RESEARCH ARTICLE

Forest Fires and Old-Growth Forest Abundance in Wet, Cold, Engelmann Spruce – Subalpine Fir Forests of British Columbia, Canada

K. Kopra[1]
M.C. Feller[2]
Department of Forest Sciences
University of British Columbia
3041-2424 Main Mall
Vancouver, B.C.
Canada, V6T1Z4

[1] Current address:
Department of Natural Resource Science, McGill University, 21111 Lakeshore Road, Ste-Anne-de-Bellevue, Quebec H9X3V9.
email: kristinkopra@yahoo.ca

[2] Corresponding author:
feller@interchange.ubc.ca

Natural Areas Journal 27:345–353

ABSTRACT: The amounts of old-growth forest present under current and pre-harvesting era disturbance regimes in the dominant higher elevation (900-2300 m) forests in eastern British Columbia (B.C.) – wet cold Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) - subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) forests (ESSFwc), and one important group of ESSFwc forests, the Northern Monashee (ESSFwc2) biogeoclimatic variant – were quantified using a GIS forest age database, with the assumption that old-growth forests were forests >140 years old. This was done in order to inform natural disturbance based management in this part of British Columbia. Database constraints restricted the analysis to the post 1800 period only and resulted in estimation of a range of old growth for any time period. The oldest trees in old-growth forests do not necessarily indicate when the forests were last disturbed by fire, as ^{14}C dating of charcoal indicated that, for two of five 210- to 320-year old stands sampled, the most recent fire event probably occurred over 1000 years ago. The amount of old growth in both ESSFwc and ESSFwc2 forests, since 1800, decreased to a minimum in the mid to late 1800s, then increased. In the case of the ESSFwc2, this increase occurred until the 1960s before the amount of old growth decreased again. Amounts of old growth in 2003 (58-59% of the forested area) were within the pre-harvesting era range of 30-60% in ESSFwc2 forests, but may be above the range of 20-50% in ESSFwc forests. Old-growth forests have dominated most subalpine landscapes in eastern B.C. for at least the last several decades. If management of ESSFwc forests is to emulate historical disturbance regimes, greater protection of old-growth ESSFwc forests than at present will be necessary.

Index terms: British Columbia, Canada, Engelmann spruce - subalpine fir forests, forest fire frequency, old-growth forest

INTRODUCTION

Forest management in British Columbia (B.C.) is currently governed by a paradigm that maintains that biological diversity can be preserved by utilizing forest harvesting regimes that closely mimic "natural" disturbance regimes (Anonymous 1995). It is generally assumed that forest harvesting will have minimal impact on biodiversity when its effects lie within the bounds of those of natural disturbance regimes (Lindenmayer and Franklin 2002) or within the range of historic or natural variability (Aplet and Keeton 1999). Before such harvesting can be applied, it is necessary to document the patterns and characteristics of the "natural" disturbance regime. This knowledge is limited for most British Columbian ecosystems, particularly those at higher elevation, which have been managed for a shorter period than the more accessible lower elevation ecosystems (DeLong and Meidinger 2003). The highest elevation forests in most parts of British Columbia east of the crest of the Coast Mountains are dominated by Englemann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). These two species have given their names to the ecological zone which they dominate – the Engelmann Spruce - Subalpine Fir (ESSF) zone. In British Columbia, ecological zones are called biogeoclimatic zones (Meidinger and Pojar 1991). Biogeoclimatic zones are subdivided into subzones based on climate and climax plant communities. The largest and most extensive ESSF subzone in British Columbia's Columbia and Rocky Mountains is the wet cold, or ESSFwc, subzone. Subzones are further subdivided into variants based on differences in regional climate and climax plant communities (Pojar et al. 1987).

Old-growth forests are an important and valuable component of biodiversity, and the proportion of old-growth forest currently present in relation to that historically present has become one means by which to assess the effectiveness of forest management in maintaining ecosystem sustainability (Lesica 1996; Swetnam et al. 1999; Agee 2003). There has been increased forest harvesting in ESSFwc forests, accompanied by a lack of knowledge of the impacts on old-growth abundance of the current disturbance regime compared to those of historical disturbance regimes. The present study has the objective of quantifying the amounts of old-growth forest present at different times in the ESSFwc subzone and the Northern Monashee ESSFwc2 biogeoclimatic variant in order to assist forest managers to maintain old-growth forests within the historical bounds of the natural disturbance regime. The ESSFwc2 variant was of particular interest as it is one of the largest of the six ESSFwc variants (occupying 842,000 ha (28%) of the 2,985,000 ha ESSFwc subzone), is one of the most important for timber production (containing the largest forest area of all six ESSFwc variants currently suitable for timber harvesting), and is the variant subjected to the most intensive silvicultural systems research (e.g., Vyse 1999).

METHODS

Study Area

The study area was the mountainous region of eastern British Columbia in which the ESSFwc subzone occurs (Figure 1). This area includes the Columbia Mountains from the United States border to near Prince George and the northern Canadian Rocky Mountains north of McBride, as well as a portion of the central Rocky Mountains between Golden and McBride. This latter area, as well as the Central Columbia Mountains, is occupied by the Northern Monashee ESSFwc2 biogeoclimatic variant outlined in Figure 1. The ESSFwc subzone occurs at elevations ranging from 1500-2300 m in the south to 900-1700 m in the north. The ESSFwc2 variant occurs at elevations of 1400-1700 m.

The ESSFwc subzone has a cold, moist, snowy continental climate with mean annual temperatures close to 0 °C and annual precipitation up to 2200 mm, 60-70% of which is snow, which builds up typically to depths of 1-4 m (Meidinger and Pojar 1991). Engelmann spruce and subalpine fir are the dominant tree species, with mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) occasionally occurring at the lowest elevations. Characteristic shrubs include white rhododendron (*Rhododendron albiflorum* Hook.), false azalea (*Menziesia ferruginea* Sm.), black huckleberry (*Vaccinium membranaceum* Dougl. ex Torr.), and oval-leaved blueberry (*Vaccinium ovalifolium* Sm.). Characteristic herbs include *Gymnocarpium dryopteris* (L.) Newman, *Valeriana sitchensis* Bong., and *Tiarella trifoliata* L. Mosses, primarily *Pleurozium schreberi* (Brid.) Mitt., *Dicranum fuscescens* Turn., and *Brachythecium* spp., cover the ground surface. Herb-moss patches with few trees dominate some of the moister depressions within these forests. Further details are given in Meidinger and Pojar (1991).

Data analysis

All results were obtained by analyzing the GIS forest cover database for B.C., supplied by the B.C. Ministry of Sustainable Resource Management. The database was obtained in February 2004 and had been updated to September 2003. Forest cover by age polygons for the ESSFwc subzone and the ESSFwc2 variant were extracted from the database for further analysis. Forest cover by age polygons had been developed by B.C. government land management agencies from air photo interpretation with some field verification. The current inventory was designed to have a stand volume allowable sampling error of ±10% at a 95% confidence level (Anonymous 1990), although tests of the accuracy of the inventory have not been published. There were no specifications for stand age accuracy.

Biogeoclimatic ecosystem classification mapping in British Columbia, involving field surveys and topographic map and air photo interpretation, is described by Pojar et al. (1987). Biogeoclimatic units have been put into digital Arc/Info format using specified criteria (Eng and Meidinger 1999).

The database was found to contain many polygons that were tiny slivers of land a meter or less in width and many kilometers long. All such polygons were eliminated from the database by excluding all polygons with perimeter/area ratios >0.1. This resulted in the exclusion of 2005 ha from the ESSFwc database and 517 ha from the ESSFwc2 database. Polygons of age 0 years that were classed as rock, swamp, lake, or alpine were considered unable to support forest, and were deleted from the database. This left 1,686,300 ha in the ESSFwc and 569,900 ha in the ESSFwc2 that could support forest.

For the ESSFwc2 variant, the first record of forest harvesting appeared in 1957. Annual areas harvested remained relatively low until 1970, when they exceeded 2000 ha for the first time (B.C. Ministry of Forests, unpubl. data; silviculture statistics database). Consequently, the current disturbance regime, rounded off to the nearest decade, is considered to have been present over a 30-year period – from 1973 to 2002.

Polygons aged in multiples of 10 years, beginning at age 100 years, had considerably greater areas than polygons of intervening ages, suggesting imprecise aging of many polygons/stands and a tendency to record stand age to the nearest decade only. This discrepancy in areas became extreme for polygons aged 200 years and more. Consequently, it was considered problematic to use these latter polygons to estimate old-growth areas. This resulted in 1806 being the earliest date used in the calculations; 1955 (shortly before significant levels of harvesting began) was the latest date used.

Although old-growth forests have been defined in numerous ways (Mehl 1992; Wells et al. 1998; Frelich and Reich 2003), and Spies (2004) considers that a consensus on a single general ecological definition of old growth will never be reached, age is an important, easily measurable characteristic of such forests and has been used to define old-growth forests in British Columbia. Old-growth forests in the ESSFwc subzone are considered to be those >140 years old, the age by which forests are considered to have the structural and biological characteristics of old forests as defined by Mackinnon and Vold (1998). Recent work in *Thuja plicata* Donn ex D. Don - *Tsuga heterophylla* (Raf.) Sarg. forests adjacent to ESSF forests in central eastern B.C. supports the age of 140 years being a cutoff for old growth (DeLong et al. 2004). Old-growth forests in 2003, the most recent year of the database, were defined as those >140 years old. Old growth forests in 2002 were estimated as those >141 years old in 2003 plus those that had been disturbed and were 1 year old in 2003. Amounts of old growth were calculated for preceding years using this same method.

The GIS database contained no information

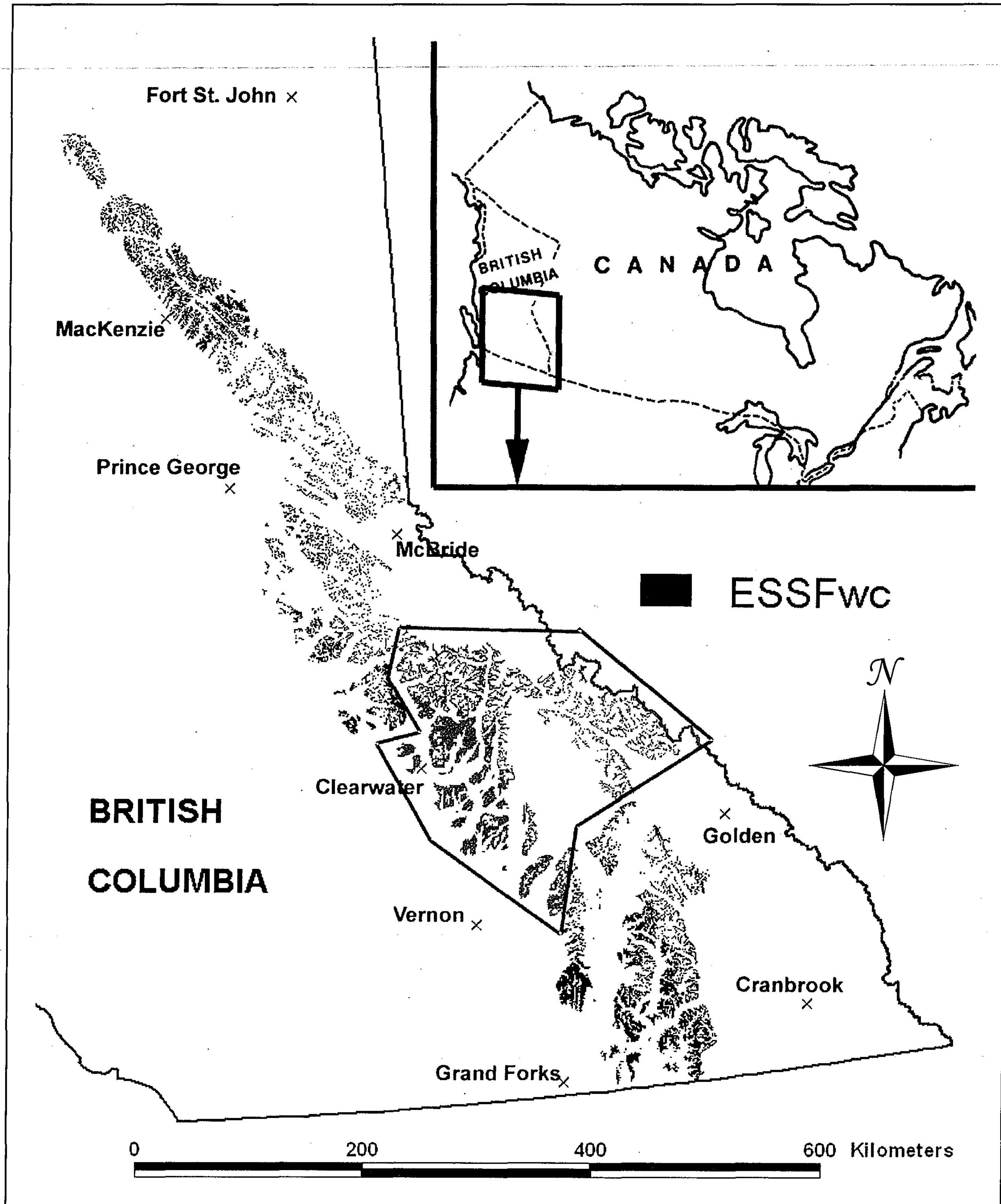

Figure 1. Location of ESSFwc and ESSFwc2 forests in British Columbia. ESSFwc2 forests are those ESSFwc forests occurring within the polygon.

about the age of a forest in a polygon prior to the disturbance that created the current forest. Uncertainty over the age of this preceding forest precluded the estimation of a single area of old growth in any given year. Instead, a range in which the area of old growth is likely to lie was calculated. Two old-growth areas were calculated – one assuming that the preceding forest was old growth and the second assuming that all forests >50 years of age were disturbed and that all such forests had an equal probability of being disturbed. Thus, if old growth comprised 60% of all forests >50 years old in a given year, then 60% of the area disturbed that year was considered to be old growth. These two methods of calculating old-growth areas defined a range in which the area of old growth was likely to have been. Old-growth areas were expressed as percentages of the total area that could support forest and calculated as an average per decade, starting in the 1800s.

All analyses of the GIS database to obtain the total area of all polygons of each age of forest (area per age) were conducted using ArcView and Arc/Info software. The area per age file was then exported into Microsoft Excel for calculations of disturbance cycles and old-growth area present.

Field sampling and analysis

Limited assessment of the accuracy of the ages of forest polygons was conducted by determining the age classes of 56 stands in the field by counting tree rings in cores taken from 10 dominant trees per stand. These age classes were compared to those given on forest cover maps related to the GIS database. Ten age classes are recognized in B.C., most age classes encompassing a 20-year interval. An attempt was made to sample six randomly located stands in each age class occurring within 1 km of a road. Four such stands could not be located, resulting in 56 sampled stands.

To assess when the most recent fire occurred in an old-growth forest, five to six separate samples of charcoal for ^{14}C dating were collected in August 2002 or 2003 from each of five old-growth stands. Three of the stands were located northeast of Vernon, and two were located northeast of Clearwater, all within the ESSFwc2 variant. Charcoal samples were extracted from the layer closest to the surface of the soil in which the charcoal was found; it was assumed that such charcoal was from the most recent fire. In all samples, this layer was either the mineral soil - forest floor interface or the deepest forest floor layers. All charcoal samples were cleaned and dried; two to three samples per area were randomly selected and sent to the IsoTrace Laboratory at the University of Toronto for ^{14}C analysis. The radiocarbon analyses were corrected for natural and sputtering isotope fractionation using the measured $^{13}C/^{12}C$ ratios. Ages are quoted as uncalibrated conventional radiocarbon dates in calendar years before present using the Libby ^{14}C mean life of 8033 years.

At least three of the largest trees in each stand from which charcoal samples were collected were bored with an increment borer to estimate stand age. Annual growth rings were counted and stand age was assumed to be approximately the age of the oldest tree rounded off to the nearest 10 years. Accurate determination of stand age was not necessary as ageing was done only to assess if the stands could have regenerated after the most recent fire whose date was estimated using the charcoal.

RESULTS

Old growth and fire frequency

A comparison of stand age with age of the most recent charcoal found in the stand indicated that the trees in only two (stands 2 and 5), or possibly three (stand 1), of the five old-growth stands sampled are likely to have regenerated following the most recent fire (Table 1). Stands 3 and 4 do not appear to have experienced significant fires for over 1000 years (Table 1).

Old growth abundance

The amount of old growth in 2003 was 59% of the total forest cover in ESSFwc2 forests, but was 58% for the ESSFwc as a whole (Figure 2). The percentage of old growth changed from the 1800s to 2003, generally dropping to a minimum in the mid to late 1800s before steadily rising in the ESSFwc or rising to a maximum in the 1960s in the ESSFwc2 and then declining again (Figure 2).

Although the precise amount of old growth cannot be calculated, it is considered to probably occur between the two lines on the graphs. These two lines reflect different assumptions – that disturbances occurred either only in old-growth forests or that all forests >50 years old had an equal probability of being disturbed, as discussed above.

The amount of old growth in 2003 was likely to have been within the pre-harvesting era historical range for ESSFwc2 forests, but possibly outside (above) the range for ESSFwc forests, although old-growth forest abundances prior to 1800 were not estimated, due to potentially large errors. Old-growth forests have comprised more than 50% of the total area of ESSFwc and ESSFwc2 forests since the 1960s and 1910s, respectively.

DISCUSSION

Causes of uncertainty in the results

1. Database errors

Eliminating polygons with unrealistic perimeter/area ratios of >0.1 is considered to have removed polygons that had boundaries that were not aligned with biogeoclimatic boundaries. Stand age errors also occurred. Field inspection of 56 stands in the ESSFwc2 variant found two stands placed in the incorrect 20-year age class, as they were approximately 40 years older than indicated by the map. Harrison et al. (2002) found that 42 of 61 (69%) forest stand ages were placed in the correct age class in an area close to McBride (Figure 1). Of the 31 of these stands located in ESSF subzones, but not the ESSFwc subzone, 20 (65%) were correctly aged, although this number would probably increase if the age of the single oldest tree sampled, rather than the mean age of the six largest trees sampled,

Table 1. Ages of trees and charcoal in old growth forests in the ESSFwc2 study area.

Stand location	Estimated stand age (years)	Charcoal age (years BP)
1. Camp Rd, Sicamous	220	340 ± 70
		340 ± 100
2. Owlhead km 18, Sicamous	210	180 ± 140
		240 ± 140
		300 ± 180
3. Kingbaker Rd., Sicamous	250	1310 ± 160
		1350 ± 260
4. Fowler Lake, Clearwater	300	2540 ± 370
		1640 ± 220
5. Shannon Ck. Rd., Clearwater	320	420 ± 120
		300 ± 180

*Errors in charcoal ages represent 95% confidence limits

had been used to age the stand (Harrison et al. 2002). The quantitative significance of these age errors is unknown, but they suggest caution in interpreting results. Harrison et al. (2002) found, however, that many of the stands, inaccurately aged as older than they really were, had structurally diverse canopies with many gaps. These features, which are characteristic of old growth, were used by air photograph interpreters to indicate older stands. Consequently, although the stands were actually younger than mapped, they could be considered old growth, suggesting that errors in stand ages might not greatly affect at least the current estimate of old-growth area. Inspection of the GIS database for the ESSFwc2 variant indicated discrepancies within the database between age class and actual age assigned to polygons. These discrepancies accounted for 0.3% of the area of the entire variant. It could not be determined, however, which age class or actual age was incorrect. Consequently, there are errors in the database; but due to the small area to which they pertain, they are unlikely to have significantly affected the results we report.

2. Age of forest at the time of the most recent disturbance

Due to the unknown age of the forest in a polygon prior to the disturbance leading to the stand described in the current GIS database, two old-growth areas were calculated, with the actual area of old growth considered to lie within these two bounds. One bound resulted from assuming that all forests preceding the most recent disturbance were old growth; the other bound assumed that all the most recent disturbances occurred in forests >50 years old. An explanation of the rationale for this latter bound follows.

Disturbance in these forests comes primarily from forest harvesting, insects, pathogens, and fire. Forest harvesting is likely to occur only in the oldest forests. This was supported by field inspection of growth rings in tree stumps in 40 harvested areas in the ESSFwc2 variant, which indicated all forests were >140 years old at the time of cutting.

The most important insects which damage *Picea engelmannii* and *Abies lasiocarpa* are the spruce beetle (*Dendroctonus rufipennis* Kirby) and the western balsam bark beetle (*Dryocoetes confusus* Swaine), respectively, and damage from these insects is greater in older forests (Lewis and Lindgren 2000; Parish and Antos 2002; Bleiker et al. 2003; Kulakowski et al. 2003). Similarly, decay and root rot fungi are also more important in older forests, although some insects and fungal pathogens do damage younger forests (Lewis and Lindgren 2000). Thus, insect and pathogen disturbances causing tree mortality are likely mainly in older forests.

In high elevation Engelmann spruce-subalpine fir forests, fires are typically very infrequent due to the low frequency of drought conditions coincident with ignition sources. Fires are also usually stand replacing due to the structure of the forests, which makes them more prone to stand-replacing fires (trees easily killed by fire; much ladder fuel and tree crowns which are close to the ground surface, facilitating crown fires) (Agee, 1993; Schoennagel et al. 2004). Within the ESSFwc2 variant in the study area, during the period 1978-2006, extreme fire danger days averaged <2 per year, while high fire danger days averaged 9 per year, applying the British Columbia Fire Danger Class assessment to the weather data from five fire weather stations. British Columbia defines five fire danger classes from 1 = very low to 5 = extreme, based on dryness of fuels and likely fire intensity.

Fires can be either crown or surface fires. Crown fires are unlikely until crowns close sufficiently. This may not occur until 50+ years after a fire, due to slow regeneration and growth (Agee 1993) as a result of relatively poor recruiting ability of the two tree species present, a short growing season, and competition from shrubs and herbs (DeLong and Meidinger 2003). In cooler subalpine fir - *Menziesia ferruginea* forests in western Montana, which are similar to British Columbian ESSFwc forests, tree canopy cover was generally only up to 15% in stands aged up to 25 years and 50% in stands aged up to 40 years (Arno et al. 1985). Crown closure was considered to have occurred only approximately 80 years after fire in an ESSFwc2 forest (Parish et al. 1999).

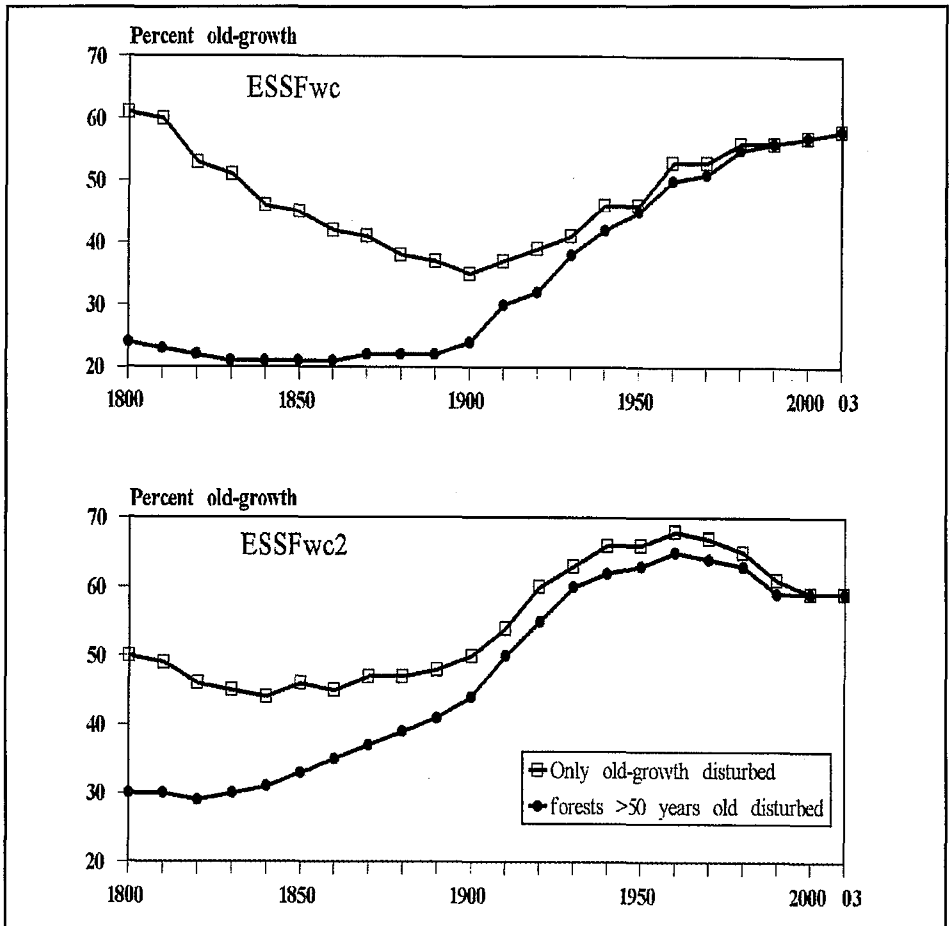

Figure 2. Percentage of the total forest cover occupied by old growth in ESSFwc and ESSFwc2 forests from the 1850's to 2003, estimated using two different methods – a) assuming only old-growth forests were disturbed, and b) assuming that all forests older than 50 years had an equal probability of being disturbed. The number for each decade is the mean value for all years in that decade.

Surface fire propagation requires a sufficient amount of dry surface fuels. Surface fuel buildup in ESSFwc forests following fire is slow. A fire in an ESSFwc forest, which kills most trees and burns off their foliage and fine branches, can leave an area relatively fuel free for extended periods due to the low fall-down rates of snags. Engelmann spruce and subalpine fir generally have longer standing snags than other trees with which they are associated (Everett et al. 1999), and 75% of snags in ESSFwc2 forests can still be standing 30 years post disturbance (Huggard 1999). While older forests can have coarse woody debris loads of 6 kg/m^2 or more (Feller 2003; Kopra 2003), Kopra (2003) found a decline in average coarse woody debris loads in these forests from 3.8 kg/m^2 in the first 20 years after fire down to 2.5 kg/ m^2 21-40 years after fire, then 1.3 kg/m^2 41-60 years after fire. Average coarse woody debris loads then increased, but did not exceed 3 kg/m^2 until after 80 years post fire.

Fine fuel loads are also generally low after fires in ESSFwc forests. The main contributors to fine fuels after stand replacing fires are herbs and shrubs. Most herbs die back every year, pushed flat to ground by snow, and decompose rapidly. Only fireweed (*Epilobium*) presents a significant fine fuel, and then only for a brief period in fall after stems have died. Forest fire danger in September-October, however, is generally low with only eight extreme fire danger days occurring during 1978-2006, and then only in one year, and 22 high danger days occurring, but only in five separate years. By 10-15 years after fire, fireweed has dropped to a minor component, and shrub cover may still be less than half that of the undisturbed forest, depending on fire severity (Hamilton and Peterson 2003). Apart from fireweed, the biomass of flammable vegetation is relatively low five years after a fire in the ESSFwc2, being lower with more severe fires (Feller 1996) typical of stand-replacement fires. Although more severe fire favors fireweed, it also favors other moist herbaceous plants, which reduce the overall fire hazard (Feller 1996; Hamilton and Peterson 2003). Fine fuel loads then are unlikely to present a significant fire hazard until conifer litterfall becomes important. The fire hazard from the initial fall of dead needles from fire-scorched trees is likely to be reduced by the herbaceous plants on which the needles fall. Fahnestock (1976) found for drier *Abies lasiocarpa* forests in north central Washington that fine fuel loading increased to a peak just before age 50, before decreasing, then rising again twice as forests aged. He found fine fuel surface area peaked around age 120.

The above discussion suggests that crown fires in ESSFwc forests are unlikely until more than 50 years after a fire, while surface fires may occur under exceptional and rare circumstances within 10 years after a fire but are more likely when fine coniferous fuels become abundant (for which precise times are unknown, but are likely to be 40-50 years after a fire). Consequently, it was assumed that fires in ESSFwc forests were unlikely to be significant in forests less than 50 years old.

Old growth and fire frequency

The fire regime in ESSFwc forests is considered to be one of infrequent (every 200-350 years) stand initiating severe fires (Anonymous 1995), suggesting that the oldest trees in a forest can be used to date the most recent fire. That this is not necessarily so was indicated by the absence of fire in two of the five stands sampled for charcoal (stands 3 and 4) for over 1000 years (Table 1), which is well beyond the life expectancy of the *Abies* and *Picea* trees present (Burns and Honkala 1990). Variable charcoal ages within the one stand might be explained by: (1) the standard errors of ^{14}C measurements and calibration from the ^{14}C to a calendar time scale, and (2) the length of time the plant from which the charcoal originated had been dead prior to burning. The latter may be substantial in some situations; Gavin (2001), for example, found it could be up to 610 years in coastal western hemlock forests in B.C. It is likely to be considerably less than this in ESSFwc forests, as Feller (2003) found that coarse woody debris became part of the forest floor 320-390 years after tree death in ESSFwc forests compared to 780-810 years in coastal western hemlock forests similar to those studied by Gavin. However, even with these potentially large errors in fire dating, the trees in stands 3 and 4 would still not have regenerated until centuries after the most recent fire in these stands. Similarly, Hawkes (1997) estimated fire cycles in some ESSFwc forests to be 530-1430 years, again suggesting that some of these forests have remained unburned for longer than the age of the oldest trees present within them. The extent to which the oldest ESSF stands do not reflect the time of the most recent fire is unknown. Even these limited data suggest it is unlikely that fire cycles can be estimated for these forests using stand age class distributions, and some old growth forest ecosystems may be considerably older than the age of the oldest trees within them.

Old growth abundance

For more than 40 (ESSFwc) and 90 (ESSFwc2) years, old-growth forests have comprised more than 50% of the total forested area. Contrary to Johnson et al. (1995), old-growth forests do not make up only a small proportion of the subalpine landscape in mountain regions containing ESSFwc forests. Wong et al. (2003), reviewing studies of other ESSF subzones, concluded that most ESSF landscapes in north-central British Columbia were dominated by older forests. MacKinnon and Vold (1998) found that 53% of all ESSF forests in B.C. were old growth. The upper elevation forests in the Coast Mountains in B.C. are in the ESSF zone on their eastern side and the mountain hemlock (*Tsuga mertensiana* (Bong.) Carr. (MH) zone on their western side. MacKinnon and Vold (1998) found that 71% of the forested area in the MH zone was old growth. Consequently, it is likely that old-growth forests have comprised a major proportion of most mountain landscapes in B.C. during recent decades.

Old-growth abundance in the pre-harvesting period (1806-1955) of 20-60% in ESSFwc forests and 30-60% in ESSFwc2 forests is generally similar to the 20-50% found for northern U.S. Rocky Mountain forests (Lesica 1996) and the 40-60% found for forests in Washington's central eastern Cascade Range (Agee 2003).

In British Columbia, old-growth forests can be protected within parks and ecological reserves or within special old-growth reserves called Old Growth Management Areas (OGMAs). In these latter areas, however, tree cutting is permissible for insect or disease infestation control when there is a perceived threat to adjacent areas. Up to 5-10% of an OGMA, depending on its size, can be cut even without any special notification. Since they are subject to tree cutting, however, they cannot be considered to truly protect old-growth forests. This happens only in provincial parks and ecological reserves.

As of February 2007, 19% of ESSFwc and 22% of ESSFwc2 forests were within parks and ecological reserves in British Columbia (T. Stevens, B.C. Ministry of Environment, pers. comm.). If forest harvesting occurs on a rotation of <140 years, preventing forests in harvested areas from ever becoming old growth, and if some natural disturbances occur in these protected areas, it is possible that the amount of old growth in these ESSFwc forests will decrease below 20% – the likely lower limit of its recent historical range. Didion et al. (2007) have shown via modeling that forest harvesting on a uniform rotation based on minimum merchantable age, as has been practiced in ESSFwc forests, can result in the stand age class distribution departing from the historical range of variation with fewer older forests, particularly with increasing fire frequency. If management of ESSFwc forests is to emulate historical disturbance regimes, greater protection of old-growth forests than at present will be necessary. Compared to all ESSFwc forests, greater areas of ESSFwc2 forests appear to have been subjected to more disturbances in recent decades than in the pre-harvesting era. This would suggest there is some urgency in protecting more ESSFwc2 old-growth forests if their historical disturbance regimes are to be emulated.

CONCLUSIONS

The abundance of old growth within British Columbia's wet cold Engelmann Spruce - Subalpine Fir forests has varied during the last 200 years. The historic natural abundance was likely between 20-50% for ESSFwc, and 30-60% for ESSFwc2 forests. Amounts of old growth in 2003 (58-59% of the forested area) were within the pre-harvesting era range in ESSFwc2 forests, but may be above the range in ESSFwc forests. Old-growth forests have dominated most subalpine landscapes in eastern B.C. for at least the last several decades.

For two of five old-growth ESSFwc2 stands sampled, fire has probably been absent for over 1000 years, which is well beyond the life expectancy of the *Abies* and *Picea* trees present. Consequently, fire cycles cannot be reliably estimated for these forests using stand age class distributions, and some ESSFwc old-growth forest ecosystems may be considerably older than the age of the oldest trees within them.

Continuing natural disturbances together with forest harvesting are likely to decrease the amount of old growth in these ESSFwc forests below 20% – the likely lower limit of its recent historical range. If management of ESSFwc forests is to emulate historical disturbance regimes, greater protection of old-growth forests than at present will be necessary.

ACKNOWLEDGMENTS

The GIS database was supplied by the B.C. Ministry of Sustainable Resource Management, and was analyzed with the assistance of J. Maedel, and particularly E. Pierce. C. Bonish, E. Pierce, and S. Pollock assisted with fieldwork. The study was funded by Forest Renewal B.C. and B.C. Forest Investment Account grants to M. Feller and a UBC fellowship grant to K. Kopra. This study has formed part of

the Sicamous Creek Silvicultural Systems Research Project of the B.C. Ministry of Forests.

Kristin Kopra is currently a research assistant at McGill University with teaching and research interests in forest ecology and social sustainability of forest and protected area management. The present study formed part of her M. Sc. Dissertation at the University of British Columbia.

Michael Feller is an Associate Professor in the Forest Sciences Department, University of British Columbia with teaching and research interests in forest fire ecology, streamwater quality, and impacts of forest management on vegetation, soils, and ecosystem nutrient cycles.

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