Short report

THE RELATIONSHIP BETWEEN BURN PROBABILITY AND FUEL TYPE DOMINANCE IN THE BOREAL MIXEDWOOD OF WESTERN CANADA*

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INTRODUCTION

In the western boreal forest of Canada, it is a widely held belief among fire managers that large tracts of coniferous fuels are conducive to significant fire spread and are usually viewed as danger areas on campaign fires. By contrast, areas dominated by deciduous fuels are considered substantially less flammable, or even fireproof. While there is some evidence to support these claims (Hirsch *et al.* 2004), it is still unclear 'how much' deciduous fuels are required to be effective at reducing the size of large fires.

In fact, despite the relative importance of landscape-scale factors promoting or interrupting fire spread (Mermoz *et al.* 2005), there is surprisingly little information on the relationship between the landscape dominance of fuels and the likelihood of burning (but see Turner *et al.* 1989, Miller and Urban 2000, Duncan and Schmalzer 2003). Moreover, to our knowledge no such study has been performed in the boreal forest. This can be attributed in part to the lack of tools to evaluate the burn probability (BP) of large areas. However, a new landscape fire model, Burn-P3 (probability, prediction, and planning) (Parisien *et al.* 2005), which maps BP over large areas (>10^6 ha) provides an opportunity. To this end, we conducted a multi-scale analysis to explore the effect of fuel type dominance on BP.

STUDY AREA

The study area, which encompasses Prince Albert National Park (PANP), is located in central Saskatchewan (Fig. 1) and covers 1 653 467 ha. The area has long, cold winters and short, warm summers. The average monthly temperature of the Prince Albert weather station, located in the southern part of the study area, ranges from –19.1°C in January to 17.5°C in July. Mean annual precipitation is 424 mm, most of it falling between May and August (Environment Canada 2005).

The study area can be described as a flat to rolling plain, a large proportion of which is covered by lakes and wetlands. It is characterized by coniferous, deciduous, and mixedwood stands of various sizes. The main conifers of the study area are white spruce (*Picea glauca* (Moench) Voss), black spruce (*Picea mariana* (Mill.) BSP), jack pine (*Pinus banksiana* Lamb.), and tamarack (*Larix laricina* (Du Roi) K. Koch.). The deciduous component is mainly represented by trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.), and white birch (*Betula papyrifera* Marshall).

The fire regime of the study area — one of the most active in Canada — is dominated by infrequent large and intense fires, more than 80 percent of which occur between May and August (Weir *et al.* 2000; Parisien *et al.* 2004). Although lightning-ignited wildfires are frequent and are responsible for most of the area burned, humans ignite most fires and have had a marked impact on the fire regime since colonization (Weir and Johnson 1998).

MATERIALS AND METHODS

The Burn-P3 Simulation Model

The Burn-P3 simulation model evaluates BP of large fire-prone areas by simulating the growth of a very large number of fires (Parisien *et al.* 2005).

Individual fires are simulated deterministically for one fire season using the Prometheus fire growth model, and this process is repeated for a large number of iterations (for example, 1000). The Prometheus model calculates the growth of each fire through complex fuels and terrain according to the FBP System (Forestry Canada Fire Danger Group 1992). All other components in Burn-P3 are stochastic: the number of fires per iteration, the location of fire starts, the burning conditions, and the burning period, and are determined from historical fire and weather databases (see below). The locations of fire starts were random, but lighting-caused and human-caused fires were distinguished, to prevent lightning ignitions in deciduous fuels. No fire starts were allowed in the grass fuel type, most of which is farmland, where very few large fires occur (P. Maczek, personal communication).

In a Burn-P3 run, fires are simulated according to a given set of landscape (fuels and topography, although the latter was not used in this study because of the relatively flat terrain of the study area), fire, and weather inputs for an iteration and recorded in a grid. This process is repeated for each iteration, and the grids of all iterations are compiled in a cumulative grid of area burned. Several internal Burn-P3 settings (for example, daily hours of burning, curing of grass fuels) were heuristically adjusted to produce a fire size distribution similar to the historical distribution (compare with Parisien *et al.* 2004).

The BP in a given cell *i* is calculated as follows:

$$BP_i = \frac{b_i}{N} \times 100$$

where b_i is the number of iterations that resulted in cell *i* being burned and *N* is the total number of iterations. BP_i, expressed as a percentage, represents the likelihood of cell *i* being burned in a single fire season. Burn-P3 was used to produce 1000-iteration BP map. A 10-km buffer was added to the study area and subsequently removed from the BP maps to prevent an edge effect.

Data Types

Historical Large-Fire Database

The Canadian Forest Service Large Fire Database (Stocks *et al.* 2003), which consists of points of ignition for all reported fires of 200 ha or more in the period 1959 to 2003, was used to determine the historical number of large fires in the study area. A database of daily progression of 130 large fires that occurred in Saskatchewan between 1991 and 2000 was used to determine the average number of days of significant fire spread or the number of spread event days (4 percent or more of the final fire size) per fire.

Daily Fire Weather

Daily noon observations of temperature, relative humidity, wind speed, wind direction, and 24-h precipitation, as well as the associated fuel moisture codes and fire behavior indices (from the Fire Weather Index System [Van Wagner 1987]), were obtained for 8 weather stations in and around the study area for the period 1990 to 2001. To integrate fire weather into the Burn-P3 model, only daily records for days with fire weather conditions conducive to significant fire spread, defined here as having an Initial Spread Index of 8.6 or more (Parisien *et al.* 2005), were extracted from the database.

Fuel Types

The fuels were represented as a grid of fuel types of the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group 1992). The FBP System categorizes vegetation into 16 fuel types; here, however, fuels were grouped into 5 main types: coniferous, deciduous, mixedwood, grasses, and slash. The coniferous fuel type produces more severe fire behavior than the deciduous fuel type, whereas the flammability of the Boreal Mixedwood fuel type lies between the two. Slash is also highly flammable, but it is uncommon in the study area. The deciduous and mixedwood fuel types are more flammable in the spring, before the deciduous trees leaf out. A map of the fuel groups used in the study is presented in Figure 2, and percent cover is presented in table 1.

Assessment of fuel type dominance

The percent cover of the coniferous, deciduous, mixedwood, and coniferous-mixedwood fuel groups were measured using a moving window

(MW) analysis in FRAGSTATS (McGarigal *et al.* 2002). The MW analysis consists of a round window of a specified radius that “slides” from one cell to the next on the entire grid to perform the required calculation. Three spatial scales (i.e., radii of the MW) based on fire spread calculations were analyzed.

The radius of Scale 1 represents the forward spread (i.e., the distance from ignition to the apex of the fire front) of a fire burning in homogeneous C-2 fuels for 6 hours under high intensity conditions (HFI = 10,000 kW/m) with 90^{th} percentile wind speed in a single direction. Scale 2 also constitutes the forward spread in a single direction, except that it used the harmonic (i.e., combined and area-weighted) rate of spread of all fuel types in the study area. Scale 3 is similar to Scale 1, except that the wind direction changes perpendicularly after 3 hours of burning (i.e., one of the fire’s flanks becomes the front). Scales 1, 2, and 3 represent 5749 m, 3400 m, and 2579 m, respectively. The reason for using these three scales is that they represent significant daily fire spread that could be achieved by a large fire.

The MW analysis for each scale and fuel group produced a grid of continuous values having the same resolution of the sampled fuel grid. Percent cover values could therefore be compared to the BP values of the control BP map. The relationship BP and fuel cover were quantified using Pearson correlations and the best relationships were displayed graphically in plots of BP v. percent cover.

RESULTS AND DISCUSSION

Of the 3 scales of the MW used to calculate the fuel dominance maps, Scale 3 (5749-m radius) yielded the highest correlation between fuel dominance and BP for all fuel type groups, suggesting that this relationship operates at a large spatial scale. It is possible that the most significant scale is even larger than that of Scale 3, but this remains to be assessed. However, the differences between highest and lowest correlation coefficients of each fuel group between scales were small (differences range from 0.015 to 0.041), suggesting that the correlation would not be much stronger if many more scales had been assessed. In any case, the observed correlations between BP and the proportion of coniferous, coniferous/mixedwood, and deciduous fuels (negative correlation) was surprisingly high (Fig. 4), given the other spatial factors that are likely to influence BP (for example, the shape of fuel patches, or the effect of lakes).

The strong correlation of BP to the proportion of coniferous fuels supports the assertion that large tracts of coniferous fuels are ‘danger areas’ in terms of potential fire spread (Fig. 4a). Conversely, the BP is effectively reduced as a function of the proportion of deciduous fuels (Fig. 4), which also supports common knowledge that large deciduous areas act as natural fuel treatments. However, it must be acknowledged that fires have burned most of the deciduous parts of the study area, despite their lower level of ignitions (*cf* ignition rules) and flammability. The proportion of coniferous-mixedwood fuels also had a strong correlation to BP (Fig. 4), and although only mixedwood had an expectedly poor correlation to BP, these fuels do contribute to increase BP when they are embedded in a largely deciduous landscape, as in the southern part of the study area (Fig. 4).

A more in-depth look into the relationship between BP and the proportion of fuel types reveals a somewhat linear increase of BP with the dominance level of coniferous fuels and a crude exponentially-decreasing relationship with the proportion of deciduous fuels (Fig. 5) for Scale 3. In fact, our results suggest that at the scale of our MW analysis (10 383 ha) a 20-30% proportion of deciduous fuels is enough to markedly reduced the regional BP, although this is surely highly site-specific and depends, among other factors, on the intermixing of fuels.

Our results also emphasize the importance of identifying the appropriate spatial scale for decision-making regarding fuel treatments (Finney and Cohen 2003). The analysis of fuel type dominance on BP strongly suggests that breaking up large tracts of flammable fuels effectively reduces BP. However, while a fuel type conversion may be appropriate for a small area, such as around a community, it is not always possible or even desirable (for example, ecologically) to treat a sizeable portion of the landscape. Therefore, if the resources are finite it is preferable to concentrate the fuels modifications (prescribed burns, fuel treatments) in strategic areas.

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Table 1. Area and percentage of each fuel group and water within the study area.

Fuel type	Area (ha)	Proportion (%)
Coniferous	511 478	30.9
Mixedwood	268 527	16.2
Deciduous	222 400	13.5
Grass	411 424	24.9
Other fuels	39 847	2.4
Water	199 791	12.1

Figure 1. The study area in central Saskatchewan covering Prince Albert National Park and its surroundings.

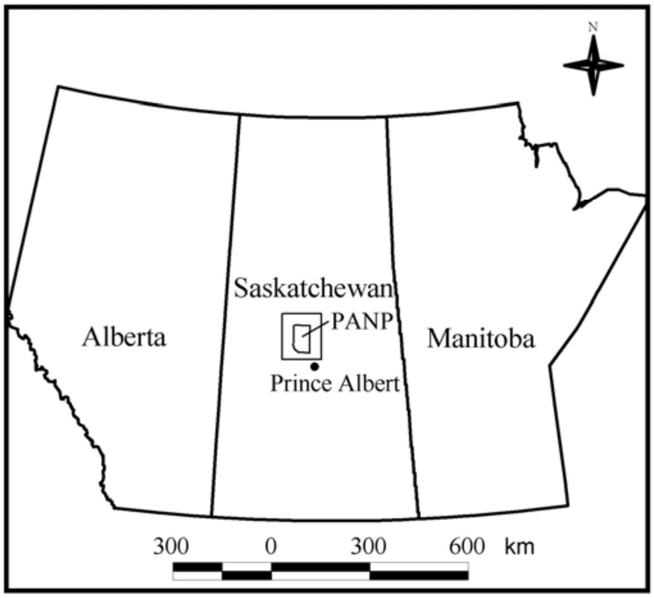

Figure 2. Major fuel groups of the study area.

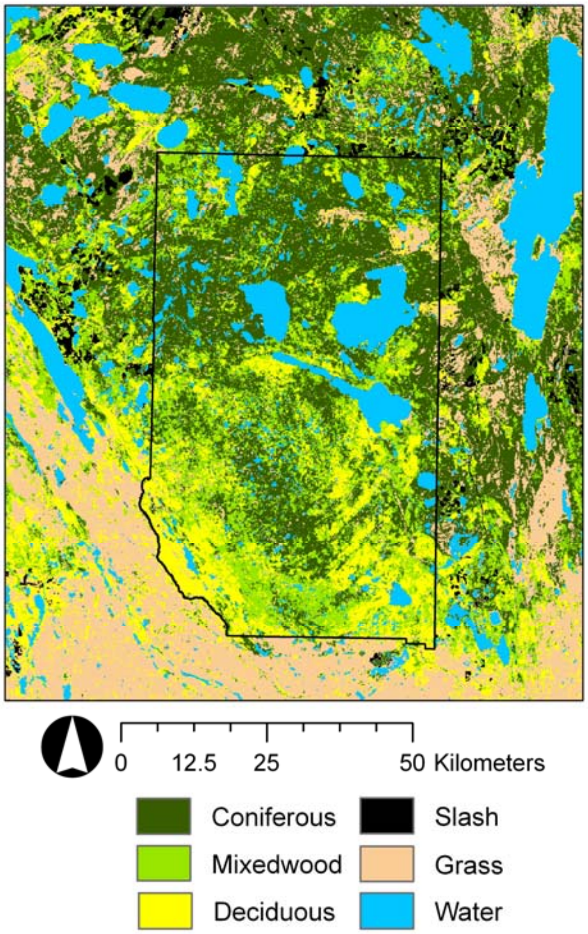

Figure 3. Baseline (i.e., untreated) burn probability in the study area. The black outline represents the boundary of Prince Albert National Park.

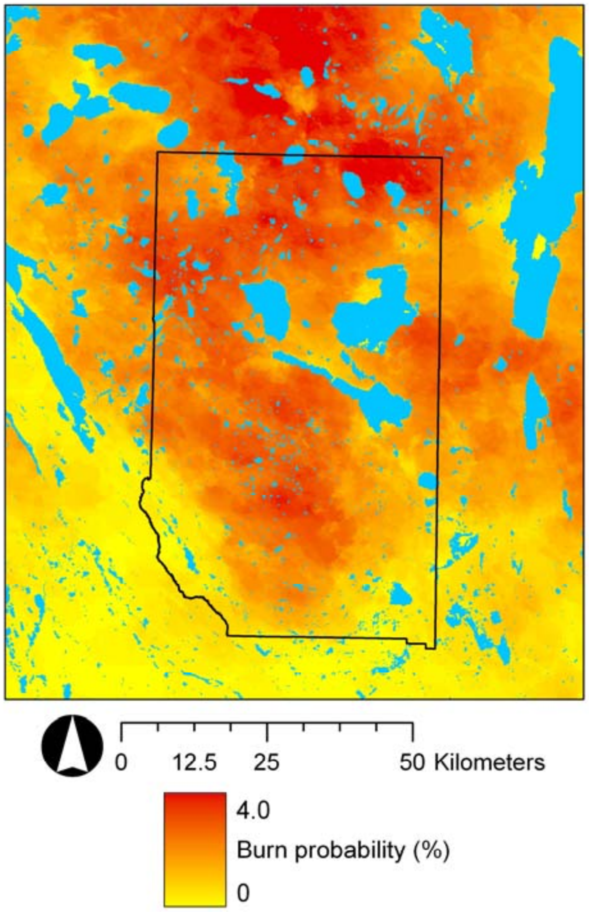

Figure 4. The proportion (percent) of fuel groups calculated in a moving window analysis using Scale 3 (radius = 5749 m). The Pearson correlation coefficient (r) comparing the proportion of fuel type v. burn probability (Fig. 3) for each cell is indicated in the lower-right corner of each map.

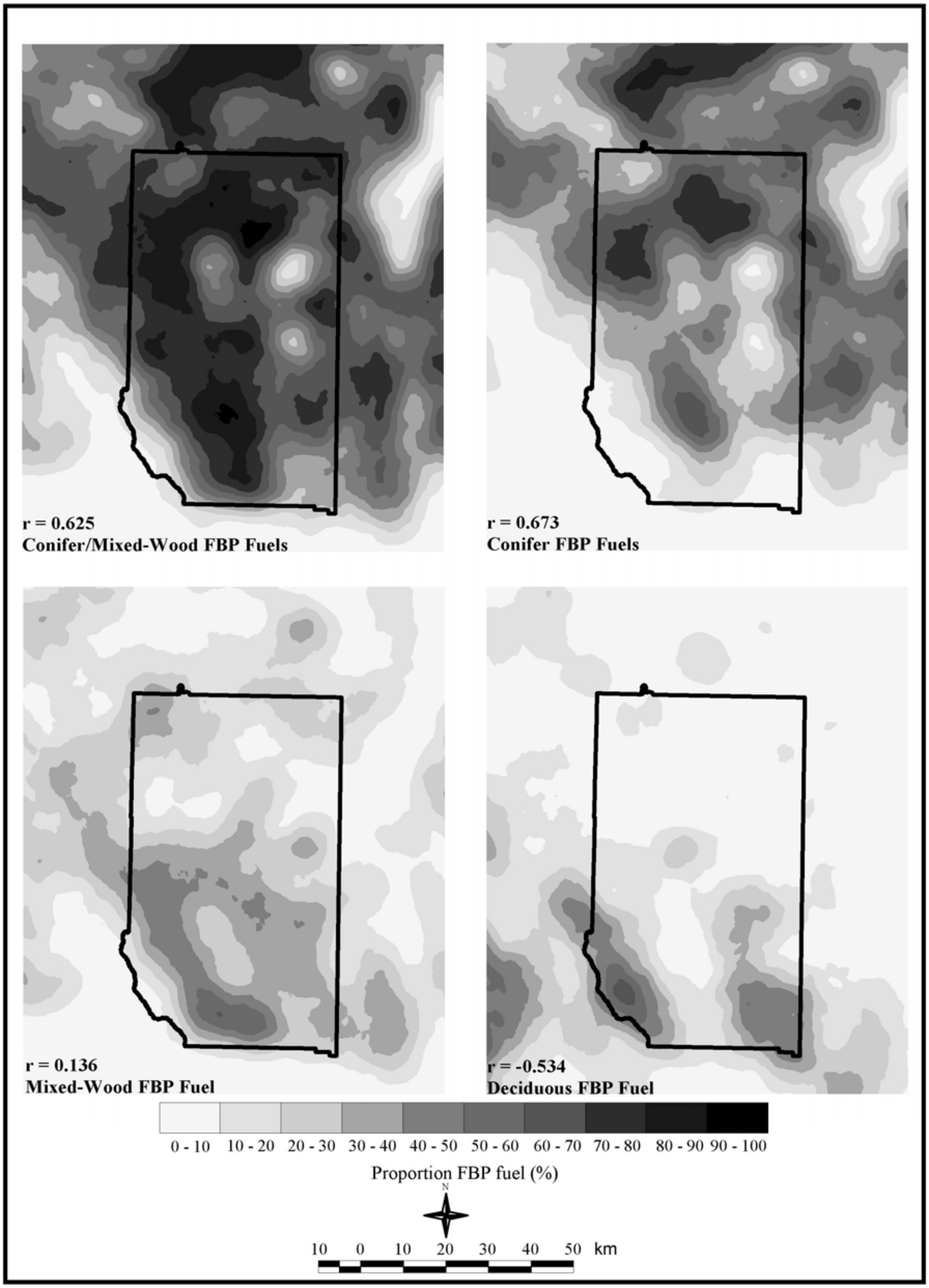

Figure 5. The mean (±SD) burn probability as a function of the proportion of the coniferous (a) and deciduous (b) fuel group.