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Evidence of mixed-severity fires in the foothills of the Rocky Mountains of west-central Alberta, Canada

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ABSTRACT

This study presents new evidence of historic low-to-moderate-severity fires, intermixed with high-severity fires, in the foothills of the Rocky Mountains of west-central Alberta, Canada. High-severity fires that burned 120–300 years ago initiated even-aged cohorts of fast-growing lodgepole pine at each of the six study sites. Evidence of subsequent, low-to-moderate-severity fires included single and double fire scars on thin-barked lodgepole pine that were as small as 3.6 cm in diameter at the time of the fire, but survived. These low-to-moderate-severity fires resulted in structurally complex stands with a broad range of tree diameters and multiple cohorts of lodgepole pine, white and black spruce, and subalpine fir. At the site level, fire return intervals were variable, ranging from 29 to 167 years, but most were <80 years. Of the 9 years in which we documented low-to-moderate-severity fires, only the fires in 1889 and 1915 scarred trees at more than one site, indicating that these fires were small and had local effects. The new knowledge of historical, low-to-moderate-severity fires provided by this study has important implications for ecologically sustainable forest management. Although we recognize that further research needs to determine the extent of low-to-moderate-severity fires at the landscape scale, our results clearly indicate that a mixed-severity fires occurred at least locally. A broader range of silvicultural systems than is currently practiced would be consistent with historic forest dynamics.

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1. Introduction

Sustainable forest management aims to conserve biodiversity and maintain ecosystem function while maintaining renewable resources. Achieving this goal requires knowledge of the spatial and temporal attributes of natural disturbance regimes and disturbance impacts on forest composition and structure (Christensen et al., 1996; Landers et al., 1999). Conceptually, the natural pattern model proposes that managing landscapes within historic forest structures and functions is a strategy that is more likely to maintain historical, and desirable, levels of ecosystem function and biodiversity (Hunter, 1991). In practice, disturbance patterns are now commonly used as general-level guides or "coarse filters" for forest management decision-making (Bergeron et al., 1999; Delong and Kessler, 2000; Fenton et al., 2009).

One of the basic requirements for adopting a natural pattern approach is an understanding of ecosystem-specific disturbance regimes, which describes the causal agent(s), areal extent, timing (frequency and predictability), magnitude (intensity and severity) and interactions among the disturbance events that occur within a defined area and period (Pickett and White, 1985). Wildfire is the most important mechanism of ecological disturbance in western North America (Johnson, 1992; Agee, 1993), and so understanding the associations between fire and forest dynamics is essential for conservation and sustainable management of forests. The traditional paradigm for the western Canadian Cordillera is that high-severity or stand-replacing fires dominated mountain forests, which has strongly influenced research methods, forest management, and policy in this region (Johnson et al., 1998, 2001).

The research methods used to reconstruct fire history tend to be specific to the fire regime being represented because of the differential effects of fire on forests. For example, high-severity fires (e.g., <20% of trees survive fire and post-fire recruitment pulse includes 71–100% of trees, Sherriff and Veblen, 2006) result in forest patches with relatively distinct boundaries that are distinguishable on air photographs and in the field. On landscapes dominated by high-severity fires, the most common fire-reconstruction method involves mapping distinct forest polygons and then determining age of the stands in combination with estimates of fire years from scars occurring at polygon boundaries (Johnson and Gutsell, 1994). Landscape-scale fire history may then be summarized using a stand-origin map (e.g., time since the last high-severity fire; Heinselman, 1973) or a time-since-fire map (e.g., time since last fire

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of any severity; Johnson and Van Wagner, 1985). From these maps, patch sizes and ages are summarized as the area-by-age distribution and the fit of the cumulative data to a negative exponential or Weibull model is assessed to represent the fire cycle, the number of years required to burn an area equal to the study area, which is equal to the average interval between successive fires at a given point (Van Wagner, 1978; Van Wagner et al., 2006). This approach, commonly applied in the western Canadian National Parks (Tande, 1979; Masters, 1990; Johnson et al., 1990; Weir et al., 2000; Van Wagner et al., 2006), explicitly assumes all fires are severe, stand-replacing fires (Van Wagner et al., 2006). It does not account for variation in fire severity, although some time-since-fire maps note trees with multiple fire scars, providing evidence of low- or moderate-severity fires (Tande, 1979).

In contrast to high-severity fires, a high proportion of canopy trees survive low- and moderate-severity fires, which result in uneven-aged forests that include trees with multiple fire scars (Agee, 1993, 1998). The boundaries created by these lower-severity fires are not distinct on air photographs, nor are they easily identified in the field. Thus, the methods associated with time-since-fire maps and fire cycle modeling are less effective for quantifying these fire regimes. In forests dominated by low-severity fires (e.g., $\geqslant$40% of trees survive fire and recruitment pulse includes $\leqslant$20% of trees, Sherriff and Veblen, 2006), fire scar records are used to reconstruct fire history and quantify fire frequency and return intervals. This method has been successfully applied in ponderosa pine forests of the southwest United States (Swetnam et al., 1999) and a growing network of research sites throughout western North America (e.g. Heyerdahl et al., 2008). In forests dominated by moderate-severity fires (e.g., $\geqslant$20% of trees survive fire and recruitment pulse includes 20–70% of trees Sherriff and Veblen, 2006), analysis of fire scars is accompanied by analyses of forest age structures and stand dynamics to reconstruct fire history and quantify fire regime metrics (Sherriff and Veblen, 2006, 2007; Beaty and Taylor, 2008). Specifically, forest age structures and detailed analysis of the growth histories of individual trees quantify the timing and magnitude of growth releases or suppressions after fire.

There is growing evidence that mixed-severity fire regimes dominate many mountain forests of western North America (e.g., Taylor and Skinner, 1998; Wright and Agee, 2004; Sherriff and Veblen, 2006; Perry et al., 2011). Mixed-severity fire regimes include low-, moderate- and high-severity fires (Agee, 1998; Lertzman et al., 1998; Schoennagel et al., 2004). In mixed-severity regimes, fires burn at variable intervals and result in structurally diverse forests with complex dynamics (Perry et al., 2011). Similar to moderate-severity fires, a combination of research methods is needed to quantify complex forest structures and to reconstruct mixed-severity fire regimes (e.g., Lentile et al., 2005; Sherriff and Veblen, 2006, 2007; Beaty and Taylor, 2008).

In contrast to the traditional paradigm of high-severity fires, recent research has shown that fires of a range of severities and, therefore, mixed-severity fire regimes had a significant influence on historic structures and dynamics of some mountain forests of the western Canadian Cordillera (Cochrane, 2007; Da Silva, 2009; Nesbitt, 2010). This discrepancy indicates a need to better understand the relative importance of fires of a range of severities. Our research aims to address this knowledge gap by investigating fire history in the Berland River watershed of the Rocky Mountain foothills of west-central Alberta. In this stand-level study, we reconstruct the timing of historical fires and their impacts on forest structure and dynamics to assess variation in fire severity. The Berland River watershed was chosen because original forest cover maps showed complex forest structures, multiple age cohorts and presence of scarred trees, although the fire regime of the region is described as high-severity fires (Beckingham et al., 1996; Andison, 1998). We hypothesized that historic fire regimes of this area were complex, including low- to moderate-severity fires intermixed with high-severity fires, which we tested using dendrochronological methods.

2. Methods

2.1. Study area

This research was conducted in the subset of the Berland River watershed that is part of Hinton Wood Products' forest management area (Fig. 1). It is part of the Berland Upland Ecodistrict of the Upper Foothills Natural Subregion (elevation 1050–1700 m above sea level (m.a.s.l.); Natural Regions Committee, 2006). Influenced by cordilleran and continental glaciers, the terrain is rolling to steeply sloping. Forest soils are predominantly Gray Luvisols, with Gleysols and Organic soils in poorly drained and wet depressions. Climate is continental; mean monthly temperatures range from 14.2 ± 1.3 °C (mean ± standard deviation) in July to −10.6 ± 5.4 °C in January at Entrance, Alberta (53° 22′ N, 117° 42′ W, 991 m.a.s.l.; Environment Canada, 2008). Total annual precipitation is 513 mm, 75% of which is rain with 47% falling in June, July and August. Forests in this subregion are characterized by closed-canopies and dominated by lodgepole pine (*Pinus contorta* Dougl. ex Loud.), white spruce (*Picea glauca* (Moench) Voss) and black spruce (*Picea mariana* (P. Mill.) BSP). Forest inventory indicates that the Upper Foothills landscape is relatively uniform in composition and structure. Previous evidence suggests this landscape is exclusively influenced by a high-severity, stand-replacing fire regime with a mean return interval of about 100 years (Beckingham et al., 1996; Andison, 1998).

2.2. Site selection

Using a geographic information system (GIS), we analyzed the Alberta Vegetation Inventory (AVI) for the 311,393-ha study area (Fig. 1). Most of the study area (278,966 ha) was classified as forested and 61% (170,767 ha) of these forests originated prior to 1900. Of the forests that were at least 100 years old, 64% (108,812 ha) were dominated by lodgepole pine and the rest by black or white spruce or were mixed pine-spruce forests; about half (52%, 89,648 ha) had at least two canopy layers while the rest of the forest was single-layered. When these attributes were considered in combination, 19% (51,708 ha) of the forests originated prior to 1900, were dominated by lodgepole pine, and had at least two canopy layers. We hypothesized that the structure of these old, multistoried lodgepole pine stands may have resulted from mixed-severity fires. From this population of stands, we identified sites that could be accessed safely and efficiently for historical reconstruction (Table 1). To maximize the fire scar record and facilitate analyses of fire–vegetation interactions, we selected six study sites with a high density of large, old trees that included exposed fire scars on living and dead trees.

2.3. Forest composition and structure

At each of the six study sites, we used a GPS-unit to locate the centre of the forest patch, which was pre-determined using GIS. From this centre point, we used a modified N-tree design to sample the composition and structure of canopy (dominant and co-dominant height classes) and subcanopy (intermediate and suppressed height classes) trees with a diameter at breast height (dbh) $\geqslant$5 cm (Brown, 2006; Heyerdahl et al., 2006). We determined the species, dbh and age of the 15 canopy and 15 subcanopy trees closest to the plot centre. The distance to the furthest sampled canopy and subcanopy tree was measured to estimate tree density per hectare (Heyerdahl et al., 2006). The tree size structure of each stand was represented using histograms with 5-cm diameter classes.

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