Historical Fire Regime for the Pothole Creek Interior Douglas-fir Research Site
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R. Gray and E. Riccius
Fire is an important historical disturbance factor in most stands of British Columbia interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*). Evidence of fire history was studied at the Pothole Creek Research Site (IDFdk1 biogeoclimatic subzone) near Merritt, B.C., as part of a larger project investigating stand development and growth and yield. A master chronology, constructed using samples taken from climatically sensitive trees, was used to cross-date samples collected from fire-scarred wood. The resulting pattern of past fire intervals was then employed to speculate about the historical fire regime at Pothole Creek. Evidence was found of fires occurring as long ago as 1693 and as recently as 1967. The mean fire interval was 13 years, within the expected range for interior Douglas-fir forests. The minimum and maximum intervals were 1 year and 46 years, respectively, indicating varying periods of both low-intensity/high-frequency fire and higher-intensity/low-frequency fire. This high disturbance frequency promotes plant species with adaptations to fire, such as Douglas-fir and pinegrass (*Calamagrostis rubescens*), and an open stand structure with sparse, patchy regeneration. The most severe fires identified on the site were not sufficiently intense to destroy the overstorey.
ACKNOWLEDGEMENTS

The authors would like to thank several individuals who made this project feasible. Catherine Bealle Statland, from the Ministry of Forests Research Branch, spearheaded this project. When it became apparent that fire may have been instrumental in the historical development of stand structure at Pothole Creek, Catherine obtained the funding to make the additional study possible.

Rob Lihou, from the B.C. Institute of Technology, helped to collect and prepare specimens.

Thanks to Ken Lertzman and the SFU Forest Ecology lab for their support.

John Parminter, also from the Ministry of Forests Research Branch, helped to locate and collect fire scar specimens in the field and later provided comments on the draft report. Emily Heyerdahl, from Simon Fraser University, also provided valuable comments on the draft report.

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1 INTRODUCTION

Forest stand structure, species composition, and succession are products of any number of combinations of biotic and abiotic influences. In the interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) plant associations of the United States and Canada, fire has been one of the most prevalent influences. Yet the influence of fire on these ecosystems has been variable, both spatially and temporally. The historic range of variability (Morgan et al. 1994) of fire—its frequency, intensity, seasonality, and extent—is collectively known as a fire regime (Martin and Sapsis 1991; Agee 1996a). Studies of historical fire regimes have been used throughout the interior Douglas-fir plant associations to give researchers and operational managers important clues about pre-settlement era disturbance regimes and their resulting ecosystems (Arno 1976, 1980; Davis 1980; Wright and Bailey 1982; Keane et al. 1990; Agee 1993, 1994, 1996b; Arno et al. 1995; Camp et al. 1995; Steele and Geier-Hayes 1995).

The goal of the ongoing research project at Pothole Creek is to determine the structure and development processes of the ecosystem. The end result of this investigation will be an ability to predict future ecosystem dynamics and to model growth and yield. Since fire was the most common disturbance agent in these forests and played an important role in maintaining forest health, understanding the historical fire regime is essential for any analysis of current stand structure and underlying processes.

2 METHODOLOGY

2.1 Site Description

The 5-ha Pothole Creek Research Site (Figure 1) is situated at 1210 m elevation, 30 km southeast of Merritt, British Columbia, at approximately lat. 49°54’ N, long. 120°36’ W. The zonal plant association at the site is Interior Douglas-fir (IDF) (Krajina 1965). The subzone is IDFdk1, which is considered to be the modal IDF subzone. This subzone is found in lower to middle elevations of the southern Interior Plateau in the lee of the Coast and Cascade mountains, east from the Tatla Lake area to north of Williams Lake, then south to southeast of Princeton (Hope et al. 1991).

Within the characteristically warm, dry, moisture deficit IDF zone, the IDFdk1 subzone is the coldest of the subzones in the Kamloops Forest Region (Lloyd et al. 1990).

2.2 Field Data Collection for Master Chronology

The width of tree rings varies in response to changes in climate parameters, which limit tree growth (Stokes and Smiley 1968; Fritts 1976). In our study area, the growth of trees on dry rocky ridges is limited by soil moisture during the growing season, which in turn is limited by precipitation. Consequently, these trees have narrow rings in dry years and wide rings in wet years (Figure 2).

We used these climatically sensitive trees to develop a master chronology, an essential tool for dendrochronological dating of the fire-scarred sections (Stokes and Smiley 1968; Fritts 1976; Fritts and Swetnam 1989).
A master dendrochronology is a time series of tree-ring widths of climatically sensitive trees in which the common climate signal has been maximized. This chronology was used to cross-date the fire-scarred sections, a process of matching patterns of wide and narrow rings among and between sites to assign the correct calendar year to every tree ring, hence every fire scar (Madany et al. 1982; Dietrich and Swetnam 1984; Brown and Swetnam 1994; Grissino-Mayer 1995). Cross-dating can identify missing and false rings that would lead to inaccurate fire dates. Radial growth is less limited by soil moisture in the fire-scarred trees, so that fire-scarred samples will not show as strong a climate signal compared with the trees.
chosen for the master chronology. Our master dendrochronology was developed from cores from 10 Douglas-fir trees growing on exposed, rocky ridges near the 5-ha research plot. We selected these trees because their growth appeared to be limited as evidenced by flattened tops, large branches, and poor form.

To cross-date tree rings within a tree, two cores from opposite sides of each tree were taken. This method ensures that narrow and wide rings are due to climate rather than the effects of other factors, such as geotropism, on an individual tree.
2.3 Field Data Collection for Fire History

Data for fire history samples were collected according to accepted methods in these types of forests (Arno and Snedek 1977; Kilgore and Taylor 1979; Brown and Swetnam 1994; Grissino-Mayer 1995; Swetnam and Baisan 1996). An initial site reconnaissance for fire-scarred trees, snags, stumps, and logs was conducted through the 5-ha research plot and the immediate vicinity. We limited the search of the surrounding area to the adjacent slope to the south and to both sides of the research plot as well as the bench area to the north. We assumed that any pre-settlement fire affecting the research plot would have influenced the surrounding area because fuels would have been continuous and the landscape contains no topographic breaks. Candidate specimens were checked for soundness and species. While several scarred lodgepole pine (*Pinus contorta* var. *latifolia* Dougl. ex Loud.) were found north of the plot, there was an insufficient number to construct a master dendrochronology for the species.

We collected data at the site of each candidate specimen and completed a field form (Appendix). Live trees outside the 1-ha intensive plot were felled and sectioned to locate the greatest number of visible scars. No live sample trees were located within this intensive plot. Stumps, snags, and logs were sectioned similarly. Candidate samples were labelled, photographed, and stored for transport to the lab.

2.4 Laboratory Methods for Master Chronology

After drying and sanding the increment cores, each core was measured using a Velmex–Quick Chek™ sliding stage system and the medir measuring program (Grissino-Mayer et al. 1996). The measurement files were run in COFECHA (Grissino-Mayer et al. 1996), a program that verifies cross-dating among measured tree-ring series. The program flags possible dating errors, which are checked by the researcher. By cross-dating the cores visually and running the measurement series through COFECHA, we quickly developed a master chronology for the study area. Figure 3 shows the average ring width for each year from the 10 samples in relation to the all-found average width of all of the annual rings from all 10 samples (0 units of standard deviation). Positive standard deviation units indicate wider than average growth rings while negative standard deviation units indicate narrower than average growth rings.

The master chronology for this area has several consistent sequences and excellent marker years, which are the longest negative spikes in Figure 3. Many decades have at least one marker year or a short sequence of distinct ring widths. The chronology spans 393 years, from 1605 to 1997.

2.5 Laboratory Methods for Fire History

Fire scar specimens were stored in a cool, dry location for approximately 5 weeks. Once dry, the samples were cut down to size and sectioned to locate the greatest number of scars.

Working samples were mounted on 6 mm (¼”) ranger board with wood glue. Each specimen was sanded with a succession of sandpapers beginning with 50 grit and ending with either 320 or 400 grit. Of the 23

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1 The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the British Columbia Ministry of Forests of any product or service to the exclusion of any others that may also be suitable.
samples collected in the field, we prepared and cross-dated 20. Three samples were too decayed to sand and date.

Scars in the samples from live trees were cross-dated by working from the bark year (1997) to the pith. The list of marker years (Yamaguchi 1991) and a binocular dissecting microscope with magnification power from 7 to 45 were also used. We assigned the season of the fire according to the position of the scar in the annual ring. Scars in the earlywood occurred early in the growing season. Scars in the latewood probably occurred in the late summer and early fall. Scars at the ring boundary occurred between growing seasons (either fall or early spring). We chose to attribute scars in the ring boundary to the fall just after the end of the growing season.

Samples obtained from dead wood (snags, stumps, or logs) were measured using the Velmex and medir programs. The undated ring-width series from the sample was run in COFECHA against the master chronology to determine the inside or pith date of the sample. This date was verified by visually cross-dating the sample with the master chronology prior to cross-dating the fire scars on the sample.

Scars that definitely resulted from fire were distinguished from scars that may have been caused by other agents such as frost kill, or sun-scalding (Table 1). Once scarred, Douglas-fir tends to produce many very small scars which cannot readily be attributed to fire. It is still unclear why this scarring occurs in Douglas-fir and what the related physiology is. Such minor injuries occurring on only one sample have a high probability of not being the result of fire. After all of the scars had been identified, those minor injuries occurring on more than one sample were re-classified as fire scars. It is still possible that some fires that did not leave distinctive scars might have been mis-identified and eliminated from the data set. Hence, the fire history for the site may be conservative. Most of the fire scars were cross-dated a second time to ensure accurate dates.
The dates for fire scars were entered into a statistical analysis package for fire history known as FH2 (Grissino-Mayer 1995). This software was used to develop graphics of the fire history for the site (Figure 4) as well as to conduct a statistical analysis of the fire intervals. The analysis includes:

1. a frequency distribution of the fire intervals for the site, tests of goodness of fit of the data with a normal distribution, as well as a Weibull distribution (fire intervals tend to fit a Weibull distribution better [see Grissino-Mayer 1995 for a full discussion of this]), and

2. a summary of statistics regarding the central tendencies and extremes in the data including: the mean fire interval (MFI), median fire interval, Weibull mean probability interval (WMPI, the central tendency for Weibull distributions), minimum fire interval, and maximum fire interval.

The sample depth, which is the number of samples having the potential to record a fire at a specific point in time, varies over time (Figure 4). For example, only three samples were able to record fires in 1700 compared with 18 samples in 1900. This variation creates the need for a standard time period for statistical analyses which is known as the period of reliability (POR) (Grissino-Mayer 1995). The sample depth is based on a combination of the age of the samples and the ability of trees to record fires. Generally, evidence of recent fires is more commonly found than evidence

<table>
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of older fires, because old wood is more difficult to find—it both decomposes and is consumed in subsequent fires.

After trees have been scarred once, they are included in the sample depth from the date of the recorded fire forward and are known as recording trees. Once a tree has a fire scar, the tree is more easily scarred in subsequent fires (Grissino-Mayer 1995) compared with an unscarred tree because the cambium is not well protected by bark at the edges of an existing fire scar and can be scorched in subsequent fires causing new scars. The circumstances for forming the initial fire scar are not well understood in field conditions (Gutsell and Johnson 1996).

A POR was identified for the fire history data based on at least three recording trees. Although the criterion is set by the researcher, it bounds the fire history data creating a consistent data set for statistical analyses. The resulting POR is from 1693 to 1967. However, although there are at least three recording trees from 1693 to 1834, most of the trees sampled begin recording fires in 1834 resulting in relatively sparse data prior to 1834. Thus, the calculated fire interval is likely to be conservative for the period prior to 1834.

The statistics package was applied to three different groups of fire scar dates representing three different intensities of fire (Table 2):

1. all fire scar dates recorded within the site by any tree,
2. only those fire scar dates recorded by at least 10% of the fire-scarred trees within the site, and
3. only those fire scar dates recorded by at least 25% of the fire-scarred trees within the site.

These three groups of fire scar dates represent different estimates of fire severity and extent (Swetnam and Baisan 1996, Grissino-Mayer 1995). Fires that are recorded on very few samples may have been insufficiently severe

**Figure 4** Fire scar dates by sample.
or too small to scar many trees. These are included in the first analysis using all of the fire scar dates. In contrast, when a larger proportion of trees are scarred we can infer a larger and more severe fire. The analyses of the fire scar data using the 10% and 25% scarred filters provide an indication of the number of fires that were more severe and perhaps larger, as well as a description of the frequency of these types of fires. Dominant patterns in fire severity and extent may become obvious by comparing the mean, minimum, and maximum fire intervals for the three analyses.

3 RESULTS AND DISCUSSION

The components of the historical fire regime determined from the study—seasonality, extent, frequency, and intensity—provide clues to past stand structure, ecological succession, and species composition. Determining intensity and extent can be difficult and is often left to speculation. Where few studies have been conducted in similar ecosystems, patterns cannot be used to bolster inferences. Data on intensity and extent are provided but, due to the lack of studies for comparison, conclusions are not presented.

### 3.1 Seasonality

The seasonality of fire, a temporal component of the fire regime, provides clues about the ignition source and fire effects for individual species. Most fires recorded in our samples are found in dormant season wood (in the ring boundary) on the increment. On the Pothole Creek site Douglas-fir may begin to shut down wood production due to moisture stress by early summer. This shut down would place the dormant season in the middle of the summer lightning season. The dormant season location of the scars may also translate to early spring fires prior to the growing season which would be well outside of the lightning season. Because of the location of the scars and the nature of the samples collected, we cannot draw a confident conclusion about the seasonality of fires.

### 3.2 Extent

Inferences could be made regarding fire size based on the fire history data that occurred on at least 10 and 25% of the recording trees, and the

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<td>61</td>
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spatial arrangement of the scarred trees in the study site. Fires that were recorded on a large percentage of trees, such as the 1834 fire which scarred 93% of the trees, could be inferred to be larger fires than those that scarred only one tree. Trees scarred by the 1834 fire were found on the east, north, and south sides of the research area indicating a fire that likely covered the entire study area. However, such inferences must be made cautiously due to the historic nature of the fuels and fuel moisture conditions under which they could have burned.

3.3 Frequency and Intensity

In this study several frequencies were determined including: the mean fire interval (MFI), the median interval, and the minimum and maximum intervals. The fire frequency, most commonly expressed as the MFI, is often used with intensity to categorize fire regimes. Concepts such as low-intensity/high-frequency versus high-intensity/low-frequency fire regimes (Heinselman 1978), and stand-maintaining versus stand-initiating fire regimes (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995), are generalizations of the fire regime of an ecosystem. General fire intensity for the ecosystem can be predicted from an MFI. Wildfire, however, has both stochastic and non-random characteristics when it interacts with the landscape, both spatially and temporally. As a result, the concept of the historic range of variability (HRV) (Morgan et al. 1994) is used to describe the non-random nature of fire occurrences and resulting fire effects on the ecosystem. In this study the HRV of frequency and intensity has been determined by analyzing the minimum and maximum fire intervals (Figure 5). Ecosystem responses can now be predicted based on the HRV of fire frequency and intensity.

The mean fire interval and the median interval provide clues to the general frequency of disturbance in the ecosystem. For the Pothole Creek site an MFI of 13 years is well within the range of MFI for other interior

![Figure 5: Fire intervals, 1693 to 1967. The height of each bar indicates the length of time between recorded fires.](image-url)
Douglas-fir plant associations (Wright and Bailey 1982; Agee 1993). With a disturbance occurring on average every 13 years, forest fuel accumulation and wildfire behaviour can be predicted. Low-intensity surface fires would be the norm on moisture-deficient sites where biomass production between fires would be limited to forbs, low shrubs, and conifer regeneration. Subsequent fires would kill poorly adapted Douglas-fir and lodgepole pine regeneration as well as top-kill all forbs and shrubs. Species with fire-adapted traits such as the ability to resprout from root collars, rhizomes, stems, or soil-stored seed would have a competitive edge over species with no adaptive traits (Agee 1993; Whittle et al. 1997). Overstorey Douglas-fir and, to a lesser extent, lodgepole pine are adapted to survive low-intensity surface fires (Fischer and Bradley 1987; Crane 1991; Uchytil 1992). Under a fire regime with this return interval, the forest would appear open with well-spaced, mature Douglas-fir and an understory of grasses and shrubs resulting from low-intensity/high-frequency or stand-maintaining fires.

The fire regime analysis also provides a stochastic view of fire on the study site by providing the historical range of variability of fire occurrences. The minimum fire interval from the sampled trees was 1 year. This minimum was recorded twice between 1693 and 1967. The nature of the fuels and subsequent potential fire behaviour on the site leaves open the possibility that other low-intensity fires may have occurred without scarring any trees. Very low intensity grass fires seldom scar trees, especially mature Douglas-fir with thick, insulating bark (Crane 1991).

The occurrence of fires two years in a row gives some indication of biomass production and species resilience. Both of the 1-year-interval fires were recorded on trees a significant distance apart indicating regeneration of continuous grass and litter fuels sufficient to allow fire spread. Native perennial grasses such as pinegrass (Calamagrostis rubescens) were likely fuels through which the fire spread. Pinegrass is well adapted to survive low- and moderate-intensity surface fires through underground rhizomes (Snyder 1991).

The maximum fire interval recorded was 46 years, found between 1788 and 1834. During this 46-year period, biomass accumulated on the site and ecological succession would have enabled non-fire-adapted species to establish. With high accumulations of coarse woody debris and live tree stocking over a 46-year period, the subsequent fire, under the right conditions of fuel moisture and weather, could have exhibited very high intensity. The data suggest that the fire in 1834, a large fire of high intensity, scarred most of the trees sampled. Under this type of regime even mature overstorey Douglas-fir could have been killed. This fire did not, however, destroy the entire overstorey because many trees scarred in 1834 were later scarred by other fires. Following these high-intensity fires, fire-adapted species would once again have a competitive advantage.

4 CONCLUSIONS

With the wide diversity in fire regimes exhibited on the Pothole Creek site, varying from periods of low-intensity/high-frequency fire to
higher-intensity/low-frequency fire, subsequent forest stand characteristics are highly variable. However, certain species and structural characteristics are consistent throughout the variations. Such a high level of disturbance favours those species adapted to frequent fire. Stand structure was probably open with very little regeneration except during long fire return intervals. Wildfires following long fire return intervals had the potential to cause overstorey mortality where surface fuels and regeneration could carry fires into the crowns. These higher-intensity fires probably exhibited localized torching and crowning but would not have resulted in the loss of the entire stand. Large gaps created by the loss of overstorey trees may have benefited regenerating Douglas-fir.
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</table>
LITERATURE CITED


