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Fuel fragmentation and fire size distributions in managed and unmanaged boreal forests in the province of Saskatchewan, Canada

Veiko Lehsten [a,*], William de Groot [b], Florian Sallaba [a]

[a] Department of Physical Geography and Ecosystem Science, Lund University, Sweden
[b] Canadian Forest Service, Natural Resources Canada, Sault Ste. Marie, Ontario, Canada

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ABSTRACT

Forest fires are an important disturbance factor of boreal forests, annually burning about 0.5% of the forested area in Canada. Wildfire regimes are influenced by climate and a number of studies project an increase in wildfire activity with climate change. Another factor influencing wildfires is human intervention (fire suppression), and one factor that has rarely been assessed is fuel fragmentation. Studies evaluating the effect of forest fire suppression concluded that in areas with strong suppression effort the burned area as well as the fire size decreased.

Here we evaluate wildfire distributions over the last three decades for two areas that differ mainly in their level of forest management and fire suppression: the Boreal Shield (unmanaged) and the Boreal Plain regions (intensively managed) in the Canadian Province of Saskatchewan.

We calculate a fuel fragmentation index and relate fire sizes and burned areas to fire weather. We use the concept of the characteristic fire size (CFS); hence we analyze how much burned area is contributed to the total burned area per fire size class.

Both areas show a uni-modal distribution of the CFS, indicating that the majority of burned area was contributed by medium sized fires (Boreal Shield $6.39 \cdot 10^4$ ha, the Boreal Plain $8.79 \cdot 10^4$ ha). Burned area as well as fuel fragmentation is lower in the managed forest compared to the unmanaged area.

The fuel fragmentation index constantly increased since the 1980s in both regions. Despite the large efforts of fire suppression in the Boreal Plains, the CFS is slightly larger in this managed region. Neither the burned area nor the fire size could be linked statistically to the weather conditions, at the time of the fire (using the Canadian Fire Weather Index).

We argue that the high fragmentation over the last decades have decreased the burned area. The slightly higher characteristic fire size in the managed area might be explained by the considerably lower fragmentation, counteracting fire suppression efforts. Fuel fragmentation is likely to decrease over the next decades due re-growth. Though a strong link between fire weather and burned area at the fine scale of this study could not be detected we expect that a decrease in fragmentation in combination with an increase in fire prone weather conditions (as expected for the future) might increase the risk of large fires in both areas. We suggest that future fire risk analysis should include an assessment of the effect of fuel fragmentation.

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1. Introduction

Wildland fire has been a prevalent natural disturbance across the North American boreal forest region for millennia (Girardin et al., 2013). The North American boreal fire regime is characterized by infrequent high intensity crown fires (de Groot et al., 2013) and the annual area burned in Canada has been episodic and variable, ranging from 300,000 to 7.5 M ha per anno. Stand-replacing crown fires currently burn an average of 2–3 M ha (~0.5% of total forest area) each year in Canada (Stocks et al., 2002) with typical fire cycles of 75–150 years. Large fires account for most of the annual area burned in the Canadian boreal region, creating a landscape pattern of large areas of young forest (established since the most recent fires) with small patches of older forest embedded, which represent unburned islands and the remnants of older fires (Johnson et al., 1998; Weir et al., 2000). The median size of unburned islands increases sharply with fire size, and the frequency of unburned islands (per 100 ha burned)

* Corresponding author at: Department of Physical Geography and Ecosystem Science, Lund University, Sölvegatan 12, SE-23623 Lund, Sweden.
E-mail address: veiko.lehsten@nateko.lu.se (V. Lehsten).

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is greatest for smaller classes of large fires (201–2000 ha) (Eberhart and Woodard, 1987). Fire shape also becomes more irregular with increasing fire size such that the largest fires create the greatest amount of edge relative to area burned (Eberhart and Woodard, 1987). Although some studies have been done on the spatial pattern of individual fires in the boreal region, there has been very limited research conducted on the pattern of fire distribution on the landscape and effect of fuel fragmentation on fire spread.

To reach a rational use of forest resources preserving long term ecosystem functionality it has been suggested that forest practices should minimize the differences between managed and unmanaged forests (e.g. Franklin, 1993; Hunter, 1993). Ecosystem-based forest management should favor interventions that lead to landscape compositions and structures close to their counterparts in natural forests (DeLong and Tanner, 1996) including disturbance pattern. Therefore a large interest in past, present and future burned areas has resulted in a number of studies focus on the relationship between climate and burned area, or projecting climate into the future and translating climatic changes into changes in burned areas (for a comprehensive review see Girardin et al., 2013). These studies have also shown that there is considerable uncertainty in the link between climate and burned area (*ibid*). Though recent increases in North American fire activity have been attributed, at least in part, to a changing climate and increasing temperature (Gillett and Weaver, 2004; Westerling et al., 2006). Amiro et al. (2004) have shown that if the climate is evaluated on a per fire basis, no trends could be detected in fire weather components within the last four decades.

Additional difficulties arise from the influence of large fires which result in an over-proportional amount caused by very few fires. Together with changes in reporting and suppression rates, as well as short term climatic variations, linkages between fire and climate might be hard to detect especially at a landscape scales (Girardin et al., 2013).

One aspect which has received very little attention in the past is the effect of fragmentation on the fire regime. When analyzing burned area and fire size distributions, Lehsten et al. (2014) found that fire size as well as burned area in Canada increased continuously from the 1960s until the 1980s and remained at a very high level in the 1990s before both characteristics dropped sharply in the 2000s. Given the decrease in the 2000s at a national scale, this raises questions about the nature of the link between temperatures and burned area, which was assumed by Gillett and Weaver (2004) to be a linear relationship, using data from 1960 until 2000. This recent decrease in burned area was hypothesized to be the result of fuel fragmentation resulting from the high fire activities in the 1980s and 1990s (Lehsten et al., 2014). If this is the case, this decrease in burned area would only last a short time period and a re-growth of forests (together with a warmer climate) would result in an increased fire activity in the following decades.

Analyzing temporal effects of fuel fragmentation is challenging for a number of reasons. Similar to other fire parameters, fuel fragmentation can be expected to be dependent on the forest type, the climatic conditions and the level of forest management, including forest protection. Additionally, data covering large spatial and temporal scales are needed to allow collection of a sufficiently large and representative distribution of small and large fires in order to detect if they are causing fragmentation. Directly linked to fuel fragmentation is the fire size distribution, as a shift towards large fires (with a constant burned total area) would result in a decrease of fuel fragmentation. Hence both fire-size and fuel fragmentation should be analyzed simultaneously. Cumming (2005) has evaluated the effect of fire management and concluded that fire suppression efforts have decreased both the burned area as well as the ratio of large to small fires. However, if the total burned area decreases, this will also decrease fuel fragmentation, which can potentially favor the development of large and thereby costly fires compared to a landscape with less fire suppression effort.

In this study we investigate the effect of forest management (fire suppression) on fuel fragmentation and fire size distribution in two areas which are relatively similar in their ecological attributes apart from their forest management history. We will also analyze the temporal development of fuel fragmentation and its relation to climatic conditions.

2. Methods

2.1. Study area

Our study areas are the Boreal Shield and Boreal Plain eco-zones (Ecological Stratification Working Group, 1995) within the Province of Saskatchewan, Canada (we will use the term Shield and Plain in the following to account for the Boreal Shield and Boreal Plain of the province Saskatchewan rather than the whole eco-zone which is larger). We used the classification scheme of the National Ecological Framework for Canada (http://sis.agr.gc.ca/cansis/nsdb/ecostrat/gis_data.html) to assign the areas (Fig. 1). Eco-zones are ecological areas based on terrestrial characteristics accounting for surface forms, soils, faunal realms, vegetation and macro climates (Marshall et al., 1999). The Shield is dominated by coniferous (83%), scattered mixedwood forest (8%), and by lakes and rivers (8%), while the Plain consists of lower amounts of coniferous forest (43%) and more mixedwood forest (16%) and broadleaved forest (14%), but additionally includes rangelands (20%) and a lower amount of lakes and rivers (5%). All other land cover classes are below 1%. The total area of the Shield is $1.83 \cdot 10^7$ ha. Though the Plain is only marginally smaller ($1.7 \cdot 10^7$ ha), its burnable forest area is ca. 22% smaller (sum of all forest types: Shield $1.68 \cdot 10^7$ ha, Plain $1.31 \cdot 10^7$ ha). Drying of forest floor organic soils in the boreal shield is generally quicker than in the boreal plains. This is because forest floor fuel loads are higher in the boreal plains than in the boreal shield for black spruce (*Picea mariana*), jack pine (*Pinus banksiana*) and aspen (*Populus tremuloides*) (Letang and de Groot, 2012), which represent the majority of the forested area in those regions. Therefore, the lower forest floor fuel loads in the boreal shield promote faster drying due to shallower, or less densely compacted, organic soils. The Shield is - until today - experiencing essentially a natural fire regime, and is classified as a fire management observation zone where values at risk are assessed with the intent to allow for fire in ecological processes (Government of Saskatchewan., 2014). On the other hand, the Plain has been used as high value commercial forest over the last decennia and is classified as either a modified or full response fire management zone with the object to control and suppress fires. We therefore decided to use the two areas as representatives of boreal forests with relatively similar ecological conditions but different fire management history.

2.2. Fire data

We used data from the Canadian National Fire Database (CNFDB)[1] (Stocks et al., 2002). We used the polygon data provided to create yearly fire maps of the Shield and the Plain. The CNFDB is a collection of forest fire polygons from Canadian provincial, territorial and national fire management agencies. We filtered out all fires that were located on non-forested areas, fires below 100 ha and used only fire data ranging from 1960 to 2010 since the fire data for earlier times and smaller fires are not considered reliable (Stocks

[1] http://cwfis.cfs.nrcan.gc.ca/ha/nfdb.

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