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Fire History of Forest Remnants in Wetter Lodgepole Pine Dominated Forests in Southern British Columbia, Canada

Abstract

Forest fires in British Columbia often leave patches of unburned vegetation (forest remnants) within their perimeters. These remnants help to maintain biological diversity and structural complexity in stands. To be able to maintain patterns similar to those created by fire, we need an understanding of the fire history of these forest remnants. We investigated the history of forest remnants in two study areas located in wetter lodgepole pine dominated forests in two Montane Spruce biogeoclimatic subzones in southern central British Columbia. The objectives of the study were to determine if there were any remnants that had never burned and, if not, what were the longest fire-free intervals within them. Aerial photographs, forest cover maps, and ground searching were used to investigate a total of 14% (47,000 ha) of one subzone and 17% (17,000 ha) of the other. This yielded 12 remnants in which plots were established to determine recent fire history. All twelve remnants had burned at some time. Stand history reconstruction, including dendrochronological analysis, of five of these remnants suggested that they had been formed from 3 different fires. The longest fire-free intervals within the remnants were estimated to range from 129 to 309 years. This is up to nearly twice as long as the longest fire-free intervals found for remnants in drier lodgepole pine forests in British Columbia.

Introduction

Forest harvesting of primary forests is occurring rapidly in British Columbia. The most important tree species harvested is lodgepole pine (*Pinus contorta* Dougl. Ex. Loud. var. *latifolia* Engelm.), which accounted for approximately 30% of the total annual volume of wood harvested in 2001 (McDougall 2002). Lodgepole pine is the most widespread tree species in western North America. Forests dominated by lodgepole pine cover some 6 million ha in the western United States and some 20 million ha in western Canada (Lotan and Critchfield 1990). In such forests, fire is one of the major natural disturbance agents (Kipfmueller and Baker 1998b). Fire regimes can maintain ecological functions, such as productivity and stability, and can also maintain plant and animal diversity over time and space by maintaining structural complexity within stands and by influencing their size, distribution, edge characteristics and dispersion across landscapes (Hansen et al. 1991). Burned forested landscapes typically consist of a mosaic of burned and unburned patches (Delong and Tanner 1996). The size, shape and location of individual forest patches profoundly affects forest community stability and productivity (Franklin and Formann 1987, Frank and McNaughton 1991). To maintain patterns similar to those created by natural disturbances—a current management objective for British Columbia's forests—we need a good understanding of the natural disturbance regimes in these ecosystems (Swanson et al. 1994).

Unburned remnants left by fire constitute the on-site resources available for rehabilitation of the burned area and affect other resources, including vertebrates (Eberhart and Woodard 1987), invertebrates (Gandhi et al. 2001), water and soil. Studies on remnants have only begun within the last three decades, and have included investigations of ecological characteristics (Delong and Kessler 2000), patch size and shape (Foster 1983, Eberhart and Woodard 1987, Stuart-Smith and Hendry 1998), distribution across the landscape (Rowe and Scotter 1973, Heinselmann 1981, Foster 1983, Eberhart and Woodard 1987, Delong 1998) and factors influencing these characteristics (Quirk and Sykes 1971, Camp et al. 1997, Kushla and Ripple 1997). Although many studies have investigated the mean fire interval or the fire history of forests or whole landscapes (e.g. Baker 1989, Everett et al. 2000), the fire-free interval of remnants is not well known. However, in drier lodgepole pine forests in central British Columbia all remnants in one study area had burned and their longest fire-free interval was 165 years (Vera 2001).

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The objective of the present study was to determine if there were any remnants in wetter lodgepole pine-dominated forests in British Columbia that had never burned and, if not, what were the longest fire-free intervals within them during the most recent 200 years, or so. This will assist the development of forest management practices which seek to mimic natural disturbance processes.

Study Area

The Montane Spruce (MS) biogeoclimatic zone of British Columbia (Hope et al. 1991), was selected because lodgepole pine dominated forests reach the wetter end of their ecological amplitude in British Columbia in this ecological zone. The MS has been subdivided into five subzones, of which the two wettest subzones—the Dry Cool (MSdc) and the Dry Mild (MSdm), - were chosen for investigation. British Columbia's Biogeoclimatic Ecosystem Classification system is described by Meidinger and Pojar (1991).

The climate of the MS zone is cool temperate, characterized by cold winters with moderate snowfall and moderately short, warm summers. The growing season lasts from May to October and is sufficiently warm and dry for moisture deficits, and thus fires, to occur (Hope et al. 1991). Precipitation varies from 600 to 830 mm, approximately 50% of which is snow. In the study area, loamy to clayey morainal deposits were prevalent (Hope et al. 1991). Soils were predominantly Brunisols in the MSdc study area and Luvisols in the MSdm study area (Hope et al. 1991). These correspond to Dystrochrepts and Eutrochrepts, and Hapludalfs, Glossudalks, and Boralfs, respectively, of the U.S. Soil Taxonomy system (Soil Classification Working Group 1998).

Both subzones studied occur in the Southern Interior Forest Region of British Columbia on the lee (east) side of the Coast Mountains. Within the MSdc, remnants were studied in the Tyaughton Creek drainage northwest of the town of Lillooet (lat. 51° 05' N; long. 122° 45' W; elevations ranging from 1420 m to 1510 m). Within the MSdm, remnants were studied in the Okanagan Highlands east of the town of Penticton (lat. 49° 30' N; long. 119° 15' W; elevations ranging from 1310 m to 1770 m).

Lodgepole pine stands of fire origin occupy much of the MS landscape (Hope et al. 1991). Without periodic fire lodgepole pine tends to be replaced by more shade-tolerant hybrid spruce (*Picea engelmannii* Parry ex Engelm. x *glauca*) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Mayr.) and western larch (*Larix occidentalis* Nutt.) occur in minor proportions (Hope et al. 1991). Both study areas belong to the Natural Disturbance Type 3 ecosystems—those "with frequent stand-initiating events" (BC Ministry of Forests 1995).

Methods

Remnant Selection and Plot Establishment

A total of 17% of the MSdc (approximately 17,000 ha) and 14% of the MSdm1 (approximately 47,000 ha) were searched for remnant forest stands using aerial photographs and forest cover maps and verified by ground searching. Remnant stands met the following criteria: 1) at least 300 m² in size (considered the minimum size to obtain enough data to characterize a remnant), 2) surrounded by a matrix dominated by lodgepole pine (suggesting a stand initiation after fire), 3) tree age at least 40 years older than the matrix, and 4) located two km or less from a road and within a walking distance of less than half an hour. Twelve remnants meeting these criteria were found and all were studied. Within the 64,000 ha searched, an additional ten less accessible remnants were not studied.

Depending on remnant size and heterogeneity, in each of these twelve remnants one or two 20 m x 20 m plots (total of 18 remnant plots; Table 1) were established according to fixed rules to avoid bias. The surrounding matrix (total of 48 matrix-plots) was characterized by systematically locating 4 plots on bearings along the four cardinal compass directions (N, S, E, W) from the remnant plot centre.

Field Sampling

Tree species composition, presence of fire indicators, tree ages, and time since last fire were determined in 2000. To ensure that remnants were left by fire and not by other disturbances, matrices were examined for evidence of a past fire by assessing species composition, and presence of fire indicators (charcoal).

Sampled remnants were examined for evidence of past fire, including charcoal in soil and on trees or coarse woody debris (CWD), and fire scars on

TABLE 1. Location and site characteristics of forest remnants. UTM coordinates (1983 datum) were determined using Forest Cover Maps (scale 1:20 000).

Remnant ID	UTM coordinates	Elevation (m)	Site moisture status
Tyaughton study area (MSdc biogeoclimatic subzone)			
R1	5659900N, 511800E	1420	zonal
R2	5659000N, 511550E	1510	zonal-dry
R3	5656400N, 517000E	1490	zonal-moist
R4	5662550N, 511450E	1420	dry-zonal
Okanagan study area (MSdm biogeoclimatic subzone)			
R5	5478500N, 336500E	1310	wet-zonal
R6	5478250N, 336650E	1310	zonal-moist
R7	5478500N, 336200E	1310	zonal-moist
R8	5487500N, 328000E	1770	zonal-dry
R9	5486650N, 327250E	1720	zonal-dry
R10	5478500N, 327550E	1540	zonal-moist
R11	5479100N, 325700E	1520	zonal-dry
R12	5486200N, 323450E	1570	zonal

trees. Their tree species composition was assessed quantitatively (measuring all trees > 1.3 m high within the 20 m x 20 m plots) to estimate their successional stage.

The fire history (tree ages and time since last fire) of five of these twelve remnants was analyzed in detail using dendrochronological methods. The five remnants were selected to determine the upper end of the range of fire-free intervals. Selection criteria were—1) domination by hybrid spruce or subalpine fir (considered late successional species within the study areas (Hope et al. 1991), 2) zonal or slightly wetter sites (considered to burn less often than dry sites (e.g. Delong and Tanner 1996, Camp et al. 1997), 3) an absence of charcoal on the forest floor, and 4) an absence of burned CWD. To obtain a large set of increment cores from sites with comparable local climate, at least two remnants located relatively close to one another were selected. The remnants that best met these criteria were partly dominated by hybrid spruce (remnants R5, R6, R7), and partly by subalpine fir (remnants R8, R9). Both remnant groups were located in the Okanagan study area.

The stand initiation dates of these five remnants and their corresponding matrices were determined using fire scar-analysis, or if no fire scarred trees were found, postfire cohort ages (Kipfmueller and Baker 1998a). Fire scars were identified by charcoal on the bark surface, scar location, scar shape, and presence or absence of beetle galleries or branches within the scar (Molnar and McMinn 1960, Stuart et al. 1983) and by exact scar dating using dendrochronological methods (Swetman 1983). Nine scarred discs were collected from trees or from stumps.

To determine postfire cohort age at least the five largest diameter trees of each tree species present within the remnant or at least the two largest diameter trees within the matrix were cored. Coring the largest trees of a stand increases the chance of identifying the oldest tree (Kipfmueller and Baker 1998a). When a species with greatest dbh had relatively few trees, as many as possible were cored. This resulted in an unequal number of cores per tree species (range - one to 15). Trees were cored at 50cm above ground to minimize the error in age due to the time taken by a tree to reach coring height.

In remnant plots, one to three small but relatively old trees of the shade-tolerant hybrid spruce and subalpine fir were also sampled for age determination. Heavy lichen growth was used to identify the oldest small trees. These trees were cut at < 10 cm above ground to minimize the error due to the time taken by the tree to reach cutting height. These suppressed trees of very fire susceptible species with branches close to the ground would likely have been killed by any fire (Brown and Kapler Smith 2000), so their ages assisted in determining fire free intervals.

Increment cores and tree discs were prepared by sanding according to Elling (1966). For those increment cores that missed the pith of the tree, the number of missing rings was estimated using Duncan's method (Duncan 1989). Measurement of tree-rings was done under a microscope (up to 40-fold magnification) in combination with a digital positioning table for tree-ring analysis (standard resolution 0.01 mm). Measurements were transferred directly to a personal computer running the programs TSAP (Rinn 1989 - 1996) and CATRAS (Aniol 1983).

For each of the five tree species present in the study areas (Douglas-fir, western larch, lodgepole pine, subalpine fir, and hybrid spruce), raw tree-ring curves from increment cores, scarred tree-discs and suppressed trees were synchronized on the light-table (Dittmar 1999) and statistically crossdated using the computer program COFECHA (Holmes 1983). Crossdated mean curves were verified with tree-ring series from Briffa and Schweingruber, Parish, Parish and Small, and Schweingruber obtained from the International Tree-ring data bank (http://www.ngdc.noaa.gov/paleo/ftp-treering.html). These tree ring series were from trees from areas with similar climates to the study area.

To increase accuracy, only those crossdated increment cores that missed the pith by 10 years or less according to Duncan's method (Duncan 1989) were considered for age analysis. Ages of suppressed trees were considered for age analysis even if they could not be crossdated. In these cases, analysis of the whole tree-disc allowed the identification of false and double rings and thus ensured that ages were not overestimated.

Ages given for remnant and matrix trees are total ages calculated by adding three years as an estimate of the time required to reach coring height (50 cm) based on Hegyi et al. (1979). All tree ages are given with respect to the year 2000.

Results and Discussion

Species Composition of Remnants and Matrices

According to the selection criteria, all investigated matrices were clearly dominated by the pioneer species lodgepole pine. Ten out of twelve remnants were dominated by late successional subalpine fir (six) or hybrid spruce (four), while two were dominated by lodgepole pine (Figure 1).

The preponderance of subalpine fir and hybrid spruce in most remnants, compared to the lodgepole pine-dominated matrix, may not be due exclusively to fire. Tree species composition could also have been affected by mountain pine beetle induced mortality of lodgepole pine that influenced remnant stand composition several decades ago. There are no studies on the impact of mountain pine beetle on landscape distribution of lodgepole pine stand structures.

Although it seems unlikely that the beetles would kill all the trees in a large area while leaving patches of undisturbed forest (e.g. remnants 4 and 11), this possibility cannot be excluded. It is also possible that the beetles killed old lodgpole pine trees in remnants, leading to domination by fir and spruce. The absence of snags or large amounts of CWD, which would be expected from beetle attacks 60 - 90 years prior to sampling, together with the presence of charcoal and fire scars in and around the studied remnants, however, suggest that fire, and not beetles, has been the dominant factor in the development of the remnants studied.

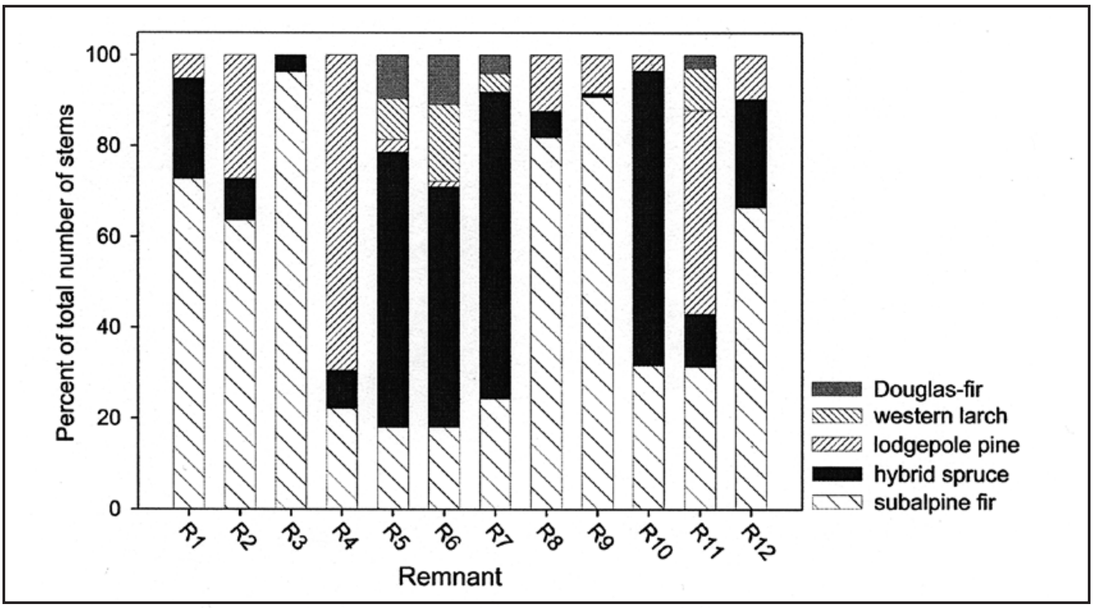

Figure 1. Species composition of forest remnants surrounded by more recently burned matrices. Percentages are based on trees > 1.3 m high.

TABLE 2. Tree ages of pioneer species in the forest matrices around remnants R5, R6, R7, R8 and R9.

Remnant	Matrix Species[1]	Mean age ± standard deviation	Age range of pioneer species (min–max) (years)	Number of matrix trees sampled	Difference between age of oldest trees in remnants and corres-ponding matrices (years)
R5	P, L	67 ± 2	63-72	16	46
R6	P, L	65 ± 3	58-69	8	54
R7	P	69 ± 2	68-72	7	46
R8					
South and east	P	69 ± 1	67-70	4	145
North and west	P	97 ± 2	95-99	4	112
R9	P	71 ± 4	62-74	8	208

[1] P—lodgepole pine; L—western larch

Fire History of Matrices

Fire scar analysis indicated that the three hybrid spruce-dominated remnants (R5, R6, R7) were surrounded by a matrix that initiated after a fire in 1926. This matrix was dominated by dense stands of even-sized lodgepole pine. The age ranges and standard deviations of the mean age of the largest trees were small (Table 2) and charcoal was found in the soil and on snags and logs. Estimated maximum ages of 72 years for both lodgepole pine and western larch (Table 2) suggest that regeneration of pioneer species within the matrices of remnants R5, R6 and R7 began within the first two years after fire.

Since no fire scarred trees were found in matrices of subalpine fir-dominated remnants (R8, R9), the date of the matrix initiating fire was estimated using the postfire cohort method. Initiation after fire was indicated by narrow age ranges of dominant lodgepole pine (Table 2), and by charcoal and burned logs. Similar maximum total ages and mean ages of the matrix south and east of R8 and of the matrix of R9 (Table 2) suggest that they initiated after the same fire around 1926. This conservative estimate is based on the maximum age of lodgepole pine (matrix of R9: 74 years, Table 2).

Only the matrix north and west of remnant R8 initiated after an earlier fire around 1901, estimated from the maximum age of lodgepole pine (99 years; Table 2). Initiation of matrices after fire is again supported by a narrow age range (Table 2) in lodgepole pine dominated stands and the presence of charcoal and burned logs.

Fire-free Interval of Remnants

All twelve remnants had apparently burned at some time. Charcoal was found in all 12 remnants and burned CWD was found in all but three remnants. A fire scar was found in only one remnant (R6).

Based on the postfire cohort method, remnants R5, R6 and R7 are estimated to have initiated after a fire about 129 years prior to sampling. This was suggested by similar maximum ages, narrow tree age ranges, low standard deviations of the mean age of the largest trees (Table 3), and decreasing trends in tree ring width. The largest trees show relatively rapid initial growth that declined about 50 years after establishment. This suggests they belonged to the first post-fire cohort that established under open conditions (Veblen et al. 1991). Temporal variation in tree-ring width of the largest trees as well as ages of suppressed trees (Table 3) suggest that remnants R5, R6 and R7 have remained free from high-intensity fires since their stand-initiation about 129 years prior to sampling. A fire at that time could also explain the fire scar found on a large (and probably old) western larch in the inner part of remnant R6 (see above). This scar could not be dated due to decay within the tree. The ages of suppressed trees also indicate that hybrid spruce-dominated remnants R5, R6 and R7 likely have not been burned by fires that scar or kill trees for 103 (R5), 65 (R6) and 81 (R7) years (Table 3). This would suggest that remnants R5 and R7 were not burned by the matrix initiating fire in 1926 (74 years prior to sampling).

Subalpine fir-dominated remnants are estimated to have initiated after fires about 235 (R8) and

TABLE 3. Tree ages and species of the largest trees and of suppressed trees in remnants R5, R6, R7, R8 and R9.

		Largest trees			Suppressed trees
Remnant	Species	Mean age ± standard deviation (years)	Age range min–max (years)	Number of remnant trees sampled	Species and age (years)
R5	D, F, L, S	113 ± 11	80-123	15	S (61) F (103)
R6	D, L, S	119 ± 6	108-129	13	S (65)
R7	D, F, L, P, S	115 ± 7	98-127	14	S (81) F (46, 73)
R8					
old age group	P	214 ± 10	199-235	18	F (110, 121)
young age group	F	112 ± 13	97-129	6	
R9					
old age group	P, S	279 ± 18	251-309	12	F (92, 118, 124)
young age group	F, S	140 ± 14	125-161	6	

[1] D—Douglas-fir, F—subalpine fir, L—western larch, P—lodgepole pine, and S—hybrid spruce.

309 (R9) years prior to sampling, based on the maximum ages of the largest cored lodgepole pine trees (old age group, Table 3). The lodgepole pine trees present have relatively narrow age ranges, a low standard deviation of mean ages (old age group, Table 3), and show relatively rapid initial growth that decreases after about 50 years. This suggests that they belonged to the first post-fire regeneration that established under open conditions (Veblen et al. 1991). Tree ages and species composition (Table 3 and Figure 1) suggest that stands of mostly shade intolerant lodgepole pine (old age group), are being replaced by shade tolerant subalpine fir (young age group) (Krajina et al. 1982). Subalpine fir (young age group) established about 106 (R8) and 148 (R9) years after the first lodgepole pine (old age group) had regenerated in the remnants (Table 3). The establishment of subalpine fir under a lodgepole pine canopy is supported by trends in subalpine fir ring widths which were steady or increasing for about the first 50 years growth (cf. Veblen et al. 1991). This succession is typical for stands in the absence of a fire that would initiate a new stand of lodgepole pine (Agee 1993). Thus, trends in tree ring widths of the largest trees, and ages of suppressed trees (Table 3) suggest that remnants R8 and R9 have remained free from high-intensity fires since their stand initiation about 235 and 309 years ago. Ages of suppressed trees and an absence of fire scars also indicate that subalpine fir-dominated remnants R8 and R9 likely were not burned by fires that scarred or killed trees for 121 (R8) and 124 (R9) years, respectively (Table 3) suggesting that they, too, likely did not get burned by the matrix initiating fires in 1926 (74 years prior to sampling) and 1901 (99 years prior to sampling).

These results suggest that all five investigated remnants have remained free from high intensity fires since their initiation, resulting in fire-free intervals from 129 to 309 years, even if the most recent fire completely killed the surrounding forest.

The criteria used to select remnants excluded remnants in less accessible lodgepole pine-dominated forests, and those that burned before they reached 40 years of age. Further study is necessary to determine whether our results can be extrapolated to all wetter lodgepole pine-dominated forests in B.C.

In order to obtain a large set of increment cores from sites with comparable local climate to increase the quality of dendrochronological analyses, a minimum of two remnants located relatively close to one another is required. However, small distances between the investigated remnants increased the spatial autocorrelation of fire histories of remnants. Spatial autocorrelation of fire histories within the two remnants groups R5, R6, R7 and R8, R9, respectively, was indicated by 1) the same matrix-initiation and remnant-initiation dates of R5, R6, R7 and 2) one common matrix-iniation date of R8, R9. Thus, fire-free intervals obtained in this study are likely based on one matrix- and one remnant-initiating fire for remnants R5, R6, R7, and on two matrix-initiating fires and two remnant-initiating fires for remnants R8, R9, giving a total of six individual fires that have been investigated in this study. The constraints of this study should be kept in mind when interpreting the results.

One matrix-initiating fire for all remnants occurred around 1926. However, while this date has been established for remnants R5, R6, R7 using fire scar analysis, it is only a conservative estimate for remnants R8 and R9 based on the postfire cohort method. The fire initiating the matrices of R8 and R9 may not have occurred in 1926. Even if it had, it is very unlikely that the matrices of all remnants initiated after the same individual fire in 1926 because the 10 km distance between the two remnant groups was covered by stands of various ages, including stands older than 74 years.

Fire suppression in British Columbia, particularly in areas away from roads, has only become effective since the late 1950's (J. Parminter, B.C. Ministry of Forests, Victoria, B.C.: personal communication). In the study areas, there was no road access until industrial forest exploitation began in the late 1970's and 1980's. Consequently, it is unlikely that the fire-free intervals of remnants have been greatly influenced by fire suppression.

There may be remnants in wetter lodgepole pine forests that never burned but were not studied because they did not meet the criteria of this study. However, an absence of unburned remnants in wetter lodgepole pine-dominated forests is consistent with published results for drier lodgepole pine forests. Vera (2001) investigated 26 remnants in lodgepole pine- dominated forests in the dry, cold Sub-Boreal Pine-Spruce biogeoclimatic subzone (SBPSxc) in west central British Columbia and also failed to find remnants that had never burned. Stuart-Smith and Hendry (1998) found fire scarred trees in remnants left by fire in the East Kootenay region of southeastern British Columbia, and Camp et al. (1997) stated that fire refugias in their study area in the dry forests of the Wenatchee Mountain Range in Washington burned less frequently than the surrounding forest. No studies were found for regions with wetter climates comparable to those of our study.

Comparison of the fire-free intervals in this study with those of other studies is difficult due to the variation between studies in forest ecosystems and size of the study area. Masters (1990), Johnson and Miyanishi (1991), and Hallett and Walker (2000) studied fire frequency in Kootenay National Park, part of which is in the MS zone, but these studies were based on areas ranging from 495 to 1400 km ^{2}. Because fire frequency is defined as 'the number of fires per unit time in some designated area" (Romme 1980) their fire frequency results cannot be compared with this study which represents 'point" estimates for single remnants each covering at most a few hectares. Gandhi et al. (2001) estimated fire free intervals of 180 to 300 years in some remnants dominated by subalpine fir, hybrid spruce, and black spruce *(Picea mariana)* surrounded by lodgepole pine forests in western Alberta. Vera (2001) found the longest fire-free interval in drier lodgepole pine-dominated forests in British Columbia to be 165 years—approximately half as long as that found in the present study of wetter lodgpole pine-dominated forests. All five remnants that were selected for a detailed fire history analysis in this study had not been burned by the matrix-initiating fire, while Vera (2001) found this to be the case for only two out of her 26 investigated remnants.

The limited number of studies on the fire history of remnants, and on the fire ecology of forests located in the MS zone, suggests that our knowledge of this is still quite incomplete and that more work is required to determine if current forest harvesting is mimicking the natural disturbance regime.

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