

# Maintaining A Natural Fire Regime Within Protected Areas in the Boreal Forest

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## Introduction

Because of its remoteness, much of the boreal forest in Canada remains relatively pristine (GFWC, 2000). However, over the past decade there has been a dramatic increase in the development of access and the rate of industrial activity in this region (AEP, 1998). This has prompted several provinces to implement processes for establishing protected area networks as a safeguard for maintaining biodiversity.

Fire is the dominant disturbance agent in the boreal forest and is responsible for much of the structure, pattern, and ultimately biodiversity, present in boreal landscapes (Johnson et al, 1998). It follows that a key design consideration for protected areas in the boreal forest is the maintenance of a natural fire regime (Noss, 1992). Unfortunately, there has been very little scientific inquiry into what size of protected area is necessary for maintaining a natural fire regime, leaving planners with little guidance. The few reports that exist provide only qualitative conclusions suggesting that protected areas need to be substantially larger than the largest disturbances (Pickett and Thompson, 1978, White, 1987, Baker, 1992).

The objective of this study was to provide quantitative data that would assist planners design protected areas capable of maintaining the natural disturbance regime typical of boreal systems. To do this I constructed a computer model to simulate the occurrence of fires within protected areas of differing size classes. The data used in the model were from northern Alberta, but the findings should be applicable in other boreal landscapes.

## Methods

The study area was northern Alberta and data on fire sizes were derived from the provincial fire database (<http://envweb.env.gov.ab.ca/env/forests/fpd>). The entire study area is comprised of boreal forest (Rowe, 1977). Only data for Class E fires (i.e., > 200 ha; n = 622) were used, as these fires accounted for 98% of the area burned. In the model the study area, protected area, and fires were all simulated as square grids with internal cell size of 1.0 ha. For each model run fires were sequentially initiated in randomly selected cells within the study area. The number of fires per year and the size of each fire was determined by sequentially reading from a list of all class E fires in the fire database. After each fire the number of overlapping cells, if any, between the fire (centered on the

initiating cell) and the protected area (located in the center of the study area) was recorded as the observed size of fire within the protected area.

The relevant time period for the simulation was considered to be the time that it takes for trees to reach old-growth status. For boreal mixedwood forests this stage begins at around 100 years post disturbance (Timoney, 1998). To achieve this time period the provincial database, which only had 37 years of data, was resampled three times, giving a total run length of 111 years.

The model was calibrated to produce the rate of burning recorded in the provincial fire database (0.41% per year) by adjusting the size of the study area (to account for water and other non-burnable areas). The final study area was 335,000 km<sup>2</sup>. The investigation was focused on comparing and contrasting the occurrence of fire in protected areas of 500 km<sup>2</sup> and 5,000 km<sup>2</sup>. The 111-year runs were repeated 1,000 times for each size class, to capture the anticipated variability in fire occurrence among runs. The runs were repeated using twice as many fires per 111-year run to simulate a scenario of twice the historical rate of burning.

Because the 37 years of fire data available for this study may not adequately represent the long-term mean distribution of fire sizes that occur in northern Alberta I repeated the simulations using fire sizes derived from a truncated negative exponential distribution. The rationale and methodology for this parametric approach is described in Cumming (1999). The model was calibrated to achieve the same rate of burning recorded in the provincial fire database; final parameters were  $s = 2.568$  and  $b = 12.0$ .

## Results

### *Runs using the fire database as input*

Averaging over all 1,000 repetitions, the proportion of the area burned in both the small (500 km<sup>2</sup>) and large (5,000 km<sup>2</sup>) protected areas did not differ from the overall provincial rate (0.41% per year). However, the large protected area captured more fires than the small protected area, simply because of its greater size (Fig. 1). As a consequence, fires greater than 500 ha occurred every 5.1 years in the large area (on average), but only every 35.7 years in the small area. In other words, less than three large forest patches per century were generated in the small protected area.

Another important difference between the two sizes of protected area was in the variability of fire occurrence. This is again apparent in Fig. 1 if one considers the fire history that would have been observed within the 500 km<sup>2</sup> square at different locations. In most spots the rate of burning would have been low or even zero, but a protected area

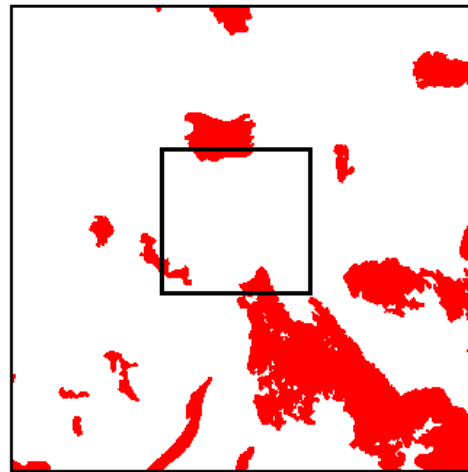


Fig. 1. Class E fires from 1940-1998 in a typical region of northern Alberta. The total area depicted is 5,000 km<sup>2</sup>; the square in the center represents 500 km<sup>2</sup>.

located at the bottom right of the figure would have been almost completely burned over. From a temporal perspective this implies that the occurrence of fire in the small protected area would be more irregular (pulsed) than in the large protected area.

Differences in the patterns of fire occurrence between the two sizes of protected area were confirmed in the computer simulations. In the small protected area the rate of burning among runs followed a negative exponential distribution, whereas in the large protected area a near-normal distribution was observed (Fig. 2). The peak in the final value for the small protected area (Fig. 2) implies that the distribution has an extended tail that has been collapsed into a single value.

When the simulated rate of burning was doubled to 0.82% per year the rate of burning among runs in the small protected area was relatively evenly distributed among most rate categories, though a declining probability was apparent in the highest categories (Fig. 3). In the large protected area the rate of burning among runs followed a well-defined normal distribution (Fig. 3).

### ***Runs using the negative exponential distribution as input***

There were no significant changes when the runs were repeated using a negative exponential distribution to generate fire sizes. However, because of a reduction in

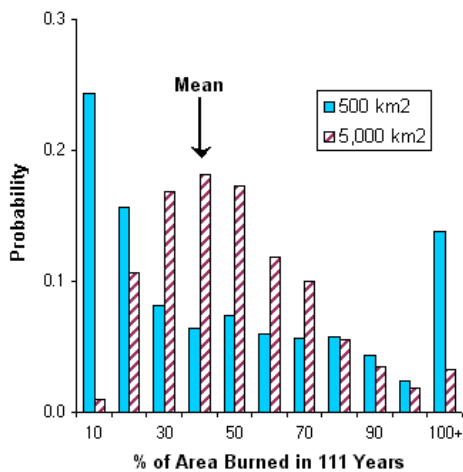


Fig. 2. Probability distribution of the percentage of a protected area burned over 111 years with annual rate of burning = 0.41% (i.e., historical mean).

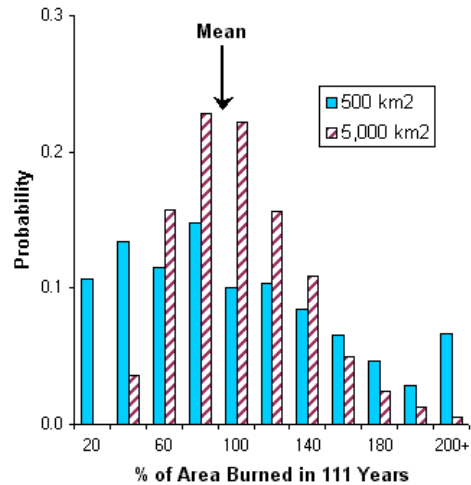


Fig. 3. Probability distribution of the percentage of a protected area burned over 111 years, with annual rate of burning = 0.82% (i.e., twice the historical rate).

sampling noise, the underlying negative exponential and normal distributions in the small and large protected areas, respectively, became slightly more apparent (data not shown).

## Discussion

Fire models typically incorporate far more detail than the model used in this study. For example, instead of simply assuming that fires are square in shape and burn randomly across the landscape, fire ignition and spread are often linked to fuel type and local weather conditions (e.g., Hely et al., 2001). However, the current study was not concerned with predicting the patterns of individual fires under varying conditions. Instead, the intent was to focus on, and isolate, the influence of protected area size on the observed occurrence of fires, given a fire regime "typical" of the boreal forest. For this purpose the model design was appropriate.

Averaging over all 1,000 repetitions the percentage of area burned in both the small (500 km<sup>2</sup>) and large (5,000 km<sup>2</sup>) protected areas was similar to the long-term mean for the entire study area (i.e., northern Alberta). This finding verifies the function of the model, but has little ecological relevance. The issue of importance for protected area design is the amount of burning that is likely to occur in an ecologically meaningful period of time, such as the time that it takes for a forest stand to reach old-growth status. Using this measure, the patterns of burning between small and large protected areas were found to be fundamentally different. In particular, the rate of burning among runs followed a negative exponential distribution in the small protected area, compared with a normal distribution in the large area. In practical terms, this means that the occurrence of fire was much more variable in the small area compared with the large area. There were also far fewer large fires in the small area than in the large area.

The observed differences can all be explained on the basis of the number of fires that each area was able to "capture". Because there were only a few fires in the small protected area in any given 111-year run, the total area burned per run was largely determined by the size of the individual fires that occurred. Consequently, the distribution of the area burned among runs followed the same negative exponential distribution as the fire-size database used as input. In the large protected area the number of fires per run was sufficiently large that individual fires did not have an overriding influence on the total area burned per run. The observed normal distribution was a simple consequence of the Central Limit Theorem (Snedecor and Cochran, 1980, p. 45).

It follows from the aforementioned mechanisms that the rate of burning in the small protected area would also stabilize and follow a normal distribution if the rate of burning was high enough. However, even doubling the historical rate of burning for the entire 111-year run was not sufficient for this to occur. The rate of burning required for stabilization would likely be so high as to result in the conversion of the boreal forest into aspen parkland (Hogg and Hurdle, 1995).

Because fire is highly variability in its occurrence, both spatially and temporally (Bergeron et al., 1998; Armstrong, 1999), it is not possible to specify an exact size of protected area required to maintain a natural fire regime. Such a determination must take into account ecological objectives and the acceptable risk of failure. If the ecological objective is to maintain representation of all forest patch types, then the results of this study suggest that protected areas of 500 km<sup>2</sup> will be deficient. In protected areas of this

size most burning occurs in pulses, typically resulting in either inadequate or extreme amounts of burning over ecologically-relevant time periods. In most cases the area burned would either be insufficient or excessive, relative to what is required to maintain patches of all ages and size classes. Maintaining representation of patches of large size would be particularly difficult, if not impossible. The implication is that active management, in the form of fire suppression and/or prescriptive burning, would be required to maintain the full range of patch types in protected areas of this size.

In contrast to the small protected area, the rate of burning in the 5,000 km<sup>2</sup> protected area was found to be relatively stable. There is a high probability that a protected area of this size would maintain the full range of patch sizes and ages.

The few scientific reports that exist on this topic have focused the ecological objective of maintaining the abundance of patch types in a steady-state termed the "shifting mosaic" (White, 1987). In a shifting mosaic landscape the composition of individual patches changes in response to fire and succession, but the overall abundance of each patch type remains stable over time. Several researchers have suggested that protected areas need to be substantially larger than the largest fire to maintain a shifting mosaic (Pickett and Thompson, 1978; White, 1987; Baker, 1992). This would imply a size of perhaps 20,000 km<sup>2</sup> or more in northern Alberta, given that the largest recorded fire in this region exceeded 11,000 km<sup>2</sup> (Tymstra et al., 1997, p.8). However, even areas of this large size may be insufficient. Cumming et al. (1996) found that equilibrium conditions were not evident in a study area of 76,000 km<sup>2</sup> in northern Alberta, as a consequence of the large but infrequent fires characteristic of this landscape.

The observation that shifting mosaic landscapes do not occur at a spatial scale comparable to the dispersal distance of most boreal species implies that the maintenance of a shifting mosaic steady state may not be an appropriate ecological objective for protected areas in this region. I suggest that we accept that the abundance of patch types in protected areas will vary over time and focus our planning efforts on ensuring that all patch types are continually represented in the system. The results of this study suggest that protected areas in the range of 5,000 km<sup>2</sup> will likely be appropriate for this purpose in northern Alberta. To further refine this estimate site-specific research should be conducted with the aim of defining and achieving appropriate minimum levels of representation for patch types that are most at risk of being lost from the system. Because the fire regime in Alberta is typical of the fire regime described in other parts of the boreal forest (e.g., Bergeron, et al., 1998; Kurz and Apps, 1999), the results provided here should provide useful guidance for park planners in other boreal settings.

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