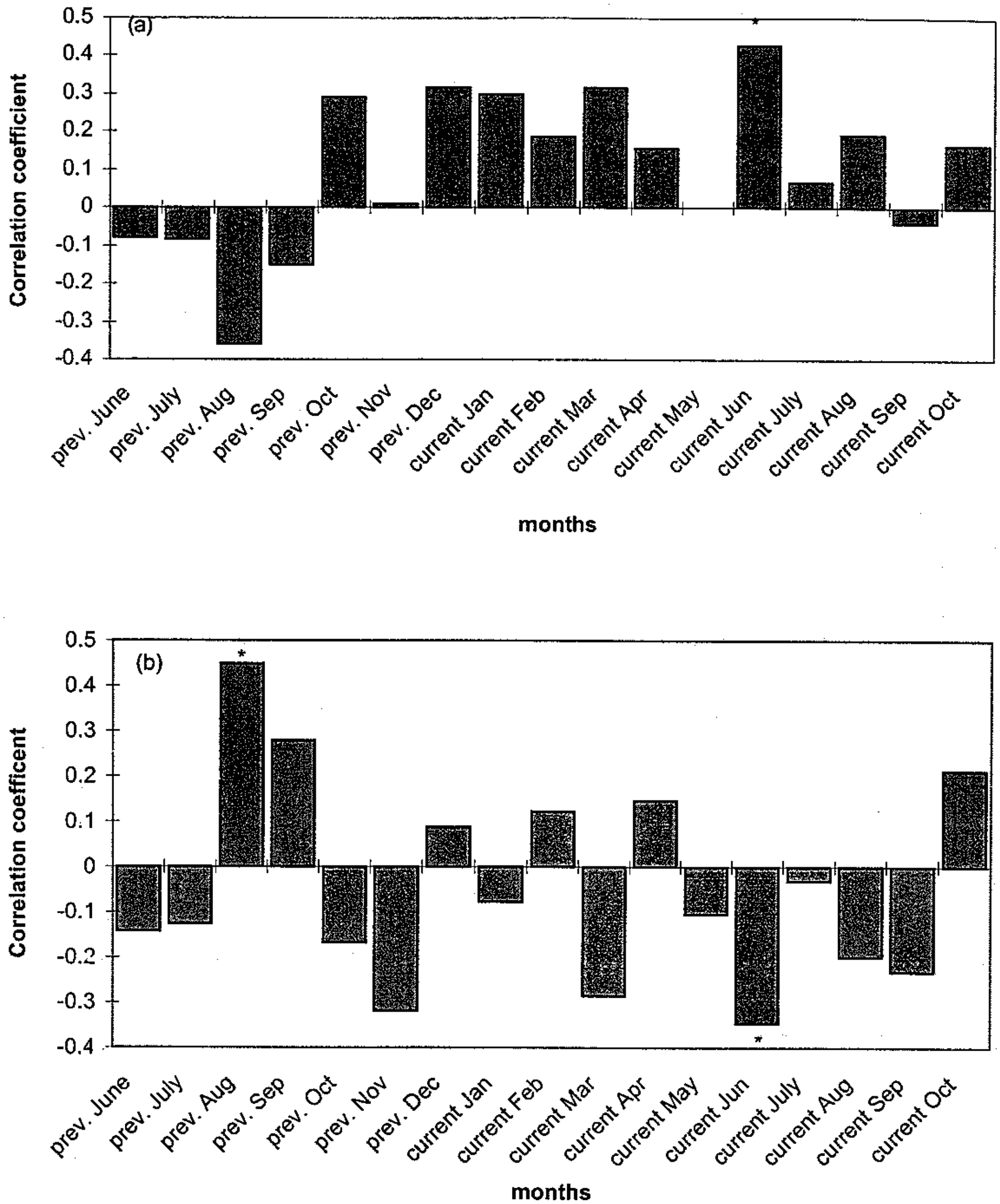


Fig. 6. Cross-correlation for annual tree growth of yellow cedar at Mt. Elphinstone and (a) mean temperature and (b) total monthly precipitation from the Hollyburn Ridge Station. The asterisk ($p < 0.05$) indicates significance.

Discussion

We have accomplished much of what we set out to do. We have collected the baseline knowledge that is acutely needed to delineate the dynamics of high elevation forests in different parts of the province. We have completed the description of the history and dynamics of the two Interior high elevation forests. A manuscript recounting the Adams Lake forest history and dynamics has been accepted by the journal, *Oecologia*. Two manuscripts describing the history and dynamics of the forest at Damfino Creek are in final stages of preparation. Our paper examining the age structure of the seedling banks on the two Interior sites was published in spring 2000 in *American Midland Naturalist.*

Antos, JA, Parish, R and Conley, K. 2000. Age structure and growth of the tree-seedling bank in subalpine spruce-fir forests of south-central British Columbia. *American Midland Naturalist* 143: 342-354.

We have completed data collection at both Coastal sites and have begun some analyses. When we complete the analysis and resulting articles we will have presented four very different disturbance regimes.

We have related our preliminary conclusions to representatives of industry and government with whom we have worked in locating sites. We prepared a poster on the application of dendroecological methods to determining disturbance regimes in southern Interior subalpine forests for the IUFRO conference in Pullman, Washington, in July 1997. Dr. Parish spoke at the Northern Silviculture Winter Workshop in Prince George in January 2000, on *Natural stand dynamics of old-growth Engelmann spruce – subalpine fir forests*. A website under the Ministry of Forests Research Branch has been created to report on stand dynamics in Interior subalpine forests. To date, information from published papers on stand dynamics at Sicamous Creek have been featured on the site. Information on the two other sites will be added once papers are accepted for publication.

Summary and Conclusions

Within a rather simple forest type with few tree species, such as spruce-fir forests, variation in dynamics and the processes controlling change can be large. There appears to exist a continuum of disturbance that ranges from frequent stand destroying events in which the post destruction cohort is never replaced to rare disturbance in which replacement follows after individual tree death. The forest we studied at Adams Lake lacked any evidence of major disturbance and showed patch dynamics only at very small scales. The forest at Damfino Creek showed evidence of a fire origin *c.* 1660, followed by quasi-episodic two-year cycle spruce budworm defoliation of varying intensity so that small gaps processed dominated the last 330 years. Much of this variation in dynamics is cryptic when examining size structure. We previously studied the age structure of another spruce-fir stand in southern British Columbia (Parish *et al.* 1999) and found that the age structure and timing of release indicated episodic disturbance events that accounted for the ascendancy of most canopy trees. The Interior stands that we have studied had similar size structures that entirely masked their very different dynamics. We anticipate that this is a common situation for forests composed of shade-tolerant trees with highly variable growth rates, and it underscores the importance of examining age structure and patterns of tree growth in order to reconstruct accurately stand history and decipher forest dynamics.

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