USING LANDSCAPE-BASED DECISION RULES TO PRIORITIZE LOCATIONS FOR PLACEMENT OF FUEL TREATMENTS IN THE BOREAL MIXEDWOOD OF WESTERN CANADA

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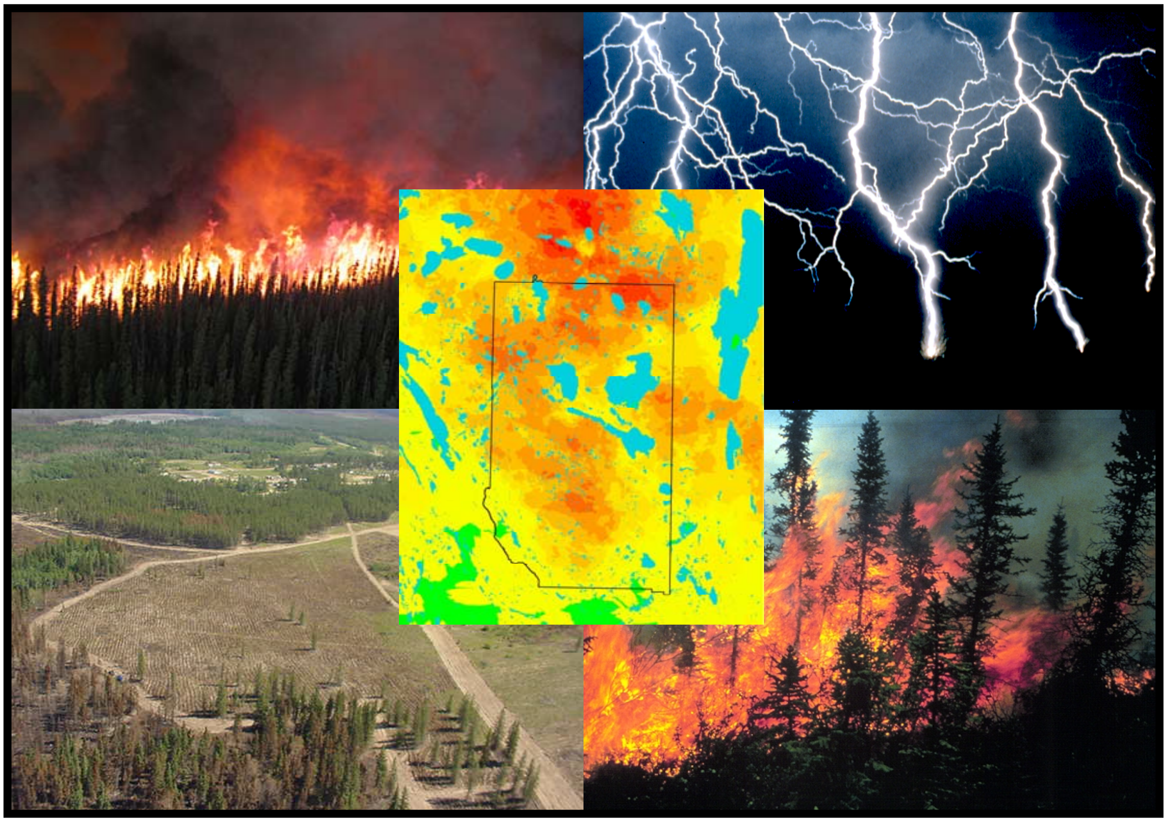

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ABSTRACT

This study used a rule-based approach to prioritize locations for placement of fuel treatments in the boreal mixedwood forest of western Canada. The burn probability (BP) in and around Prince Albert National Park in Saskatchewan was mapped using the Burn-P3 (Probability, Prediction, and Planning) model. Fuel treatment locations were determined according to three scenarios and five fuel treatment intensities. Fuel treatments were located according to jurisdictional boundaries and BP; BP only; and nonflammable landscape features, BP, and fuel treatment orientation. First, a baseline BP map was created from the original fuel grid. Fuel treatments were then added to the grid and BP maps produced for each combination of scenario and treatment intensity. BP values for the treated landscapes were compared with those of the baseline BP map. Results varied substantially among scenarios and treatment intensities. Locating fuel treatments as a function of the jurisdictional boundaries and BP yielded the lowest reduction in BP. These results suggest that clumping fuel treatments within a limited area or using landscape features to maximize the large-scale spatial benefits of the fuel treatments can significantly reduce landscape-level BP. Although these two strategies may produce similar overall reductions in BP, their appropriateness and utility depend on management objectives.

INTRODUCTION

A fuel treatment consists of a stand-level modification of flammable vegetation aimed at reducing specific aspects of fire behavior, such as rate of spread, fire intensity, and fire severity (for example, crown involvement) (Agee *et al.* 2000). This strategy is receiving increasing attention from land managers and scientists in North America, especially since the catastrophic wildland–urban interface incidents of 2003 in Kelowna, BC, and San Diego, CA. Furthermore, the alarming rate of expansion of the wildland–urban interface (Radeloff *et al.* 2005) is forcing managers and policy-makers to find ways of mitigating the negative impacts of large wildfires (Stephens and Ruth 2005).

There is a growing body of evidence on fire behavior responses to fuels modifications from empirical (Pollet and Omi 2002; Finney *et al.* 2005) and simulation (van Wagtendonk 1996; Stephens 1998; Stratton 2004) studies. Although much remains to be learned about fire behavior in fuel-treated areas, a substantial fuel modification will always translate into a change in physical fire processes (Agee and Skinner 2005). For instance, a heavy reduction in crown and ladder fuel load (for example, by reducing tree density or pruning trees) will reduce fuel consumption and hence fire intensity. Similarly, conversion of a flammable coniferous fuel type to a less flammable deciduous fuel type can significantly reduce fire behavior severity and fire size (Hirsch *et al.* 2004). At present, most of the research on fuel treatments in North America is based on stand-level information. However, the spread of large fires is also influenced by landscape-level factors that promote or interrupt fire spread (Mermoz *et al.* 2005), and these factors should be taken into account for fuel treatment design and evaluation.

To this end, equations were developed to determine the optimal shape and size of fuel treatments (Finney 2001). This technique, known as strategically placed areas of treatments (SPLATs), represents the first known spatial extension of this concept and is gaining popularity with managers working in the fire-dominated biomes of North America. Although assessments of effectiveness remain fragmentary, SPLATs reduced fire behavior in two large, high-intensity Arizona fires (Finney *et al.* 2005). The SPLAT design represents an advancement in the science of fuels management, but it does not address such critical landscape-level aspects as the placement of fuel treatments or the most suitable treatment fraction (treatment intensity).

Spatial modeling studies have shown that the connectivity of flammable fuels affects the size of fires (Miller and Urban 2000; Duncan and Schmalzer 2004). From a fuel treatment viewpoint, an increase in the relative proportion, as well as aggregation, of less-flammable fuels reduces the spread of fire (Bevers *et al.* 2004; Loehle 2004), but this approach is often unrealistic on a real landscape. First, a large fraction of the landscape (usually more than 50 percent) must be treated to achieve an appreciable reduction of fire spread; second, the random placement of treatments implies inefficiency (Finney 2003); and third, the shape of these aggregates may be suboptimal and they may therefore provide only a small reduction in area burned.

Despite some preliminary data, the best placement of fuel treatments on the landscape remains a crucial but largely unanswered question. This information is particularly important in the Canadian boreal forest, where fuel treatments may be necessary to reduce the spread of large fires burning at intensities that preclude direct fire suppression. Because financial resources to create fuel treatments are limited, land managers need to quantify fire risk and apply fuel treatments where they are most needed and can meet management objectives (Sanchez-Guisandez *et al.* 2002). A scarcity of spatially explicit tools for long-term strategic planning in fire management has inhibited significant progress, but the recent development of approaches for mapping burn probability (BP), such as Burn-P3 (Probability, Prediction, and Planning) (Parisien *et al.* 2005), represents an opportunity. Reliable estimates of BP are necessary to examine the combined effects of altering the type and spatial configuration of forest fuels.

The goal of this study was to develop and assess a rule-based approach to prioritizing the placement and level of fuel treatments in a boreal mixedwood forest. Our working hypothesis was that incorporating landscape-level features would enhance the effectiveness of fuel treatments. In this article, we explore landscape “recipes” for fuel modifications using the Burn-

P3 simulation model. Our specific objectives were (1) to create a BP map for the study area, (2) to identify areas where the effectiveness of fuel treatment could be maximized, and (3) to assess the relative benefit of increasing treatment intensity (that is, total area treated). The results are discussed in the context of current land management objectives for the study area.

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 (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). The main fire management policy in the area consists of aggressive initial attack of small fires and fire suppression operations aimed at limiting fire spread. However, in recent years Parks Canada has committed to restoring the fire regime in PANP (Weir and Pidwerbeski 2000) to achieve a level of burning similar to that of historical fire cycles and thereby maintain ecological integrity (Weir *et al.* 2000).

METHODS

Data Types

Three types of data were required as inputs for the Burn-P3 analysis: records of historical large fires, daily fire weather conditions, and fuel 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.

Fuel Treatment Dimensions

Fuel treatment dimensions were determined according to the SPLAT design (Finney 2001). In brief, this design consists of multiple treatment units (blocks) that are less flammable than the surrounding forest. The aim of a SPLAT is to slow down the fire front and promote flanking, thereby reducing forward spread of the fire. The width (*W*) and length (*L*) of the treatment units are based on estimates of typical forward fire spread (*D*) (the distance between the point of ignition and the fire front), the distance between rows of treatment units (*S*), the overlap between units (*O*), and the angle at which the units are slanted (Fig. 3) (see Finney 2001 for details). The dimensions of the treatment units are arbitrary as long as their spatial configurations are adjusted according to the SPLAT design equations; however, the units must be large or numerous enough to significantly reduce fire spread.

The fuel treatments in this study consisted of 3 rows of treatment units for deciduous fuels (Fig. 3b). The SPLAT dimensions were calculated for high-intensity wind-driven fires (10 000 kW/m and 90th percentile winds) in coniferous forests, which represent the threshold conditions above which direct fire suppression is impossible. We used a consistent SPLAT design so that our analysis of treatment location and intensity would not be obscured by design factors. We opted for a conversion to the deciduous fuel type as a treatment because it provides a realistic yet effective way to reduce fire spread in the boreal mixedwood (Hirsch *et al.* 2004) and its fire behavior characteristics are well known. In addition, we selected treatment unit dimensions similar to those for typical cutblocks in the boreal forest, where *W* = 300 m and *L* = 900 m (total area = 27 ha). The separation (*S*) between unit rows was set at 200 m and the units were angled at 20°. These dimensions were consistent throughout the study, but the overall length of the area with multiple fuel treatments varied according to location on the landscape, as dictated by the scenarios.

Modeling Scenarios

We developed three modeling scenarios from different sets of decision rules for SPLAT placement and tested each of them according to 5 treatment intensities: 1500, 3000, 4500, 6000, and 7500 ha. A baseline BP map was produced from the original fuel grid to guide placement of the fuel treatments. In all scenarios, the deciduous fuel treatments had to be embedded in areas dominated by coniferous or mixedwood fuels.

In the first (boundary) scenario, fuel treatments were positioned exclusively around the periphery of PANP. The 7500-ha treatment intensity covered the entire periphery of PANP where it was dominated by coniferous and mixedwood forest (Fig. 4a). The second rule specified that SPLATs for the other treatment intensities would be positioned as a function of the highest value of BP in the baseline BP map.

In the second (BP-only) scenario, SPLATS were located solely as a function of BP. To identify the areas of highest BP, the values of the baseline BP map were “contoured” by intervals of 0.5 percent. The 1500-ha area class was thus associated with the highest BP region, the 3000-ha with the highest and second-highest BP regions, and so on. To entirely cover the areas of high BP, the 3-row fuel treatments were stacked in a clustered, rather than linear layout. As a result, the SPLATs for the 7500-ha area class corresponded to 3 very large areas of high BP and several smaller localized areas (Fig. 4b).

Unlike the first two scenarios, the third (lake-linking) scenario located SPLATs according to a hierarchal set of rules based on the linkage of nonflammable landscape features (lakes), the highest BP values, and the most suitable orientation of fuel treatments. Fuel treatments were used to connect large lakes that were no more than 20 km apart, an arbitrary maximum distance that is realistic for landscape-level fuel treatments in the area. The minimum lake size to be considered was determined by classifying areas of the BP map as having either above-average or below-average BP and calculating the frequency of lakes of different sizes (in 50-ha classes) that were adjacent to below-average BP areas. Using this method, we determined that lakes of 350 ha represented the smallest size class in which all lakes were adjacent to areas with below-average BP. Among all possible links between lakes, prioritization occurred as a function of BP, as in the

BP-only scenario, except that in the lake-linking scenario the fuel treatments were not stacked (Fig. 4c). The final rule was that if multiple fuel treatments were identified for a BP contour, priority was given to the fuel treatments that had an angle of 45° (that is, spanning the northeast–southwest axis), the orientation perpendicular to the most likely direction of large fire spread (Parisien *et al.* 2004).

The SPLATs for each combination of scenario and treatment intensity were added to the original fuel grid in a geographic information system to create a total of 15 modified fuel grids. When the SPLATs were added, cells in the grid that were classified as water, nonfuel, or already deciduous were not replaced. Because it was nearly impossible to obtain exactly the targeted treatment area (for example, 7500 ha), we allowed a variation of 100 ha for each treatment intensity.

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). Burn-P3 models only large fires because these fires are responsible for virtually all of the area burned in Canada (Stocks *et al.* 2003). 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 elliptical growth of each fire through complex fuels and terrain according to the FBP System (Forestry Canada Fire Danger Group 1992) and fire spread mechanisms (Richards 1995). Fires are recorded in Burn-P3 only if they reach 200 ha. 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.

The number of fires per iteration was input as a frequency distribution of the number of fires of at least 200 ha per year (mean 1.06 fires/year), stratified by two seasons: spring (April 1 to May 31) and summer (June 1 to August 31). 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). The duration of the burning period for each fire was input as an exponential frequency distribution, on the basis of the average number of spread event days from the daily fire progression database (mean 3.8 days). Burning conditions were randomly drawn from a database of daily fire weather conditions conducive to fire growth for each spread event day.

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.* 2005).

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

$$BP_i = \frac{b_i}{N} \times 100 \qquad [1]$$

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.

Analysis

Burn-P3 was used to produce 1000-iteration BP maps for the original grid with unmodified fuels (the baseline BP map) and for each combination of scenario and treatment intensity. A 10-km buffer was added to the study area and subsequently removed from the BP maps to prevent an edge effect.

The results for each combination of scenario and treatment intensity were compared with those of the same areas in the baseline BP map. The comparison areas consisted of the SPLATs and 2-km buffers around them. The buffer distance was selected through comparison of the BP response at several buffer distances. The mathematical comparison of the treatment BP maps with the baseline BP map was a step-wise process. In the equations below, the scenarios are denoted as *j*, where scenarios 1, 2, and 3 are expressed as *j* = {1,2,3}, respectively, and the treatment intensities are denoted as *k*, where the *k* = 0 treatment intensity refers to the baseline BP map, and the baseline and 1500, 3000, 4500, 6000, and 7500 ha treatment intensities are expressed as *k* = {0,1,2,3,4,5}, respectively.

First, the mean BP, $\overline{BP}_{jk}$, for each buffered area was defined as follows:

$$\overline{BP}_{jk} = \sum_{i=1}^{n} \frac{b_{ijk}}{n_{jk}} \qquad [2]$$

where b_{ijk} is the value of BP for any given cell *i* for the scenario *j* and the treatment intensity *k*, and n_{jk} is the total number of cells in the buffered area for each combination of *j* and *k*.

The calculated values of $\overline{BP}_{jk}$ were then standardized as follows:

$$\overline{BP}(s)_{jk} = \frac{\overline{BP}_{jk}}{\overline{BP}(t)_{jk}} \qquad [3]$$

where $\overline{BP}(s)_{jk}$ represents the standardized $\overline{BP}_{jk}$ for each combination of *j* and *k*, and $\overline{BP}(t)_{jk}$ is the mean BP of the total of all cells in the baseline BP grid of *j* and *k*. The purpose of standardization was to account for background variability in $\overline{BP}_{jk}$ among BP grids. Although this variability is usually minimal, it can partially obscure the patterns of reduction in BP observed between treatment and baseline BP.

Finally, the relative difference (i.e., reduction) in $\overline{BP}_{jk}$, ΔBP_{jk}, expressed as a percentage, was calculated using the following equation:

$$\Delta BP_{jk} = \frac{\overline{BP}(s)_{jk} - \overline{BP}(s,u)_{jk}}{\overline{BP}(s,u)_{jk}} \times 100 \qquad [4]$$

where $\overline{BP}(s,u)_{jk}$ is the mean BP calculated for the area corresponding to each combination of *j* and *k* in the baseline BP map.

In an additional analysis, the values of ΔBP_{jk} were adjusted for area in terms of an arbitrary comparison area (50 000 ha) to assess the spatial "coverage" of the different fuel treatment layouts. The area A_{jk} (in ha) was obtained for each buffered fuel treatment of scenario *j* and treatment intensity *k*. Then, an area factor, $F(A)_{jk}$, was calculated as follows:

$$F(A)_{jk} = \frac{A_{jk}}{5 \times 10^4 \, ha} \qquad [5]$$

The area-adjusted mean change in BP (ΔBP_{jk}), $\Delta BP(a)_{jk}$, was obtained for each *j* and *k*:

$$\Delta BP(a)_{jk} = \Delta BP_{jk} \times F(A)_{jk} \qquad [6]$$

The resulting ΔBP_{jk} and $\Delta BP(a)_{jk}$ were plotted as a function of treatment intensity for each scenario.

RESULTS AND DISCUSSION

The baseline BP map had localized areas of high and low BP (Fig. 5). High-BP values were usually found in conifer-dominated areas. The relative reduction in BP for treated landscapes varied substantially by scenario and by treatment intensity (Fig. 6a). At all treatment intensities, the boundary scenario yielded the lowest reduction in BP. A larger relative reduction in BP was expected at the lower treatment intensities because the minimum treatments were linked to areas where fuel treatments would be most needed (high BP). That this was not borne out for the boundary and BP-only scenarios suggests that there are optimal treatment intensities for large-scale effectiveness of SPLATs. The SPLATs in some locations did not always yield an important reduction in BP (not shown), especially for the boundary scenario. Some of the treated areas at the PANP boundary were virtually unaffected by the fuel treatments, which suggests that locating linear SPLATs as a function of jurisdictional boundaries and BP represents a poor option. This outcome may be due to a number of factors, notably the ineffectiveness of SPLATs that are oriented parallel to an oncoming fire (Finney 2001) and the critically low portion of the landscape treated (Bevers *et al.* 2004; Leohle 2004).

Without adjustment for area, the 6000-ha and 4500-ha treatment intensities for the BP-only scenario performed the best, with a BP reduction of more than 40 percent (Fig. 6a). The 7500-ha treatment intensity did not yield as high a reduction in BP because the small, isolated clumps of fuel treatments (Fig. 4b), which were not retained with the smaller treatment intensities, were unsuccessful in reducing BP. Large fires presumably wrapped around these clumps readily. In contrast, bigger clumps were highly effective at reducing BP, which suggests that stacking fuel treatments is effective in reducing BP. These stacked SPLATs not only represented greater impediments to fire spread, but also were more versatile in terms of reducing the spread of fires burning from a range of directions.

The observed reduction in BP in the lake-linking scenario was fairly constant among treatment intensities, but this scenario was more effective at the 3000-ha and 1500-ha treatment intensities than the other two scenarios (Fig. 6a), which suggests that this set of decision rules would be superior to the others when only a small area can be treated. The reduction in BP with the lake-linking scenario would also be much higher if the BP reduction around the lakes to which the fuel treatments were linked had been considered in the calculation of the buffered fuel treatment area. Furthermore, the compound effect of closely spaced fuel treatments on BP reduction in this scenario (Fig. 7) suggests a synergistic effect of adjacent placement of fuel treatments. However, to maximize the treated area, managers should avoid placing too many treatments in the same locations. There is thus a need to evaluate the optimal proximity of neighboring fuel treatments.

The high effectiveness of the lake-linking scenario supports previous suggestions that one of the most effective layouts of fuel treatments is one that compartmentalizes areas of high wildfire susceptibility (Agee *et al.* 2000; Hirsch *et al.* 2004). One way to determine the most suitable compartments is to take into account the spatial effects of SPLATs on BP reduction (Fig. 7). The 2-km buffer proved appropriate for the analysis and was consistent with a field study reporting a marked decrease in fire frequency within a 2-km radius around large lakes in the boreal forest of Quebec (Cyr *et al.* 2005). However, the reduction in BP may extend far beyond the 2-km buffer, depending on several spatial features of the landscape (Parisien *et al.* 2003). Consideration of the scale of BP reduction would certainly have favored the lake-linking scenario in this analysis.

The potential benefits of fuel treatments are explicitly linked to their area of influence or spatial coverage, which is far greater for the buffered area of the boundary and lake-linking scenarios than for the BP-only scenario (85 794, 91 917, and 63 290 ha, respectively), where the fuel treatment buffers are “shared” among rows of treatments because they are stacked. High spatial coverage thus extends the effects of the treated areas to a larger proportion of the landscape. If an area adjustment is taken into account in the BP reduction, the lake-linking scenario performed the best in terms of BP reduction for all but the 1500-ha treatment intensity (Fig. 6b), where all three scenarios performed equally.

IMPLICATIONS FOR LAND MANAGEMENT

The classic definition of wildfire risk considers two components, BP and potential impacts (Finney *et al.* 2005). At present, the main challenge in estimating wildfire risk is that few approaches provide a quantitative estimate of landscape-level BP. However, according to Finney (2005), without this measure “it is not possible to estimate the cost-effectiveness of management activities that may be proposed for mitigating potential fire impacts.” In this respect, BP modeling represents an important advance in assessing wildfire risk. The strength of this approach is that it allows us to directly measure the change in BP that results from landscape modifications, such as fuel treatments, prescribed burns or wildfires, and changes in land use.

Given the costs of implementing SPLATs over a large area, a tool such as Burn-P3 can provide valuable new information to land managers. A BP map is very useful in itself, but is perhaps most helpful when used in “what if” scenarios of landscape change (Miller 2003), as showcased in this study. In the PANP area, where fire and land management policies differ substantially within and outside the park, strategic management planning can be challenging, especially given the high numbers of large fires. Our results strongly suggest that simple decision rules based on in-depth knowledge of an area and its fire environment provide a robust framework for SPLAT placement and that the straightforward nature of this approach makes it simple to explore and implement. However, we acknowledge that much could be learned by combining these methods with more sophisticated ones, such as spatial optimization (Zuuring *et al.* 2000) and succession modeling of fuels (He *et al.* 2004).

Even at the 7500-ha treatment intensity the overall treated area was small relative to the entire study area. Converting 7500 ha of coniferous and mixedwood forest to deciduous forest appears to represent a massive effort, but in most of the commercial forest of western Canada, it could easily be achieved, given the extensive harvesting and site preparation associated with forestry operations. In fact, Stratton (2004) suggested that fuel treatment units could be shaped like forest patches without significantly affecting the benefits of fuel treatments. Where there are no forestry operations, as in PANP, fuel conversion could be an alternative in strategic areas because it requires minimal maintenance. However, the use of prescribed burns as a fuel treatment, either alone or combined with deciduous conversion, is preferred, because it also contributes to restoring the historical fire regime.

Ideally, the effectiveness of fuel treatments should be measured not only by their effect on BP but also by the reduction in fire behavior potential. Although the decision rules of the BP-only and lake-linking scenarios produced appreciable reductions in BP (more than 40 percent in some cases), in reality fires would rarely burn freely: some level of fire suppression, even minimal, would be undertaken. In fact, the purpose of fuel treatments in PANP is largely to enhance fire suppression operations (Weir and Pidwerbeski 2000). If the rate of spread and fire intensity can be markedly reduced by fuel treatments, fire suppression is more likely to succeed Furthermore, the treated areas can be used for indirect attack to contain burnout operations, a technique that is widely used by boreal fire management agencies.

Our results emphasize the importance of identifying the appropriate spatial scale for decision-making regarding fuel treatments (Finney and Cohen 2003). At a local landscape scale, it appears that the clumping of fuel treatments is the most effective way to reduce BP. In fact, at an even smaller scale (for example, in a single community) it is often feasible to concentrate fuel management efforts and reduce the BP to almost zero, effectively creating a “fuel break.” By contrast, at a larger spatial scale it is not always possible or even desirable (for example, ecologically) to treat a sizeable portion of the landscape. If resources are finite, it is preferable to spread out the potential benefits of fuel treatments by using strategic decision rules. Moreover, at a large spatial scale, a decision scheme like that of the BP-only scenario may position fuel treatments where they are not needed, whereas the lake-linking scenario not only extends the spatial coverage of the treatment but also is more flexible in terms of identifying adequate fuel treatment locations. Comparison of the observed BP reduction among scenarios also suggests that the use of nonflammable landscape features in our decision rules is highly profitable, which further exemplifies the importance of using spatial data in decision-making for placement of fuel treatments.

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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.

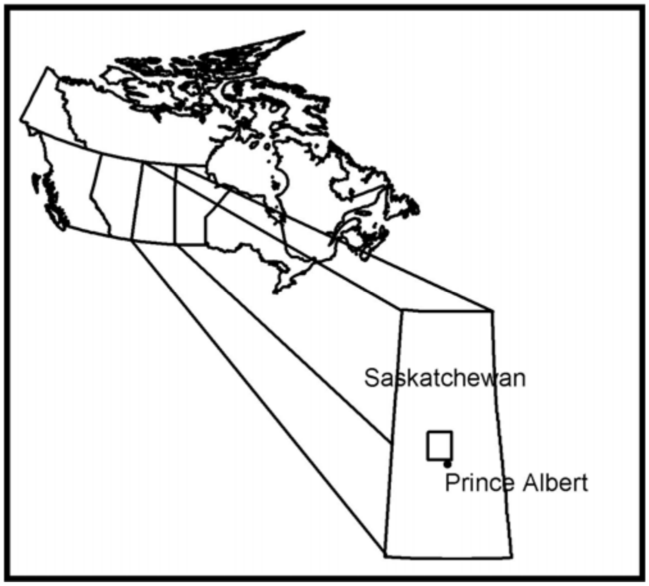

Figure 2--Major fuel groups of the study area.

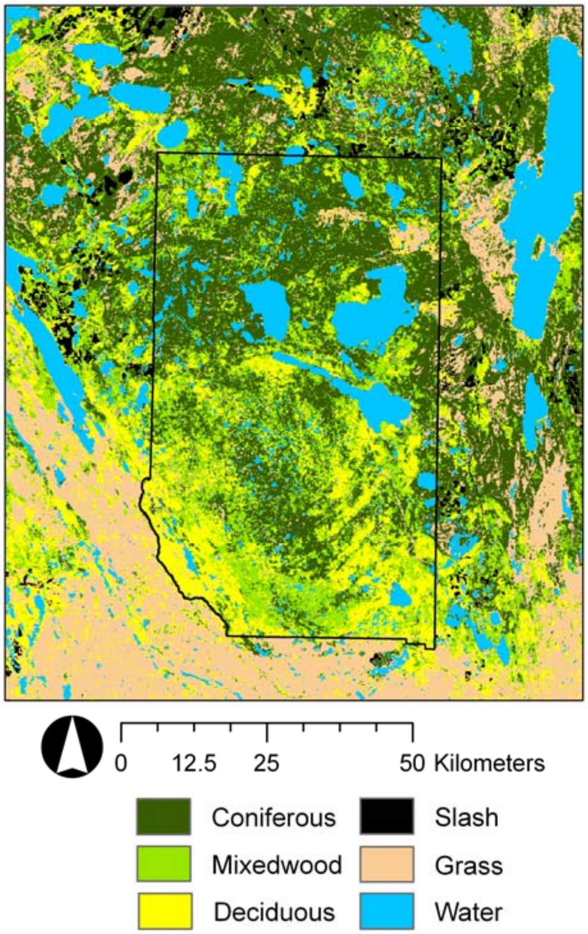

Figure 3--(a) A multiple "nonslanted" fuel treatment design, where *W* (width) and *L* (length) define the dimensions of each unit (i.e., block). The location of units in relation to each other is determined by the overlap (*O*) and separation distance (*S*) between unit rows. (b) Slanted units, as used in this study, are inclined at an angle (θ) to block openings through the pattern. Both fuel treatments consist of three rows, or superimposed layers of treatment units. This figure was modified from Finney 2001.

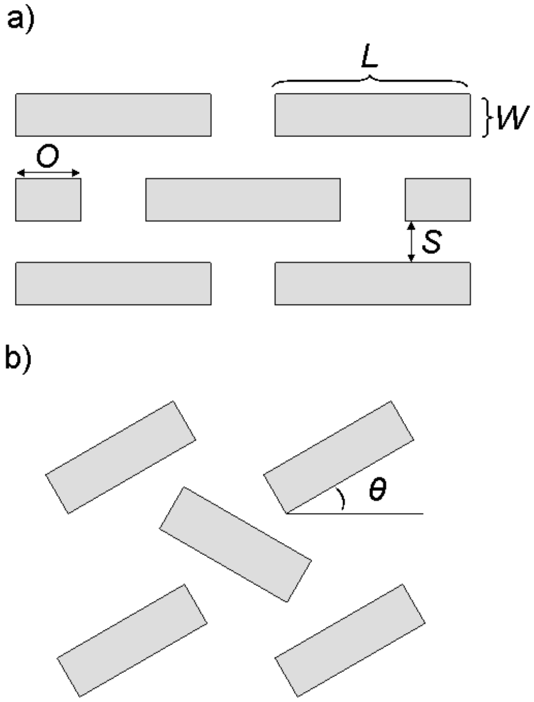

Figure 4--The fuel treatments (in black) for the boundary scenario (a), BP-only scenario (b), and lake-linking scenario (c) for the 7500-ha treatment intensity. The black outline represents the boundary of Prince Albert National Park; lakes are shown in gray. BP = burn probability.

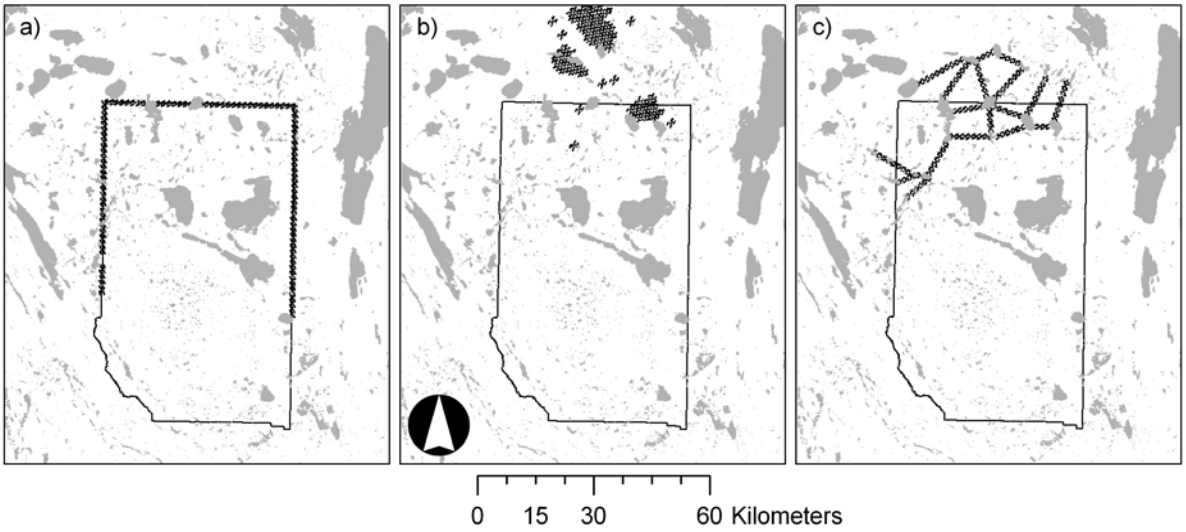

Figure 5-- Baseline (i.e., untreated) burn probability in the study area. The black outline represents the boundary of Prince Albert National Park.

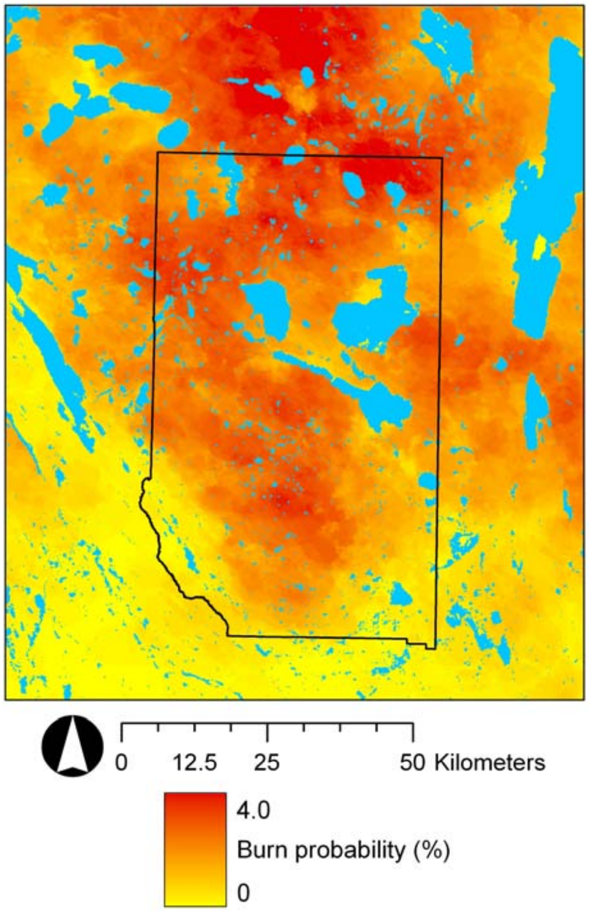

Figure 6--The relative reduction in burn probability as a function of decreasing treatment intensity by scenario without (a) and with (b) an area adjustment to 50 000 ha.

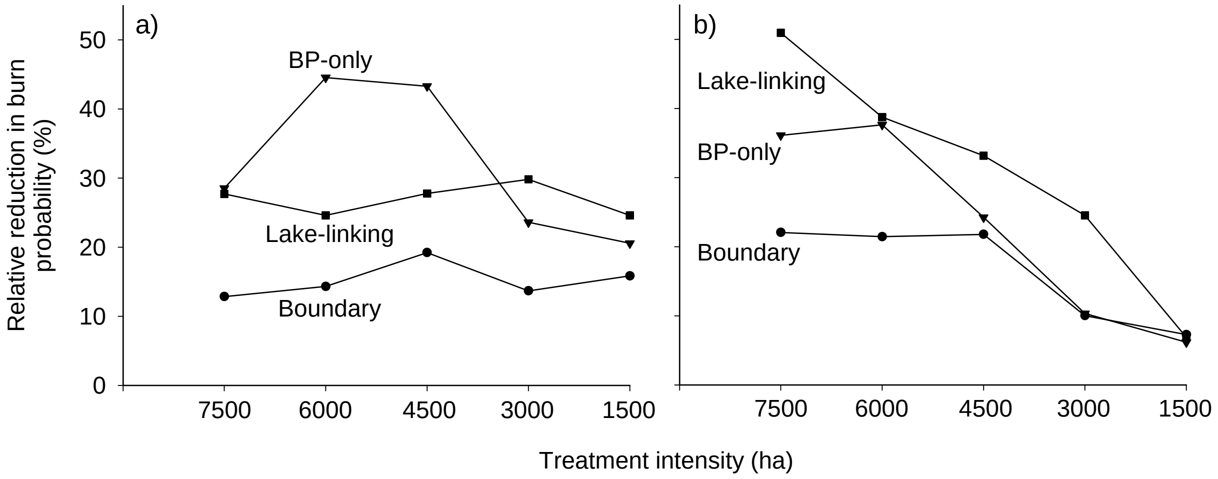

Figure 7--Part of the burn probability map of the baseline (i.e., untreated) landscape (a) and the same part of the burn probability map of the treated landscape with the lake-linking scenario (b) for the 7500-ha treatment intensity. The overlaid fuel treatments are shown in black.