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THE PERIPHERAL REDUCTION IN BURN PROBABILITY AROUND RECENT BURNS IN THE BOREAL FOREST

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1. INTRODUCTION

Despite increasing knowledge of the factors responsible for landscape flammability, predicting its magnitude and spatial distribution over a large area has been largely unattained. This exercise is even more challenging in highly variable fire regimes such as the boreal forest of Canada, where most of the area burned is caused by few large fires that occur only periodically. In fact, in this biome, 2-3% of the fires are responsible for 97% of the area burned (Weber and Stocks 1998).

In order to better predict the likelihood of burning on the boreal landscape, one must understand the factors that drive the spread of large fires and, perhaps more importantly, the variability in time and space associated with this phenomenon (Lertzman et al. 1998). Furthermore, as the forest undergoes succession and land-use changes, the flammability of the forest changes accordingly. This change is reflected both locally by the structure and composition of forest fuels and on a larger spatial scale through changes in relative abundance and connectivity (Finney 2001).

It is well known that recent burns in the boreal forest are unlikely to re-burn for a number of years. The flammability within the perimeter thus becomes low to nil for a certain period of time. However, intuitively, it is reasonable to speculate that the likelihood of burning outside the perimeter of recent burns should also be reduced for two main reasons: large burns effectively disrupt the paths of incoming fires, and the chance that a fire ignites nearby is decreased.

The aim of this study is to examine the spatial relationship between large recent burns and their effect on landscape flammability, as expressed by burn probability (BP), in the western boreal forest of Canada. The BP provides an estimate of the present likelihood that a given point (e.g., cell) on a landscape could burn. It is calculated over a large area with the landscape fire model BURN-P3 (probability, prediction, and planning). The change in BP around recent burns of different sizes and shapes was assessed in both homogeneous and heterogeneous landscapes.

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2. METHODS

2.1 *The model*

The BURN-P3 model (Kafka et al., *in prep.*) integrates the physical components of fire spread to the probabilistic aspects of the fire regime. While fire spread is simulated through physical fire growth modeling (WILDFIRE, Todd 1999) based on the Canadian Forest Fire Danger Rating System (Van Wagner 1987, Forestry Canada 1992), the probabilistic aspects of BURN-P3 are based on historical data, and include:

(i) the location and frequency of ignitions,
(ii) the rate at which fires escape initial attack and become large,
(iii) the number of days each fire experiences significant spread,
(iv) the weather conditions associated with this spread.

Fires are simulated throughout a fire season, called an iteration, according to historical variability. This same fire season is simulated a larger number of times (e.g., 1000 iterations) and compiled. Thus,

$$BP = 100\% \times \frac{\text{number of times each cell has burned}}{\text{number of iterations}}$$

and represents the likelihood (%) that a fire will occur during a given fire season.

2.2 *The scenarios*

BURN-P3 was used to produce BP maps for multiple scenarios that consist of landscapes with recent burns of different sizes and shapes. The heterogeneous (*actual*) landscape is a boreal mixedwood area of central Saskatchewan that is covered by many different types of vegetation, ranging from pure coniferous (most flammable) to pure deciduous (least flammable). The homogeneous (*control*) landscape represents a uniform cover of the Boreal spruce fuel type (C-2 in CFFDRS), the most flammable fuel type in terms of fire intensity.

As the BP around actual recent burns (1993 to 2002) were examined in the *actual* scenarios, burns of four artificial shapes were tested for the *control* landscape: (1) *circle*, (2) *ellipse* with a 2:1 length to breadth ratio, (3) *square*, and (3) ellipse with rugged edge, the *rugged ellipse* (Fig. 1). To test the effect of the size of recent burns, three sizes for each burn shape were considered: 1000 ha, 10,000 ha, and 100,000 ha.

All historical factors are retained in the production of the *actual* landscapes' BP maps. For the *control* scenarios only the historical weather was used, although wind direction was randomized. The *control* scenarios were produced with 1000 iterations and the *actual* scenarios with 500, which represent adequate simulation sizes for these types of landscapes (see Kafka et al., in prep.).

2.3 *Analysis*

Preliminary analyses were conducted to explore the magnitude and variability of the reduction in BP around the different fire shapes and sizes in *control* landscapes. This has not yet been addressed for *actual* landscapes, because of the large number of covariates to consider, such as fuel types, landscape features, and historical ignition patterns.

The mean and coefficient of variation (CV) of the BP were computed for an area within a 5-km buffer surrounding the recent burns and compared to the average BP outside this area (Fig. 1b). In order to assess the effect of proximity to the recent burn on BP reduction, further analysis was carried out within the 5-km buffer. Mean and CV BP for a 1-km buffer around each burn was compared to the regions from 1 to 5 km for the *rugged ellipse*.

3. RESULTS AND DISCUSSION

Visual assessment shows a clear reduction in BP at the periphery of recent burns for both *actual* and *control* landscapes (Fig. 1). That this reduction is highly spatially variable is expected in *actual* landscape, because of (1) different forest fuels, (2) the amount and configuration of landscape features, such as lakes, and (3) the direction of predominant winds. However, BP was also highly variable in *control* landscapes, where these factors do not play a role. This variation is instead probably due to high spatial autocorrelation resulting from the exaggeratingly large fire growth in continuous C-2 fuel type. By contrast, *actual* landscapes limit and, to some extent, direct fire propagation (Hargrove et al. 2000) and thus form more spatially stable patterns of BP.

The shapes that most effectively reduce BP around burns are the e*llipse* and *rugged ellipse*. These shapes might be more effective at disrupting fire paths on their elongated side and increasing the likelihood of creating a 'fire shadow'. As expected, the reduction in BP is also consistently more prevalent around larger fires, except for the *circle* shape, where the 1000 ha fire has the most important reduction (Table 1). Clearly, the high spatial autocorrelation of BP adds uncertainly to these results; this type of analysis would largely benefit from being detrended with spatial statistics techniques to assess fine-scale spatial patterns.

At any rate, to have a significant decrease in BP for a distance as long as 5 km from the burns' perimeter demonstrates a definite influence of recent burns, especially >10,000 ha, on landscape flammability. However, the BP is evidently at its lowest at close proximity to the perimeter of these burns (Fig. 1). Further analysis of the *rugged ellipse* map shows that BP increases significantly past a 1-km buffer around the burns (Table 2), this fact being more pronounced around the 10,000 and 100,000 ha fires. In fact, the BP within the 1-km buffer of these fires is 31% and 42% less, respectively, than the mean regional BP. To have such a decrease in a *control* landscape leads us to believe that the BP could be reduced even more where other obstacles to fire spread exist. We can therefore speculate that there exists strategic locations (e.g., 'pinch points') where a reduction in BP is most pronounced in *actual* landscapes.

Understanding the factors that drive the likelihood of burning is an undeniable asset in optimizing fire and forest management activities. For example, the size and configuration of cutblocks could be planned to minimize the risk of loss to fire, without however compromising profitability (Hirsch et al. 2003). In their review of prescribed burning effectiveness, Fernandes and Botelho (2003) state that "optimization of the spatial pattern of fire application is critical but has been poorly addressed by research […]." Hopefully, this and future studies of the factors affecting landscape flammability will help address this issue.

4. REFERENCES

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Fig. 1. Examples of burn probability maps of *actual* (heterogeneous) (a) and *control* (homogeneous) (b) landscapes. The gray areas represent recent burns, the blue areas are water bodies, and the black line in (b) is the 5-km buffer around the recent burn *rugged ellipse* 100,000 ha.

A. *Actual* landscape B. *Control* landscape

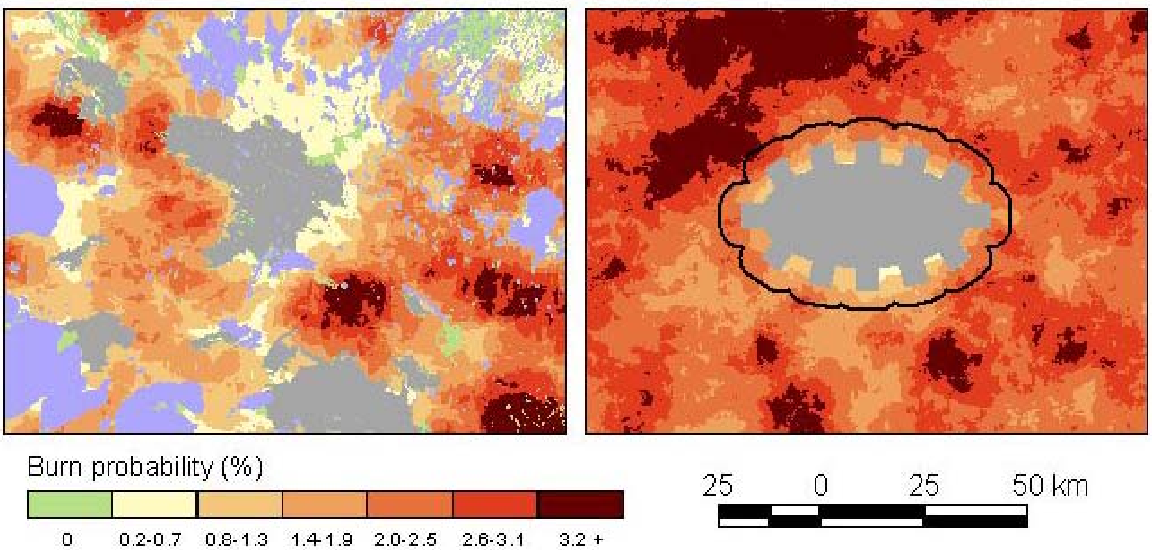

Table 1. Mean ± coefficient of variation (%) of the burn probability within and outside the 5-km buffer area surrounding the simulated burns.

Burn size (ha)	Circle		Ellipse		Square		Rugged ellipse	
	Within buffer	Outside buffer	Within buffer	Outside buffer	Within buffer	Outside buffer	Within buffer	Outside buffer
1000	2.1 ± 7	2.5 ± 19	2.3 ± 13	2.5 ± 18	2.8 ± 9	2.6 ± 18	2.5 ± 11	2.4 ± 19
10,000	2.3 ± 9	2.5 ± 20	1.7 ± 19	2.5 ± 20	2.1 ± 21	2.5 ± 20	2.2 ± 28	2.6 ± 21
100,000	2.2 ± 41	2.5 ± 20	1.9 ± 21	2.7 ± 20	1.9 ± 24	2.4 ± 20	1.9 ± 30	2.6 ± 21

Note: Means within and outside the buffers for each burn size are significantly different (Mann-Whitney test, $p<0.0001$).

Table 2. Mean ± coefficient of variation (%) of the burn probability within a 1-km and 1 to 5-km buffer area surrounding the *rugged ellipse* and the percent difference between the means.

Burn size (ha)	1-km buffer	1 to 5-km buffer	Percent difference
1000	2.3 ± 12	2.6 ± 11	10
10,000	1.8 ± 33	2.3 ± 25	22
100,000	1.5 ± 37	2.0 ± 26	25

Note: Means of the 1-km and 1 to 5-km buffers for each burn size are significantly different (Mann-Whitney test, $p<0.0001$).