Modeling the Influence of Fire Ignition Source Patterns on Fire Regimes of West-Central Alberta

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Abstract

Fire management is a component of contemporary sustainable forest resource management. A better understanding of the relationships among different descriptors of a fire regime is desirable to assist fire management planning. Since existing empirical observations are insufficient for evaluating these relationships, a simulation model experiment together with spatial information and geographic information systems (GIS) technology is expected to provide useful insight. This paper presents an analysis of a spatial data set of historical fire occurrence records in Alberta of Canada, and a model experiment based on the GIS information of a study area in west-central Alberta. A spatially explicit model for landscape dynamics (SEM-LAND) was used for the model experiment. A 3.5 to 4-year average interval between two successive peak years of fire ignition source was found in three regions of Alberta. The total fire ignition source level was more frequent in the southern region than that in central and northern regions. The numbers of lightning fires were higher during a period from 1979 to 1995 than that from 1961 to 1978. However, the human fire numbers increased with time, and then decreased since 1990. Results from the model experiment suggested that different temporal patterns of fire ignition sources might not produce different fire regimes in terms of fire number and fire cycle. Under an intensive fire management scenario, however, various fire ignition source patterns could result in significant different fire regimes. Different levels of fire ignition source may not alter the simulated fire regimes under natural conditions, but could result in significant different fire regimes under an intensive fire management scenario.

Keywords

Forest dynamics, SEM-LAND model, geographic information systems (GIS), fire ignition source pattern, fire regime, fire management

Introduction

Fire management is a component of contemporary sustainable forest resource management. The determination of long-term fire management strategies requires a better understanding of the relationships among different descriptors of a fire regime, such as fire frequency, intensity, severity, seasonality, size, type, *etc*. These descriptors characterize different aspects of a fire regime (Weber and Flannigan, 1997). However, existing empirical observations are insufficient for evaluating these relationships. To complement this shortage of empirical data, Li (2000) developed a spatially explicit model for landscape dynamics (SEM-LAND) to reconstruct natural fire regimes from current forest landscape conditions. An earlier version of SEM-LAND has been used to investigate the relationship between fire frequency and size distribution under natural conditions (Li *et al.*, 1999). This paper investigates the influence of different fire ignition source patterns on other descriptors of a fire regime such as fire number and frequency.

The occurrence and development of a fire event determined by many factors such as the existence of a fire ignition source, as well as appropriate fuel and weather conditions. Fire ignition sources can be from natural (such as lightning strikes) and human activities. Annual fire number in different regions is one of the common statistics reported in literature (*e.g.*, Canadian Council of Forest Ministers, 1997). Time series analysis has also been employed for such data, *e.g.*, Li *et al.* (1997) analyzed the 11,295 historical fire occurrence records of Northwestern Ontario, Canada, during the period of 1967 to 1994 on a total land area of 144,960 km^2. The results indicated that a 3.6-year cyclic pattern was evident in all three data sets (lightning, human, and total fire ignitions). Although the mechanism for this cycle remains unclear, similar phenomena have also been found in Alberta, Canada (Cumming *et al.*, 1995), and Sweden (Granström, 1993). In Alberta, 10 peak years of fire incidence appeared between 1961 and 1994, *i.e.*, a cycle of 3.5 years in average. In Sweden, the time series of yearly lightning ignition density (lightning/10,000 ha/yr) from 1944 to 1975 indicated a 4-yr interval in southeastern Sweden and a 3-yr interval in northern Sweden. Despite the unknown mechanism, an important question that remains to be answered is whether a cyclic fire ignition source pattern would influence the fire regimes observed in nature. This paper attempts to address this question with an analysis of historical fire ignition source patterns in Alberta, and a simulation experiment using the SEM-LAND model.

Methods

The investigation was first to determine the historical fire ignition patterns in Alberta by analyzing a spatial set of fire occurrence. A simulation experiment was then carried out by using the SEM-LAND model to investigate the possible consequences of a fire regime under different fire ignition source patterns.

Fire ignition source patterns of Alberta

Forest fire ignition source patterns of Alberta were identified by the analysis of historical forest fire data (1961 to 1995). A grid of rectanguler cells was superimposed onto a map of Alberta. Each cell represented a land area of 20 by 20 km^2 (Figure 1). A total of 220 cells were established for the forested land of Alberta (National Parks were not included). Therefore, 24,738 fire records on a total land area of 88,000 km^2 were under analysis. To take a closer look at the data, the total forested land was divided into three regions: north, central, and south. The fire ignitions in each cell were separated into fires caused by lightning and humans. The average regional annual fire ignition sources were then calculated.
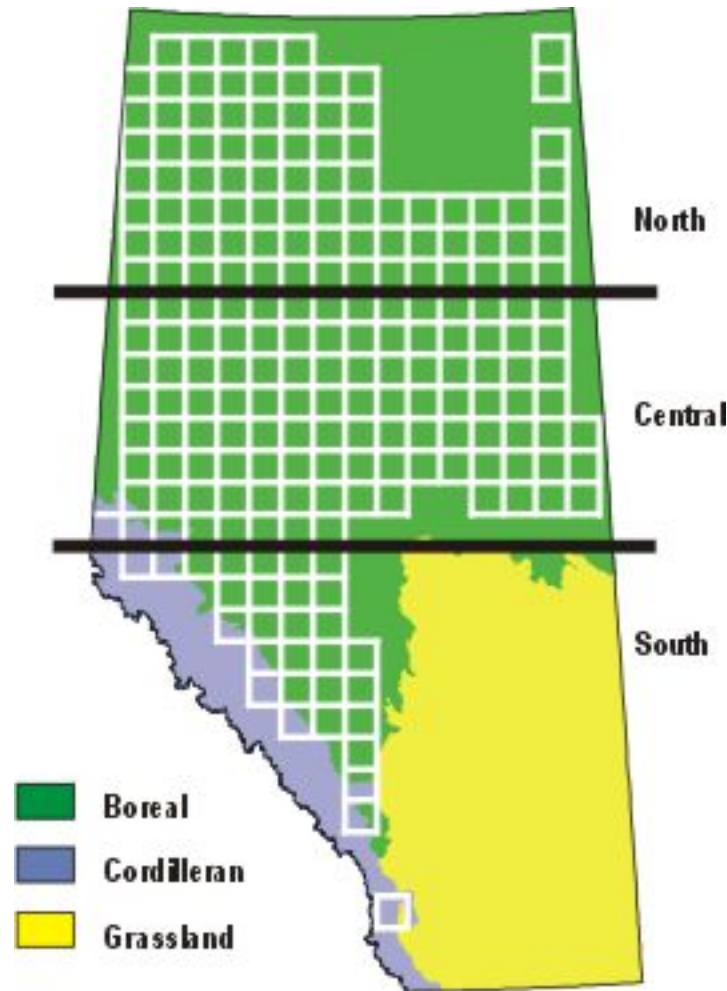

Figure 1. A grid of rectangle cell superimposed onto the ecoprovince map of Alberta, Canada. Each cell represents a land area of 20 by 20 km^2.

The SEM-LAND model

The SEM-LAND model simulates the dynamics of forest and fire simultaneously at the landscape scale. Since the model has been described in detail in Li (2000), only a brief summary is presented here.

Three main components were included in the SEM-LAND model: forest growth, fire disturbance,

and re-vegetation after fire. Forest growth was simulated according to the individual tree growth models and species composition, and the tree growth models are from Alberta Forest Service (1984) where volume, basal area, tree height, and tree density were calculated. Fire disturbance component was a detailed fire process simulation according to the relationships summarized in the Canadian Forest Fire Behavior Prediction System (FBP) (Forestry Canada Fire Danger Group, 1992; Hirsch, 1996) and the Canadian Fire Weather Index System (Van Wagner, 1987). The simulation mainly focused on the influence of weather condition and landscape topography. A fire process was simulated in two stages: fire initiation and spread. Fire initiation started from the presence of a fire ignition source at a particular location, until most trees in that location were burned. Once a fire initiation occurs, the fire spread stage begins. A fire would spread continuously until it is stopped by non-flammable land cover, boundaries of the region, or when rainfall exceeded a certain critical amount. The re-vegetation after fire was assumed to be self-replacement, *i.e.*, same vegetation cover type would return (Suffling, 1983; Ratz, 1995; and Li *et al.*, 1997). The model was validated by comparing the simulated natural fire regimes to observed historical fire regime before 1900 (Li, 2000).

The model experiment

The possible consequences of different fire ignition source patterns are investigated by carrying out a model experiment. The model experiment is to examine the influences of fire ignition source levels and temporal patterns of fire ignition source on resulting fire regimes. The level of fire ignition source refers to the mean annual fire source per unit area. Two such levels were used in the model experiment: 0.6 and 0.3 per year per 10,000 km^2. The former is assumed to correspond with a scenario under natural conditions, and the latter is referred to a scenario of high success in controlling human fires. The temporal patterns of fire ignition source examined in the model experiment are cyclic with a period of 3.6 years and randomly fluctuated around a mean value following a Normal probability distribution. The scenarios under investigation include two fire cycles: around 106-year (a scenario of under natural conditions, see Li, 2000) and longer than 500-year (a scenario of under intensive fire management). Ten replications applied for each scenario. 1,200-year's simulations were run for each replication, but only the last 1,000-year results were used in the analysis to avoid any possible effect of initial conditions.

The experiment was carried out by using a GIS data set of the Athabasca Working Circle Compartment 24 of Weldwood of Canada Limited (Hinton Division) in west-central Alberta, Canada. The total area of this study area is 7,432 ha, and it is located between latitude 53.7161 to 53.809 and between longitude 117.335 to 117.534. The major tree species were lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.), white spruce (*Picea glauca* (Moench) Voss), black spruce (*Picea mariana* (Mill.) BSP), balsam fir (*Abies balsamea* (L.) Mill.), and trembling aspen (*Populus tremuloides* Michx.).The historical fire and weather data and detailed GIS data set on current landscape conditions are available for this area.

Results

Historical fire ignition source patterns

1. The fluctuation patterns of fire ignition sources in three different regions are similar. Figure 2 shows the dynamics of mean fire ignition source per cell. There were 9 to 10 peaks during the 35-year records, *i.e.*, the average interval between two successive peaks was 3.5 to 4 years. However, the average fire ignition source per year in the southern region (5.07) was higher than the central region (3.66) and the northern region (3.02).
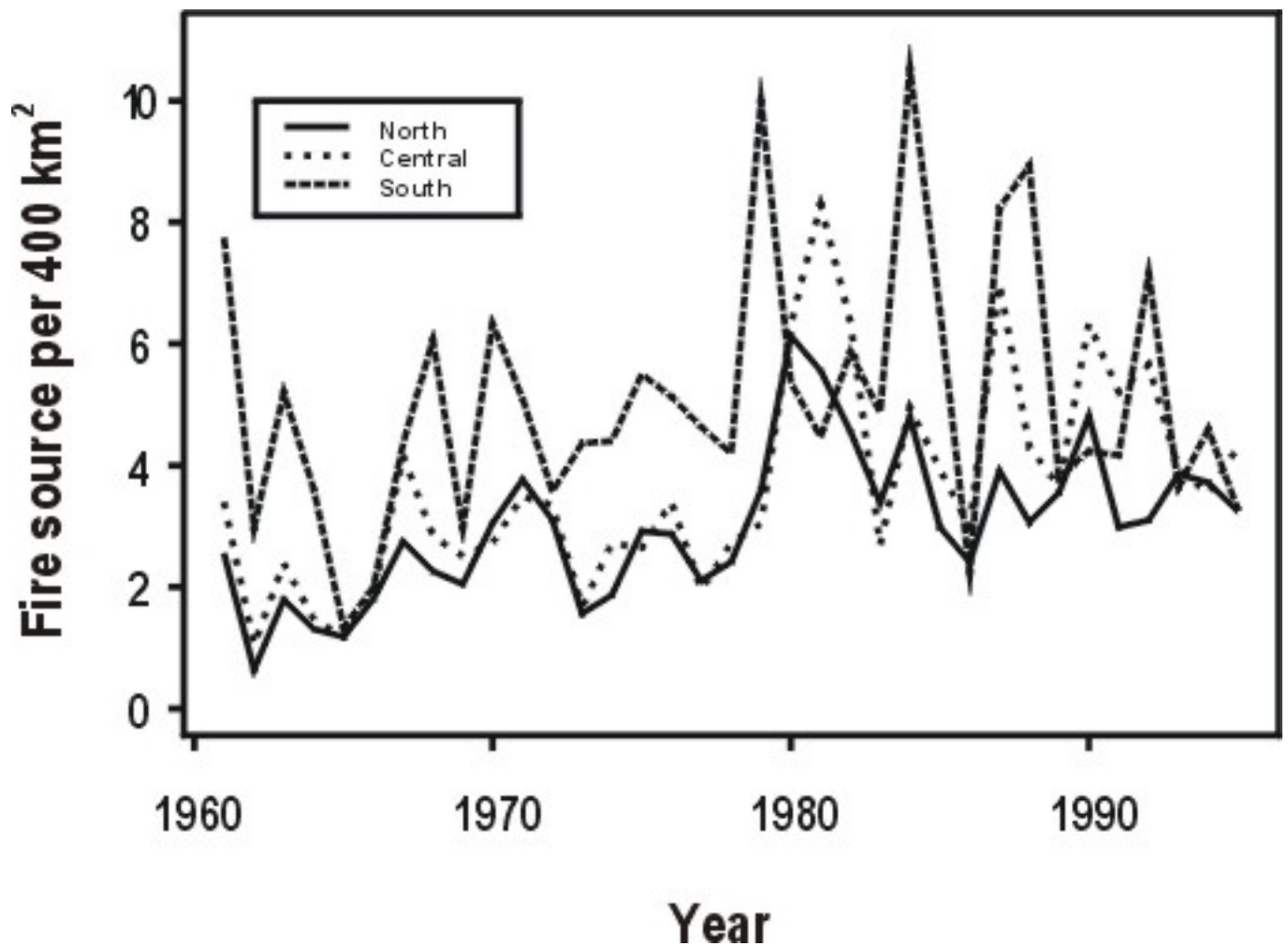
Figure 2. Dynamics of mean fire ignition source per 400 km^2 in 3 regions of Alberta, Canada.

2. Fire ignition source patterns caused by lightning and humans are different. For lightning caused fires, two levels of fire ignition sources can be identified during the periods of 1961-1978 and 1979-1995 (Figure 3). The mean annual fire ignition source in the second period is significantly higher (2 to 3 times) than that of the first period (Table 1).

Region	Lightning fire		Human fire	
	1961 to 1978	1979 to 1995	1961 to 1978	1979 to 1995
North	0.73	1.88	1.49	1.98
Central	0.82	2.39	1.71	2.46
South	1.18	2.20	3.24	3.56
Total	0.84	2.17	1.83	2.43

Table 1. Mean annual fire ignition source in different periods.

For human caused fires, the increase of mean annual fire ignition source in the second period was less significant (Table 1). The fluctuation patterns for human caused fires may be better described as a trend which increased with time, and followed then by a decrease since 1990.
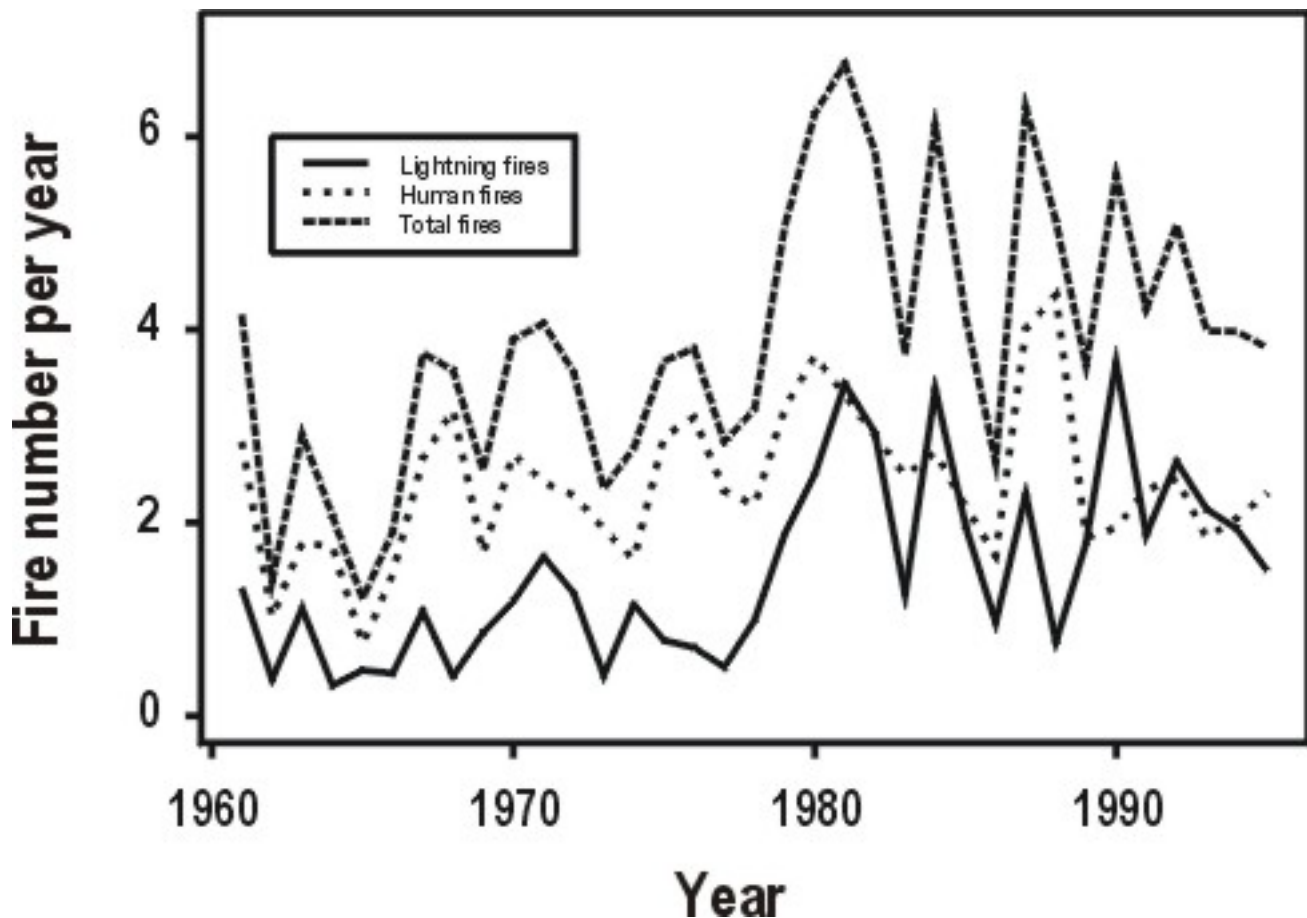

Figure 3. Dynamics of mean fire ignition source by lightning and human activities.

Simulated fire regimes

1. With a fixed higher level of annual fire ignition source (0.6 fire per year), there is no significant

difference in simulated total fire numbers and fire cycles under different fire ignition source patterns (normal and cyclic). However, a longer fire cycle scenario (*i.e.*, intensive fire management) and fewer fire ignition sources (0.3 per year per 10,000 km^2) could produce significant differences in simulated fire regimes. For example, lower fire number (200 *vs.* 230 per 1,000-year, $p = 0.00014$) and even longer fire cycles (1110-year *vs.* 850-year, $p = 0.039621$) can be expected under a cyclic fire ignition source pattern.

2. Different levels of fire ignition sources could result in significant fire regimes. Table 2 summarizes the results from the simulation experiment. When the level was reduced from 0.6 to 0.3 fire per year, the simulated fire cycles could become longer and fire numbers become fewer. Furthermore, a lower fire ignition source level could result in proportional reduction of fire numbers, but appeared less efficient in altering fire cycles (50% reduction of fire ignition source may lengthen fire cycle by 74.5% under natural conditions and by 16.7% under a fire management scenario).

Table 2a

Fire source level	0.6 fire/year/10,000 km^2		0.3 fire/year/10,000 km^2	
Temporal pattern	Normally distributed	3.6-year cycle	Normally distributed	3.6-year cycle
Fire cycle	108	112	189	186
Fire number	350	360	184	178

Table 2b

Fire source level	0.6 fire/year/10,000 km^2		0.3 fire/year/10,000 km^2	
Temporal pattern	Normally distributed	3.6-year cycle	Normally distributed	3.6-year cycle
Fire cycle	730	590	850	1110
Fire number	420	435	230	200

Table 2. Simulated fire cycles and fire numbers per 1,000 years under various scenarios: (a) under natural conditions
(around a fire cycle of 106 years); and (b) under intensive fire management (with fire cycles over 500 years).

Discussion

Forest dynamics have been studied extensively at the stand level including the processes of forest growth, survival, and renewal after its destruction. These processes are influenced by a number of environmental factors such as natural disturbances and weather conditions. At the landscape scale, the requirements of forest resource management presented a challenge to the modelers

because the inclusion of data pertaining to spatial variability and heterogeneity in forest dynamics on forest landscapes is instrumental in making sound resource management decisions. The combination of spatial information, geographic information systems (GIS) technology, and spatially explicit modeling can be a useful approach to assist forest managers in making such decisions.

Fire is one of the major disturbances in shaping the dynamics of Canadian forests, especially in the boreal region. Without the presence of a fire ignition source, a fire event can never happen even when other conditions are the most favorable for fire spread. Since the appearance of favorite conditions for a fire event can be described as a stochastic event, the temporal pattern of a fire ignition source could have a significant influence on the occurrence of fire disturbances, hence the fire regimes.

The results of analyzing the historical fire records in Alberta, Canada, suggested that human fires were more frequent than lightning fires during the period of 1961 to 1995. For lightning fires, there was an increase of average fire source since 1979. For human fires, however, this increase was less evident, and the average fire source even decreased since 1989. This is probably the result of successful fire management.

The fire ignition sources are not fixed but fluctuated every year. The temporal patterns of such fluctuation can be obtained from the analysis of historical fire records. Alberta's fire ignition source patterns appeared similar to Ontario, Canada, and Sweden reported in literature, *i.e.*, a 3 to 4-year interval between successive peak years. Although the mechanism for such cyclic patterns remains unclear, the question of whether such cyclic patterns could result in significantly different fire regimes, compared with a random fluctuation scenario, was investigated in this paper through a simulation experiment.

The simulation results suggest those different patterns of fire ignition sources might not always be able to alter fire regimes. For example, different temporal patterns of fire ignition sources could not result in significantly different fire regimes under natural conditions (Table 2a). However, the situations under fire management might be different (Table 2b), where different fire ignition source patterns could result in different fire regimes in terms of fire cycle.

Therefore, the fire ignition source pattern warrants more attention in areas under fire management. The implication of this model experiment result in fire management is that the restriction of human activity in high fire seasons might lead to significant fire regimes.

Acknowledgements

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