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Modeling fire susceptibility in west central Alberta, Canada

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ABSTRACT

Strategic modification of forest vegetation has become increasingly popular as one of the few preemptive activities that land managers can undertake to reduce the likelihood that an area will be burned by a wildfire. Directed use of prescribed fire or harvest planning can lead to changes in the type and arrangement of forest vegetation across the landscape that, in turn, may reduce fire susceptibility across large areas. While among the few variables that fire managers can influence, fuel conditions are only one of many factors that determine fire susceptibility. Variations in weather and topography, in combination with fuels, determine which areas are more likely to burn under a given fire regime. An understanding of these combined factors is necessary to identify high fire susceptibility areas for prioritizing and evaluating strategic fuel management activities, as well as informing other fire management activities, such as community protection planning and strategic level allocation of fire suppression resources across a management area. We used repeated fire growth simulations, automated in the Burn-P3 landscape-fire simulation model, to assess spatial variations in fire susceptibility across a 2.4 million ha study area in the province of Alberta, Canada. The results were used to develop a Fire Susceptibility Index (FSI). Multivariate statistical analyses were used to identify the key factors that determine variation in FSI across the study area and to describe the spatial scale at which these variables influence fire susceptibility at a given location. A fuel management scenario was used to assess the impact of prescribed fire treatments on FSI. Results indicated that modeled fire susceptibility was strongly influenced by fuel composition, fuel arrangement, and topography. The likelihood of high or extreme FSI values at a given location was strongly associated with the percent of conifer forest within a 2-km radius, and with elevation and ignition patterns within a 5-km radius. Results indicated that prescribed fire treatments can be effective at reducing forest fire susceptibility in community protection zones and that simulation modeling is an effective means of evaluating spatial variation in landscape fire susceptibility.

1. Introduction

The composition and configuration of landscape vegetation types in northern forest ecosystems can influence wildfire susceptibility. Stands characterized by different species and age classes will have different fuel complexes and structures that will either support or restrict the spread of fire from adjacent stands. Homogenous fuel, weather, and topographic conditions across an area are generally associated with larger, more uniform fires because continuous areas become simultaneously receptive to fire ignition and spread (Turner and Romme, 1994; Delong, 1998; Ryan, 2002). In the Boreal and Foothills natural regions of Alberta, large but infrequent high-intensity fires are characteristic (Tymstra et al., 2005). These fires kill the majority of the trees and over long periods and large spatial scales, produce a diverse mix of landscape patches that differ by age and cover type. Dominant tree species in these ecosystems can be divided into two groups—the conifer fuels that fires select for, such as white spruce (*Picea glauca*), black spruce (*Picea mariana*), and lodgepole pine (*Pinus contorta*) and the deciduous fuels, such as aspen (*Populus tremuloides*), that limit or arrest fire ignition and spread (Cumming, 2001; Krawchuk et al., 2006).

Because the fires characteristic of these areas can affect large areas over short periods, they can pose a sudden and significant threat to forest resources, forest-based communities, and the industries and economic activity associated with both. Fire suppression has reduced area burned in northern forest ecosystems (Cumming, 2005; DeWilde and Chapin, 2006; Martell and Sun, 2008) and there are concerns that effective suppression over long time periods in these ecosystems may potentially contribute to increasing fuel continuity that could result in some fires reaching sizes that would otherwise have been constrained by the landscape mosaic. The mechanisms of this process are summarized by Chapin et al. (2008) for black spruce forests in boreal Alaska, where the moisture content of deciduous early post-fire successional species are thought to create fuel breaks between adjacent

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black spruce stands, thus reducing landscape fire susceptibility, or the likelihood that an area will be burned by a fire.

Landscape management initiatives such as FireSmart (Hirsch et al., 2001) have been proposed for northern forest ecosystems and aim to reduce fire susceptibility through the spatial allocation of activities such as prescribed burning, harvest cut-blocks and roads. These activities create breaks in continuous flammable areas with non-fuel barriers or the introduction of less flammable vegetation types or ages into the landscape mosaic. The goal of this type of landscape fuel management is to strategically reduce the likelihood of large and costly fires in or near high-value areas, such as communities.

While vegetation type and configuration are among the few fire determinants that can be influenced by land managers, many other factors will influence the susceptibility of an area to wildfire. To be effective, strategic fuel management planning must account for the combined variations in fuel, weather and topography that together determine which areas of the landscape are more likely to burn under a given fire regime. Integrated mapping of fire regime and fire environment factors has applications to many fire management activities and has been an important area of fire research for some time.

Geographic information systems (GIS) have been used to rate fire susceptibility at individual locations on the basis of spatial data for biophysical, fire regime, and other characteristics, sometimes in combination with fire behavior models (e.g., Burgan and Shasby, 1984; Chuvieco and Congalton, 1989; Hawkes and Beck, 1997; Núñez-Regueira et al., 2000; Haight et al., 2004). Statistical models have also been used to map spatial variations in fire susceptibility as a function of variables such as vegetation, weather, topography, and human activity on the basis of historical data for locations where fires occurred (e.g., Cardille et al., 2001; Dickson et al., 2006; Syphard et al., 2008). In regions where fires can have dramatic and sustained impacts on vegetation composition and structure, explanatory variables related to forest fuels must pre-date the historical fire activity under consideration. The resulting statistical model can then be applied to current conditions or projected future conditions to map fire susceptibility.

Fire growth simulations can be used to assess fire potential under current landscape conditions. Simulation models are a particularly powerful tool for assessing fire susceptibility because they incorporate the influence of surrounding areas on the potential for a particular location to be burned by a fire. Spatial context is captured when a computer fire growth model is used to simulate the ignition and spread of fires. One approach involves simulating many fires over large landscapes to identify general patterns in fire prone areas (e.g., Mbow et al., 2004). Impacts of proposed fuel management activities, such as prescribed fires or harvest treatments, can be evaluated by altering fuels and conducting subsequent simulations for comparison (e.g., LaCroix et al., 2006; Duguy et al., 2007; Schmidt et al., 2008; Suffling et al., 2008). Simulation modeling has also been used to explore fundamental interactions between fire activity and landscape structural features by comparing simulated fires on hypothetical landscapes that are created to represent specific conditions (e.g., LaCroix et al., 2008). When fire ignitions and burned areas are simulated repeatedly over a large number of model runs or iterations, the frequency of times a location burns can provide a spatially continuous rating of fire susceptibility (e.g., Farris et al., 2000; Carmel et al., 2009).

We used repeated fire growth simulations, automated in the Burn-P3 landscape-fire simulation model (Parisien et al., 2005), to assess spatial variation in fire susceptibility across a 2.4 million ha study area in west central Alberta, Canada. We combined simulation results with multivariate statistical analyses to identify the key factors that determine variation in fire susceptibility across the study area and to describe the spatial scale at which these variables influence fire susceptibility at a given location. Finally, we assess the impact of proposed fuel management activities (prescribed fire treatments) on fire susceptibility in our study area. The objectives of our study were threefold: to explore the usefulness of simulation modeling for evaluating the effectiveness of fuel management activities; to provide insight into those factors that determine variation in forest fire susceptibility in northern forest ecosystems; and to characterize the spatial context captured in this type of fire simulation modeling exercise, where the characteristics of surrounding areas influence fire susceptibility at any given point.

2. Methods

2.1. Study area

Bounded to the north by Lesser Slave Lake, the 2.4 million ha study area falls within the Boreal and Foothills natural regions in the province of Alberta, Canada (Natural Regions Committee, 2006) (Fig. 1). These regions are characterized by short, wet summers with peak precipitation occurring in July. Mean annual precipitation ranges from 461 mm to 588 mm and mean daily temperatures between May and September are 11–13 °C. Dominant tree species include aspen (*P. tremuloides* Michx.), lodgepole pine (*P. contorta* Dougl. ex Loud. var. *latifolia* Engelm.), white spruce (*P. glauca* (Moench) Voss), and balsam poplar (*Populus balsamifera* L.). There is considerable variation in vegetation patterns across the study area with mixedwood and deciduous stands dominating the Lower Foothills subregion and conifer dominating the Upper Foothills Subregion. The Dry Mixedwood Subregion is characterized by aspen-dominated forests. Elevations range from 350 m to 1350 m ASL. The average slope in the study area is less than 10%, with just a few areas in the Upper Foothills Subregion having slopes between 20% and 50%.

Between 1976 and 2003 annual fire occurrence in the study area varied substantially from year to year, with an average of 109 fires each year. Fire sizes during this period ranged from less than 0.1 ha to 168,863 ha. Small fires (<4 ha) accounted for 93% of fire events, and only 1% of fires exceeded 200 ha. Only five fires reached a final size greater than 5000 ha, but these fires each burned an average of 50,000 ha, or 2% of the burnable area in the study area. Significant large fires in the study area are shown in Fig. 2, the largest being the 1998 Virginia Hills fire, which burned 167,000 ha.

Annual area burned also varied substantially between 1976 and 2003, from 49 ha to 229,995 ha. The majority (93%) of the total area affected by fire during this period was burned during 3 years (1981, 1998, and 2001). On average, 11,191 ha of the study area burned each year; this represents 0.48% of the burnable area contained within the study area, very close to the estimate of 0.42% reported by Stocks et al. (2002) for the Boreal Plains ecozone, which contains our study area. Ninety-seven percent of area burned occurred between late April and early September. About half the fires that occur in the study area are from lightning ignitions and half are from human sources. The majority (77%) of lightning-caused fires occurred between June 1 and August 15. Human-caused fires begin in early April and peak at the beginning of May, then decline through to October.

2.2. Simulation model

We assess fire susceptibility for the current state of our study area by repeatedly simulating the ignition and spread of fires. We used Burn-P3 (Parisien et al., 2005) to automate the simulations and to incorporate fire regime characteristics associated with our study area. Burn-P3 is a fire-landscape simulation model that can