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Sensitivity of reconstructed fire histories to detection criteria in mixed-severity landscapes

Vanessa Stretch [a,*], Ze'ev Gedalof [a], Jaclyn Cockburn [a], Michael F.J. Pisaric [b]

[a] Geography, University of Guelph, 50 Stone Road E, Guelph, ON N1G 2W1, Canada
[b] Geography, Brock University, 1812 Sir Isaac Brock Way, St. Catharines, ON L2S 3A1, Canada

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ABSTRACT

In heterogeneous forest landscapes prone to wildfires, accurate classification of the fire regime beyond direct observations and records is difficult. This is in part due to the methods used to reconstruct historical fires in complex, heterogeneous landscapes with varying fire severities. Mixed-severity fire regimes, defined as variations in wildfire severity over time and/or space, have important implications for ecosystem functioning and forest management. Fire event detection is used to reduce uncertainties in historical tree-ring proxy records. The number of fire events considered in fire regime classification varies based on detection criteria (filters) that are researcher-selected, such as number of trees or plots recording fire. Here we analyzed the sensitivity of fire regime classification to common detection criteria in a mixed-severity fire regime in the eastern foothills of the Rocky Mountains, Alberta, Canada. We found that detection criteria bias records toward high-severity events and against potentially ecologically significant low-severity fires in mixed-severity regimes, ultimately classifying them as higher severity. We conclude that detection criteria methods must address the scale that is relevant to the ecological or management questions being addressed.

1. Introduction

Mixed-severity fire regimes represent variability in the ecological effects of fire on forest ecosystems over both space and time. A single fire event may result in varying sized patches of high-, moderate-, or low-severity effects with a range of tree mortality, if there is high variability in microsite (plot-level) topography (Moritz et al., 2011; Perry et al., 2011; Hessburg et al., 2016). Mixed-severity fire regimes can also be described at a range of spatial scales, from the site- or stand-level up to the regional- or landscape-level (usually desired for management) (Peterson, 1998). Fire can also be mixed in severity over time, depending on fire weather, time-since-last-fire, and rates of fine fuel production (Agee, 1993, 2003; Arno et al., 1995; Perry et al., 2011; Hessburg et al., 2016). For example, high-severity fires may be interspersed with low- or moderate-severity events. Together the variability of severities over both space and time make understanding and detecting mixed-severity fire regimes difficult.

A variety of evidence is retained from differing fire events over space and time, thus complicating the detection and classification of mixed-severity fire regimes. For example, at the stand-level, low-frequency, high-severity fire often kills the majority of vegetation (Turner and Romme, 1994; Peterson, 1998; Meyn et al., 2007). Subsequent regeneration in the years following fire may result in even-aged tree cohorts and previous fire evidence may be lost. Reconstructing these events is complicated by the criteria used to identify post-fire cohort dates. Post-fire cohort detection is researcher-defined, usually with consideration of species time-to-coring height. However, this detection is complicated furthermore by the uncertainty in the cause of establishment (*e.g.* another form of high-severity disturbance, such as an insect outbreak). Higher frequency, low-severity fires kill understorey vegetation and/or leave fire scars on mature trees (McBride, 1983; Gutsell and Johnson, 1996). Reconstructing these regimes is complicated by differential preservation of fire scars by species, as well as minimum numbers of replicate scars found on other trees. These challenges are typically addressed by using post-sampling fire event detection criteria (filters) to increase certainty that these events represent fire activity.

In areas where fire regimes are well understood, target sampling for fire evidence of known severities results in successful fire regime reconstructions (Farris et al., 2010, 2013). For example,

* Corresponding author at: Climate & Ecosystem Dynamics Research Laboratory, Geography Department, University of Guelph, 50 Stone Road E, Guelph, ON N1G 2W1, Canada.

E-mail address: vanessa.stretch@gmail.com (V. Stretch).

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in ponderosa pine (*Pinus ponderosa*) forests in the western US, fire scarred trees are purposely selected for analysis (Baker and Ehle, 2001). It was well established that this region has been characterized by low-severity, surface fire regimes. However, in understudied areas where an assumption of the fire regime is made (*i.e.* assuming a regime based on forest type or a neighbouring regime), sampling for a range of unknown fire evidence may result in more accurate fire regime representation. For example, North America's boreal forests, which were historically believed to be represented by a single low-frequency, high-severity fire regime resulting in a mosaic of even-aged stands, is now understood as a spatially dynamic fire regime (Bergeron et al., 2001). Individual high-severity fires can also result in complex mosaics at different spatial scales (Margolis et al., 2007, 2011; Margolis and Swetnam, 2013; O'Connor et al., 2014). Sampling solely for high-severity fire evidence (*i.e.* stand establishment) in boreal forests would result in a simplification of the fire regime. For example, Marcoux et al. (2015) found evidence of a high-severity fire regime in southeastern British Columbia, Canada that resulted from 20th-century surface fire suppression and harvesting that homogenized forest structure. However, the authors found evidence of a historically mixed-severity fire regime in this location. We hypothesize that targeted sampling areas of a single, known severity may bias the regime classification to either end of the classification continuum in mixed-severity regimes (Heinselman, 1973; Agee, 1993; Swetnam et al., 1999; Van Wagner et al., 2006).

Canadian boreal forests have historically been managed with the assumption of infrequent, high-severity, stand-replacing fires being the dominant disturbance agent (Johnson, 1992). However, Amoroso et al. (2011) found evidence for mixed-severity fire regimes in the Rocky Mountain Foothills, on the western edge of Canada's boreal forest. A probable explanation for this regime is the degree of topographic variability that may result in mixed-severity fire effects, as both even-aged stands and fire scars were found (Amoroso et al., 2011). Similarly, recent studies found evidence of mixed-severity fire in the montane cordillera directly adjacent to the Foothills (Chavardes and Daniels, 2016; Marcoux et al., 2013, 2015). There is a need for a broader search for mixed-severity fire regimes in these areas.

Here, we present a case study from the eastern foothills of the Rocky Mountains, Alberta, Canada, and test the sensitivity of common fire regime classification methods to mixed-severity regimes. Our objectives were: (1) to incorporate high- and low-severity fire evidence to reconstruct fire regimes in a complex region with little-to-no known fire histories in order to classify the fire regime and (2) to analyze the impact of post-sampling detection criteria on the final fire regime classification, in order to ensure the ecological integrity of forest management.

2. Methods

2.1. Case study area

In this case study we analyze two sites (ZS and PC) in the northern portion of the Hinton Wood Products Forest Management Area (HWP FMA) in the eastern foothills of the Rocky Mountains near Hinton, Alberta, Canada (Fig. 1). HWP manages approximately one million hectares of land extending east from the Rocky Mountains into the boreal plains ecozone. Here the eastern foothills are considered part of the Alberta upland ecoregion (Ecological Stratification Working Group, 1996), which is classified as the western edge of the boreal forest in Canada. The forests are dominated by lodgepole pine (*Pinus contorta*) and black spruce (*Picea mariana*), with lesser amounts of white spruce (*Picea glauca*), trembling aspen (*Populus tremuloides*), balsam fir (*Abies balsamea*), and western larch (*Larix occidentalis*).

The HWP FMA has had minimal fire activity since the 1990s and is therefore classified as extreme to high risk for wildfire in current management planning. It is believed that about 44,000 ha (<5% of the managed area) have burned since the 1930s, with most events being small (<1–10 ha) in size (Hinton Wood Products, 2010). Harvesting (pulp and timber extraction) activities have been ongoing since 1956, with a current sustainable harvesting management plan in place that involves mimicking the natural wildfire disturbance regime by using variable cutblock sizes and shapes and retaining remnant stands, as well as burning harvest waste in situ. Prior to 1956, there was minimal known activity in the area; it was used mostly as hunting and camping grounds for nearby settlements.

2.2. Site and sampling selection

Using a combination of random and condition-based sampling techniques, we reconstructed wildfire activity at two sites. Working in a large potential sampling area (almost one million hectares), and with the hopes of incorporating multiple lines of fire evidence, we surveyed the landscape at more than 30 sites looking for signs of historical evidence of fire occurrence since at least the mid-1900s to suggest mixed-severity before selecting our final two study sites. These sites were selected because they are of interest to the forest management agency and have a complex harvesting histories, are well-forested and accessible, and are topographically diverse. These characteristics would be sufficient to preserve evidence of mixed-severity fire should it exist here.

To select specific plots for sampling within each study site (~10,000 ha), we used a condition-based selection approach. To facilitate a multi-century reconstruction, we used Alberta Vegetation Index (AVI) stand age polygons to eliminate stands less than 100 years old (Environment and Sustainable Resource Development, 2008). By excluding these stands, we are not biasing the record against recent high-severity fires; most of the excluded stands were harvested, and large, stand-replacing fires were relatively rare during the past 100 years (Hinton Wood Products, 2010). We then randomly selected six accessible stand polygons from each cardinal direction (24 plots at each site), in order to assure sampling was dispersed across the site (Fig. 1). Sampling plots were established in the centre of each polygon and permanently staked (plot sizes ranged from 0.0019 to 0.0716 ha).

2.3. Tree-ring data collection and analysis

To capture the high-severity fire record, canopy and subcanopy trees (if present) were sampled for tree establishment estimation (Barrett and Arno, 1988; Baker and Ehle, 2001; Heyerdahl et al., 2012). We used an *n*-tree sampling design that resulted in variable plot sizes. This was done by coring to pith within the lower 30 cm (basal coring) of the 10 closest canopy and 10 closest subcanopy trees (with a DBH > 5 cm) to plot centre.

Because post-fire cohorts on their own do not represent all fire activity (Lorimer, 1985), and to capture the low-severity fire record, cross-sectional and partial cross-sectional sampling was carried out at sites where visual fire evidence existed (McBride, 1983; Lorimer, 1985; Rist et al., 2011). Fire-scarred trees within the plot were sampled (identified by charring, catfaces, and basal triangular scars); as well, downed wood was cut into to examine for evidence of buried fire scars and sampled if appropriate (Agee, 1993, 1998; Swetnam et al., 1999; Niklasson and Drakenberg, 2001). To reduce sampling redundancy, at most five samples were selected from both dead and live trees.