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# Recent fire regime (1945-1998) in the boreal forest of western Québec[1]

Patrick LEFORT & Alain LEDUC, Groupe de Recherche en Écologie Forestière Inter-universitaire et Département des sciences biologiques, Université du Québec à Montréal, P.O. Box 8888, Succ. Centre-Ville, Montréal, Québec H3C 3P8, Canada.
Sylvie GAUTHIER[2], Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre, 1055 du PEPS, P.O. Box 3800, Sainte-Foy, Québec G1V 4C7, Canada and Groupe de Recherche en Écologie Forestière Inter-universitaire et Département des sciences biologiques, Université du Québec à Montréal, P.O. Box 8888, Succ. Centre-Ville, Montréal, Québec H3C 3P8, Canada.
Yves BERGERON, Groupe de Recherche en Écologie Forestière Inter-universitaire et Département des sciences biologiques, Université du Québec à Montréal, P.O. Box 8888, Succ. Centre-Ville, Montréal, Québec H3C 3P8, Canada, and Chaire industrielle CRSNG-UQAT-UQAM en aménagement forestier durable, Université du Québec en Abitibi-Témiscamingue, 445 boul. de l'Université, Rouyn-Noranda, Québec J9X 5E4, Canada.

*Abstract*: The forest fire regime was characterized for the boreal forest of western Québec using the provincial government's digital databases (1945-1998). Lightning- and human-caused fires account for 71% and 29% of the total area burned, respectively. With regard to ignition sources, lightning was responsible for 38% of the fires while humans were the ignition agent for 62% of fires. The fire regime parameters (burn rate, fire occurrence, and size) were subjected to a stepwise regression analysis on the basis of regional landscape units. Models indicate that climatic factors, particularly summer precipitation and maximum temperatures, play a primary role in forest fire dynamics, regardless of the ignition source. Fire occurrence models were the most predictable with $R^2$ values of 0.79 and 0.60 for lightning fires and human-caused fires, respectively. Models of burned areas reached an $R^2$ value of 0.63 for lightning but only 0.22 for human-caused fires; on the other hand, the fire-size model for human-caused fires showed an $R^2$ value of 0.57 but only 0.24 for lightning fires. In the case of human-induced fires, the density of the road network and sand deposits were important in fire occurrence and burned areas models. Once characterized, landscape units tend to group together naturally, forming extensive areas in which the fire regime is relatively homogeneous. The results of the regionalization based on lightning fire regimes are discussed from the standpoint of sustainable forest management.
*Keywords*: boreal forest, climate, fire regime, Québec, regionalization, sustainable forest management.

*Résumé* : Le régime des incendies de forêt a été caractérisé pour la forêt boréale de l'Ouest du Québec à partir des bases de données numériques du gouvernement provincial (1945-1998). Les feux de foudre et d'origine humaine ont été respectivement responsables de 71% et 29% des superficies incendiées totales. En ce qui a trait à l'allumage des feux, 38% des feux ont été initiés par la foudre contre 62% par l'homme. Les paramètres du régime de feux (superficies incendiées, fréquence et taille des feux) ont fait l'objet d'analyses de régression pas à pas sur la base des unités de paysages régionaux. Les modèles indiquent que les facteurs climatiques, particulièrement les précipitations estivales et les températures maximales, jouent un rôle prépondérant sur la dynamique des feux de forêt, peu importe la source d'allumage. Les modèles d'apparition de feux sont les plus prédictifs, avec des valeurs respectives de $R^2$ de 0,79 et 0,60 pour les feux de foudre et ceux allumés par l'homme. Les modèles sur les superficies incendiées atteignent un $R^2$ de 0,63 pour la foudre mais de seulement 0,22 pour les feux allumés par l'homme. Par ailleurs, le modèle de la taille des superficies incendiées montre une valeur de $R^2$ de 0,57 pour les feux allumés par l'homme mais de seulement 0,24 pour les feux de foudre. Dans le cas des feux d'origine humaine, la densité du réseau routier et les dépôts de sable se sont avérés importants pour les modèles prédictifs sur les événements de feux et les superficies incendiées. Une fois caractérisées, les unités de paysages tendent à se regrouper naturellement, formant de grandes zones à l'intérieur desquelles le régime de feux est relativement homogène. Les résultats de la régionalisation fondée sur les régimes de feux de foudre sont discutés dans une perspective d'aménagement durable des forêts.
*Mots-clés* : aménagement durable des forêts, climat, forêt boréale, Québec, régime des feux, régionalisation.

## Introduction

The fire regime, defined by several variables, including areas burned, the number of fires, and their size, is known to be variable across Canada's boreal forest (Wein & Moore, 1979; Payette *et al.,* 1989; Masters, 1990; Weir, Johnson & Miyanishi, 2000; Bergeron *et al.,* 2001; Bridge, 2001). Variations in the forest fire regime can generally be explained with reference to conditions that are expressed at different scales. In general, the scientific literature views broad-scale climatic conditions (thousands of $km^2$) as having the greatest influence on the fire

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[2]Author for correspondence.

regime (Johnson, 1992; Johnson & Wowchuk, 1993; Flannigan & Wotton, 2001), particularly in relation to the annual area burned and the size of fires. For example, precipitation and drought periods are factors that affect the annual area burned along with the areal extent of individual fires (Flannigan & Harrington, 1988; Harrington & Flannigan, 1993).

On a more regional scale, permanent environmental components such as the predominance of some types of surficial deposits, the number of water bodies, and/or the topography are additional factors that are likely to influence the fire regime, including fire size (Zackrisson, 1977; Dansereau & Bergeron, 1993; Larsen, 1997; Kafka, Gauthier & Bergeron, 2001). Regionally and locally, the general composition of the forest mosaic, that is, the proportion of coniferous and deciduous species, also has an effect on the flammability of forest stands (Eberhart & Woodard, 1987; Turner & Romme, 1994; Kafka, Gauthier & Bergeron, 2001). However, since vegetation composition also changes in response to disturbances (Bergeron & Dubuc, 1989), its direct effect on the fire regime is more difficult to measure.

A number of researchers have shown that humans, whether through the development of an agricultural matrix or through fire suppression activities, have also had some effect on the fire regime (Wein & Moore, 1979; Stocks & Simard, 1993; Lefort, Gauthier & Bergeron, 2003). However, Urban, O'Neill, and Shugart (1987) point out that it is difficult to evaluate the impact of these practices on natural ecosystems and on the fire regime because of the concomitant occurrence of climatic variations.

In this paper, our goal is to examine the importance of these various types of factors (climate, permanent environmental components, vegetation, and humans) on the current forest fire regime of the southwestern part of Québec's boreal forest. Archive databases (Ministère des Ressources naturelles du Québec, Direction de la conservation) on forest fires from 1945 to the present (1998) were used in order to characterize the present fire regime within this area of nearly 250,000 km$^2$. The aims of the present article are *i*) to describe the fire regime (areas burned, fire occurrence, and size) of the boreal forest of western Québec, *ii*) to examine factors including climate, permanent environmental components of the territory (deposits and relief), and forest cover influencing the fire regimes, and *iii*) to regionalize the boreal forest according to variations in the fire regime. More in-depth knowledge of broad-scale fire regimes appears essential for delimiting natural forest regions in which silvicultural practices and strategies should be better adapted to fire activity. Therefore, this regionalization could complement the ecological classification and the boundaries of the forest management units established by the Québec Department of Natural Resources (MRNQ). Although evaluating the significance of human impacts was not a primary objective of this study, we have endeavoured to assess the magnitude of the effects of human-caused fires on the lightning fire regime of the landscape units.

## STUDY AREA

The fire regime was characterized for the western part of Québec's boreal forest. Historically, this part of the forest has a shorter fire cycle, about 200 y (Bergeron *et al.,* 2001), than does the eastern part, such as the Côte–Nord, which has a fire cycle of about 500 y (Foster, 1983; Gauthier *et al.,* 2001). The study area extends from the Abitibi region (79ϒ 35' W) to the area east of Lac St-Jean (70ϒ 00' W), encompassing parts of the balsam fir–white birch bioclimatic domain (47ϒ 45' N) and the black spruce–feather moss bioclimatic domain (51ϒ 30' N; Grondin *et al.,* 1996; Figure 1). In Québec's ecological classification system, a bioclimatic domain is defined as an area characterized by the nature of the potential vegetation growing on mesic sites, expressing the effects of climate (Robitaille & Saucier, 1998). This

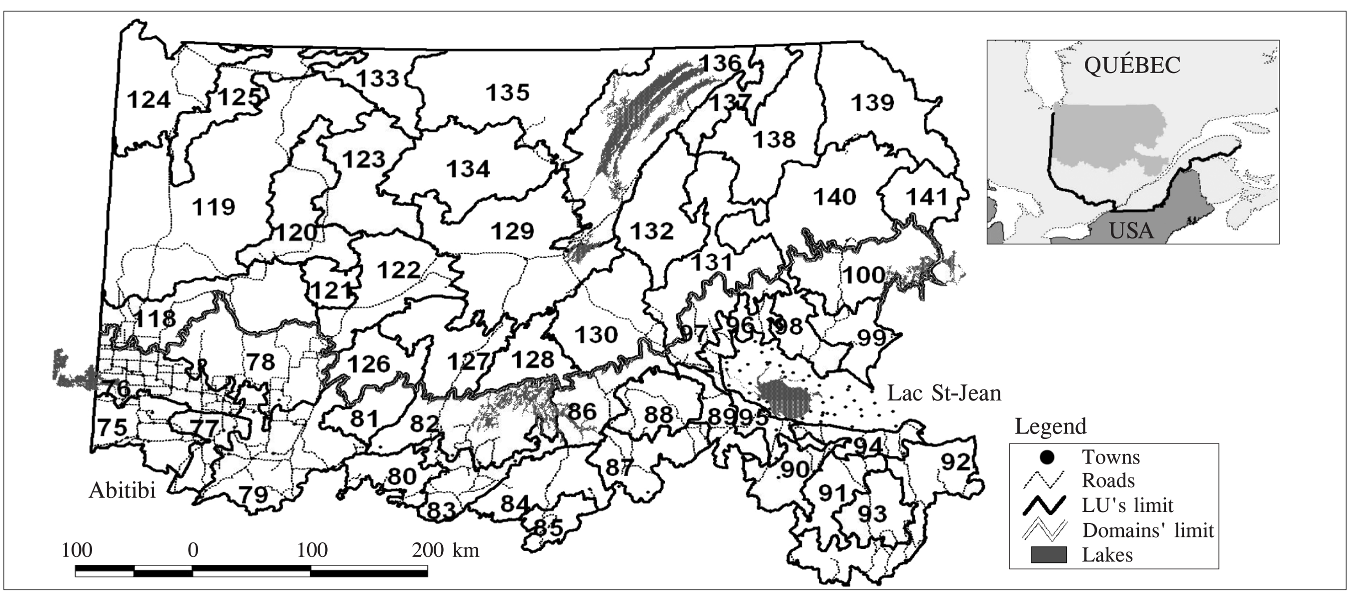


FIGURE 1. Geographic location of the 50 landscape units (LU) in the western boreal forest of Québec. Landscape unit boundaries are shown in dark grey with their identification number.

system divides the bioclimatic domains into a number of lower levels nested within one another in a hierarchy: the bioclimatic subdomain, the ecological region, the ecological subregion, and the regional landscape unit. The last of these levels, the regional landscape unit, is the ecological reference framework chosen for this study. A landscape unit is defined as an area characterized by recurrent arrangement of the main permanent ecological features of the environment such as slope and surface deposits and vegetation (Robitaille & Saucier, 1998).

The balsam fir–white birch subdomain in the west is made up of 26 landscape units (Figure 1) covering 97,011 $km^2$ for an average size of 3,731 $km^2$ per unit (standard deviation ± 1,867). The landscape units of this subdomain are identified with numbers lower than 100, the smallest number belonging to the ecological region located at the western part of the study area and the largest one being located at the eastern part. Excluding the water bodies and anthropogenic sectors such as farmlands, urban zones, and mining sectors, the forested area corresponds to 87,394 $km^2$. The black spruce–moss subdomain of the west is characterized by a total of 24 landscape units covering 170,158 $km^2$. The landscape units of this subdomain are identified with numbers higher than 100, the smallest number belonging to the ecological region located at the western part of the study area and the largest one being located furthest east. The average area of each unit is 7,090 $km^2$ ± 4,222 (mean ± SD). Excluding water bodies and built areas, the forested land area totals 152,158 $km^2$. In this study, we opted to use the landscape unit as a scale of resolution for two reasons: *i*) their areal extent appears sufficient to describe the fire regime in the boreal forest, since the average size of lightning-caused fires in the study area, 37 $km^2$, is at least 50 times smaller than the average size of the landscape unit, which is 4,800 $km^2$ (Shugart & West, 1981), and *ii*) the landscape units have undergone a detailed characterization of their permanent components (physiography and topography), characteristics which can be drawn on in explanatory analyses of fire regimes (Robitaille & Saucier, 1998).

Because of its size, the study area includes three regions with distinct geophysical characteristics, arrayed along a west-central-east gradient. The Abitibi region (the western portion) is part of a major physiographic entity, the Clay Belt, which is characterized by vast plains of low altitude created by the deposit of clay sediments from the proglacial lakes Barlow and Ojibway (Vincent & Hardy, 1977). Consequently, the relief in this region is fairly even, with abundant bogs and peatlands. In the centre of Québec, the presence of the Canadian Shield, an area of Precambrian rocks, gives rise to noteworthy physiographic changes. The relief is more rugged than in the western part, and the number of lakes is much greater. The landscape is dominated primarily by till deposits, with the mean proportion of rock outcrops increasing in the northern (west of Lake Mistassini, 51° 00' N, 73° 00' W) and extreme southern (Robitaille & Saucier, 1998) sectors. In the final third of the study area, the altitude increases even more in the northern and southern sectors, but declines around Lac St-Jean, which constitutes a depression in the Canadian Shield (Girard & Perron, 1989). This territory is also characterized by rugged terrain with numerous lakes, except on the periphery of Lac St-Jean, where till deposits remain dominant.

The balsam fir–white birch domain in the west has a continental climate: there is no marked dry period during the growing season, and the mean annual temperature is slightly above the freezing point, that is, about 1 °C (Grondin, Blouin & Racine, 1998). The length of the growing season decreases slightly, from 160 to 150 d, along an east to west gradient, whereas total mean annual precipitation ranges from 800 to 1,200 mm, with snow cover of nearly 45%. The western black spruce–moss domain has a subpolar continental climate with a mean annual temperature of about 0° C in the southern portion and about -2.5 °C near the northern boundary (Bergeron, Grondin & Blouin, 1998). The growing season is 155 d in the southern portion and ranges from 120 to 130 d in the northern area. Total annual mean precipitation varies between 800 and 1,000 mm in the south and between 700 and 800 mm close to the northern boundary, with the proportion of snow being highly variable throughout the territory (25% to 50%).

In general, few sectors have been spared the effects of human activities, whether through forest management, forest fire control, agricultural development, or urban expansion. On average, urbanized areas cover less than 1% of the area of each landscape unit. However, the Abitibi area and the area around Lac St-Jean are more densely populated and affected by human activities, as attested by the density of the primary road network and the distribution of towns and villages (Figure 1). Historically, logging in the study area took place primarily near the urbanized zones of the Abitibi and Lac St-Jean areas (Vincent, 1995). In the past few decades, the main concentration of forestry activities has gradually shifted towards the north and centre of Québec. At present, the high plateaus located on the point at the southernmost part of Lac St-Jean are no longer the site of large-scale harvesting and neither is the northern portion of the study area, which corresponds approximately to the northern limit of forest allocations.

## Methods

### Fire regime variables

In this study, we compiled the total surface area burned, the total number of fires (*e.g.,* the fire occurrence) ignited during the study period (1945-1998), and the median size of the fires (50th percentile) for each landscape unit. Owing to the strong asymmetry of the fire size distribution frequency, it seemed more appropriate to use the 50th percentile than the mean. These three variables define the fire regime and were calculated from digital data obtained from the MRNQ's forest conservation branch, which has compiled data on all the fires that occurred in Québec between 1945 and 1998 (Direction de la conservation des forêts, 2000). The attributes in the database include the ignition source (humans or lightning), the area burned, the type of stand burned, the geographic location of the fire, and the fire ignition date. Two filters were applied to the MRNQ database. First, all the fires smaller than 50 ha were discarded, regardless of ignition source, in compiling the three fire regime variables. This minimum size of 50 ha was deemed necessary to lessen the effect of the change in fire detection capability over time. In addition, for all fires taken together (regardless of ignition source), fires smaller than 50 ha were responsible for less than 1% of the total area burned. The second filter involved determining how to attribute fire occurrence and size in cases where a given fire straddled more than one landscape unit. We applied the following rule: final size of the fire (*i.e.,* its total area) and fire occurrence were compiled for each landscape unit provided that at least 30% of the total area burned was located within that landscape unit. These decision rules were applied to strengthen potential relationships between the permanent environmental components and the fire regime, as these relationships can be masked by fires attributed to simple lightning strikes or to very small-scale fires that do not respond to environmental conditions.

We used a base unit of 100 $km^2$ of strictly forested land (excluding water bodies and urban or agricultural areas) for the area burned in order to permit comparison of landscape units differing in surface area. Since the survey period was the same for all landscape units, namely 54 y, data relative to the areas burned are expressed on an annual basis ($\cdot 100\ km^{-2} \cdot y^{-1}$), giving an annual rate as a percentage. This annual burn rate was expressed in terms of fire cycles to facilitate data comparison (*i.e.,* 1/x of the annual rate). In the case of fire occurrence, the procedure is identical, except that the number of annual fires is expressed per 1,000 $km^2$. The median fire size was also computed for each landscape unit that had more than five fires (after the application of the filters). Although this study deals mainly with the lightning fire regime, we also analyzed human-caused fires to determine their potential influence in this boreal forest regionalization exercise.

### EXPLANATORY FACTORS FOR FIRE REGIMES

Fire regime may be explained by a wide range of variables. In this study, four groups of factors were identified *a priori* according to their scale and/or order of influence: *i*) climate, *ii*) permanent environmental components (deposits, slope), *iii*) composition of the forest cover, and *iv*) extent of human modification on the environment. Environment Canada's digital databases (Environment Canada, 1993) and those of the MRNQ (Robitaille & Saucier, 1998; J. Noël, unpubl. data) enabled us to define a total of 32 variables for each landscape unit in relation to these four hierarchical levels. The seven climatic variables retained are climate normals over a 30 y period: total annual mean precipitation (mm, snow and rain), mean rainfall (mm), mean precipitation (mm) during the fire season (May to August), maximum and minimum mean temperatures from May to August (°C), mean number of degree-days per month (May to August), and the mean vapour pressure deficit (in mbar) from May to August. Available data were not appropriate to compute the fire danger index or drought index values, which necessitate the use of daily values.

A total of 15 variables were retained in order to describe the permanent components: mean altitude (m), mean slope (%), absolute change in elevation ($m \cdot km^{-1}$), altitudinal amplitude (m), the percentage of deposits in each landscape unit dominated by tills, clay, fluvio-glacial material, sand, organic matter, rocky substrate, percent coverage by water bodies, and areal percentage of xeric, mesic, subhydric, and hydric soils. All these data came from the MRNQ database on landscape units.

The forest cover was described using seven variables (J. Noël, unpubl. data; defined from forest inventory maps): percent cover (areal extent) by landscape unit made up of deciduous stands, mixed stands dominated by conifers, spruce-dominated coniferous forest, jack-pine dominated coniferous forest, fir-dominated coniferous forest, total coniferous stands along with the proportion of unforested surface area (bare wet or dry, alders, etc). The extent of human modification of forest mosaic is defined by the following three variables: density of the primary and secondary road systems ($km \cdot 100\ km^{-2}$), the proportion of cutovers (or regenerating < 30 y), and the proportion of landscape units (in 1998) characterized by agricultural, mining, or urban land use (*i.e.,* strictly nonforest).

In order to characterize the major gradients observed in those variables in the study area and to describe the correlations among the 32 explanatory factors, a principal component analysis was performed for the first two axes using the CANOCO software program (ter Braak, 1991). The position of the 50 landscape units (sample scores) was also plotted on a second ordination graph in order to identify the influence of explanatory factors on landscape units.

Stepwise regression analyses were then performed for each ignition source to determine the extent to which climatic factors, permanent environmental components, forest cover, and human factors could explain each of the fire regime variables (stepwise procedure, SAS Institute, 1990). The four groups of variables were successively introduced into the model according to a hierarchy specific to each ignition source. In the case of lightning fires, the order in which the groups of variables were introduced was as follows: climatic factors > permanent environmental components > vegetation > human factors. This meant that, for the first stage in the model, climatic variables were the only ones that could be selected, followed by physical environment variables and so on.

We hypothesized that the human factors would have a predominant influence on the human-caused fire regime and accordingly used the following order in inputting variables to the model: human factors > climatic factors > permanent environmental components > vegetation. This procedure permitted the successive incorporation, in order of importance, of the independent variables explaining the greatest amount of variance with respect to the different fire regime characteristics, by ignition source.

### REGIONALIZATION OF THE STUDY AREA

To facilitate the identification of relatively homogeneous broad cartographic zones, the areas burned and lightning fire occurrence were grouped into three classes. The burn rates were expressed in terms of short, intermediate, and long fire cycles: < 200 y, 200-500 y, and ≥ 500 y. For fire occurrence, the classes were defined using the natural breaks method in ArcView (geographic information system). This procedure identifies the breakpoints in the data distribution by forming groups that minimize the variance within each of the classes; this involves using a statistical formula given by Jenk's optimization (ESRI, 1996, p. 104). Subsequently, the lightning fire regime was defined by a combination of a fire cycle class with a fire occurrence class. Nine potential fire regimes were defined according to a three-cycle class by three occurrence class matrix. A single fire regime was assigned to each landscape unit based on the individual fire cycle and fire occurrence values for the landscape units.

To evaluate the influence of human fires on this regionalization, we repeated the regionalization exercise looking at the combination of lightning- and human-caused fires simultaneously. This involved combining the annual burn rate (reported as fire cycles) and the fire occurrences for the two ignition sources. A fourth fire-occurrence class was added to take into account the many fires started by humans. The fourth class encompasses all the landscape units for which the fire occurrence value is higher than the maximum lightning fire occurrence class. Maps based on lightning alone and a combination of lightning and human-caused fires were then produced in order to identify homogeneous zones with a similar fire regime.

## Results

### Description of the fire regime variables

Between 1945 and 1998, 523 lightning-caused fires and 866 human-caused fires larger than 50 ha were inventoried in the study area (Table I). Lightning fires accounted for only 38% of the total number of fires ignited during the study period, although they constituted 71% of all areas burned. With regard to fire occurrence per landscape unit, the values ranged from 0.0 to 0.18 fire·1,000 $km^{-2} \cdot y^{-1}$ for lightning fires, whereas human-induced fires were generally more frequent, varying between 0.0 and 0.80 fire·1,000 $km^{-2} \cdot y^{-1}$. Some landscape units remained virtually untouched by fire during the recent 54-y period covered by the records. The largest annual burn rate per landscape unit amounted to 0.74% and 0.38% for lightning fires and human fires, respectively (Table I); these annual burn rates correspond to minimum fire cycles of 135 y for lightning fires and 262 y for human-caused fires (Appendix I). The median fire size of lightning fire was higher, 3.8 $km^2$, than the one for human-caused fire, 2.0 $km^2$.

### Correlation set between explanatory factors and fire regime position

Principal component analysis (PCA) of the explanatory factors is illustrated in Figure 2a. The first PCA axis explains 31% of the variance and the second one 25%. Axis I is strongly influenced by longitude, with units from the western section of the study area on the negative side of axis I, opposed to those from the east. It indicates a strong gradient in surface deposits and permanent environmental components, as well as a gradient in precipitation, notably that during the fire season. Organic and hydric soils are located in the left quadrants and are negatively correlated with slope, altitude, and soils that have good drainage (till or fluvio-glacial deposits). The longitude also illustrates the change from a poorly drained lowland relief (in the west, Abitibi region) to a more rugged and better drained relief (in the east, Lac St-Jean region), correlated with the relative importance of mesic environments and till deposits. The amplitude, slope, altitude, and change in elevation represent strongly correlated variables that also increase from west to east in the study area. Moreover, higher precipitation is observed in the east, where the topography is more rugged.

Axis II is strongly correlated with latitude, with northern units located on the negative side and southern units tending to be on the positive side. The latitudinal gradient seems to be correlated with two other gradients, namely an increase in maximum temperatures from the north to the south and an increase in coniferous composition (jack pine and spruce) of the forest moving towards the north. The percentage of water bodies increases from the south to the north, whereas summer temperature and growing degree-days increase from north to south, together with the proportion of mixed and deciduous stands. The variables associated with vegetation type generally lie along an axis perpendicular to the axis representing drainage quality and deposit type. Human factors like cutovers and road network are correlated with deciduous and mixed stands at low latitudes. The percentage of farmland, in the lower right quadrant, is barely correlated with the other variables.

In Figure 2b, we see the ordinations of each LU. It is obvious that the main gradient is a west-east one, with all western sites being located on the negative side. Moreover, all the black spruce LU but two (118, 122) are located on the negative side of axis II, while balsam fir–white birch LU are located on the positive side at lower latitudes (see Figure 2a). More specifically, western LU of the Abitibi region (LU 75-79 and 118-125) are characterized by a flat topography with sand and clay deposits in the southern portion (LU 75-79), whereas the northern sector underwent enrichment of organic deposits, particularly in the black spruce domain. Agricultural,

TABLE I. General characteristics of the fire regime for the 50 landscape units (LU) (1945-1998)*.

| | Ignition source | | |
|---|---|---|---|
| | Lightning | Human | Total |
| Total fire occurrence (> 50 ha) | 523 (38%) | 866 (62%) | 1,389 (100%) |
| Total burned areas ($km^2$) | 19,459 (71%) | 7,855 (29%) | 27,314 (100%) |
| Median fire size ($km^2$) percentile $50^{th}$** | 3.8 | 2.0 | |
| Max. occurrence / LU (fires·1,000 $km^{-2} \cdot y^{-1}$) | 0.18 | 0.80 | |
| Max. burned areas / LU (annual %) | 0.74 | 0.38 | |
| Shortest fire cycle (y) | 135 | 262 | |

* Only forest fires larger than 50 ha have been considered.

** Estimated for landscape units with a fire occurrence ≥ 5.

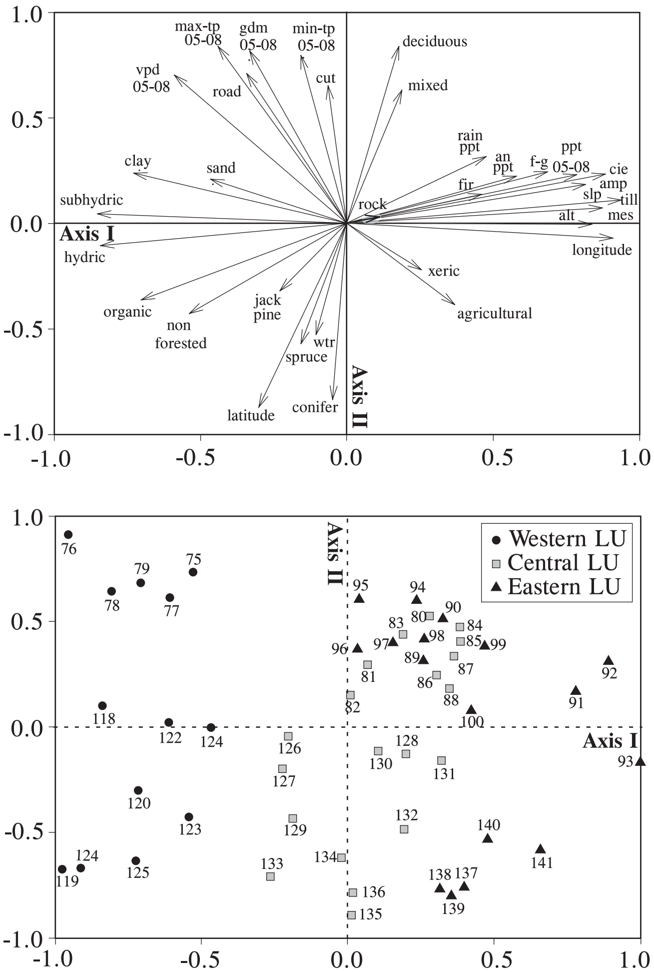


FIGURE 2. Principal component analysis showing the correlations among the 32 explanatory factors (a) and position of the 50 landscape units (LU) based on the sample scores (b). Codes: alt, altitude, amp, amplitude; an ppt, annual precipitation; cie, change in elevation; f-g, fluvio-glacial; gdm 05-08, growing degree month/May to August; max-tp 05-08, maximum mean temperature/May to August; mes, proportion of mesic soil; min-tp 05-08, minimum mean temperature/May to August; ppt 05-08, mean rain precipitation/May to August; rain ppt, mean rain precipitation; vpd 05-08, vapour pressure deficit/May to August; wtr, water bodies.

forestry, and/or urban development influenced the southern portion; thus, the abundance of deciduous and mixed forest stands is higher than in the northern landscape units. In the centre of Québec (LU 80-88 and 126-136), the altitude, the change in elevation, and the slope increase, creating a rugged relief. The landscapes are dominated primarily by till deposits and fluvio-glacial material. Both the proportion of xeric sites (LU 128 and 130-132) and that of jack pine stands (LU 126-129 and 133-136) are high in the black spruce domain. In the eastern third of the study area (LU 89-100 and 137-141), the altitude, the change in elevation, and slope are also greater, particularly in LU 91-93, in comparison with the first two thirds of the area, continuing the pattern of rugged terrain that began in central Québec. LU 94-97, around Lac St-Jean, show an abundant proportion of deciduous and mixed stands as well as a high degree of human activities.

### FACTORS THAT INFLUENCE THE LIGHTNING FIRE REGIME

Stepwise regression analysis showed that variations in the occurrence of lightning fires are related to four main factors: the mean maximum temperature for May to August, the cumulative amount of precipitation during the same period, the proportion of water bodies, and the proportion of jack pine stands in each landscape unit ($R^2$ = 0.7920, Table IIa). The maximum temperature and the total precipitation for May to August have a negative effect on the fire occurrence; fire occurrence is low when maximum temperature and precipitation are high. Conversely, the proportion of water bodies has a positive effect on lightning fire occurrence and the proportion of jack pine per landscape unit could also be seen as positively correlated; thus, fire occurrence is high in landscape units with large proportions of water bodies and jack pine stands.

With regard to the annual burn rate, Table IIa indicates that the explanatory factors are the same as for lightning fire occurrence, except for water bodies ($R^2$ = 0.6335). When precipitation and temperature from May to August increase, the area burned decreases. On the other hand, large burned areas are associated with large values of jack pine in the landscape units. Finally, the median size of

TABLE II. Explanatory factors ($P < 0.05$) for a) natural and b) human fire regime. All variables are significant at $P < 0.01$ except for variables marked with an *, where $0.01 < P < 0.05$.

a) Lightning-caused fires (model: climate > permanent ecological features > forest cover > human modification). Max tp 05-08 = maximum mean temperature from May to August; ppt 05-08 = mean precipitation from May to August; annual ppt = mean annual precipitation.

| Fire occurrence | | | Burned areas | | | Median fire size | | |
|---|---|---|---|---|---|---|---|---|
| Variables | Effects | Partial $R^2$ | Variables | Effects | Partial $R^2$ | Variables | Effects | Partial $R^2$ |
| Max tp 05-08 | - | 0.3049 | Max tp 05-08 | - | 0.2309 | Annual ppt | - | 0.2356 |
| Ppt 05-08 | - | 0.1440 | Ppt 05-08 | - | 0.1001 | | | |
| Water bodies* | + | 0.0312 | Jack pine | + | 0.2080 | | | |
| Jack pine | + | 0.0357 | | | | | | |
| Total $R^2$ | | 0.7920 | | | 0.6335 | | | 0.2356 |

b) Human-caused fires (model: human modification > climate > permanent ecological features > forest cover).

| Fire occurrence | | | Burned areas | | | Median fire size | | |
|---|---|---|---|---|---|---|---|---|
| Variables | Effects | Partial $R^2$ | Variables | Effects | Partial $R^2$ | Variables | Effects | Partial $R^2$ |
| Roads | + | 0.3895 | Ppt 05-08* | - | 0.0789 | Max tp 05-08 | - | 0.3066 |
| Sand | + | 0.1018 | Sand* | + | 0.1219 | Ppt 05-08 | - | 0.2915 |
| Total $R^2$ | | 0.5974 | | | 0.2241 | | | 0.5653 |

lightning fires appears to be affected by the total annual precipitation in a landscape unit ($R^2$ = 0.2356, Table IIa); the greater the total annual precipitation, the smaller the median size of fires.

#### FACTORS THAT INFLUENCE THE HUMAN-CAUSED FIRE REGIME

When we try to explain spatial variations in fire occurrence, human-caused fires are more numerous in landscape units with a denser road network and more widespread sand deposits ($R^2$ = 0.5974). However, when the annual burn rate is examined, even when humans cause the fire, it remains primarily under the influence of the landscape unit's climate and physiography. The variability in mean precipitation from May to August and the percentage of sand deposits appear to influence the annual burn rate ($R^2$ = 0.2241, Table IIb). Summer precipitation values are negatively correlated with the burn rate, whereas the percentage of landscape units covered by sand deposits is positively correlated with the burn rate. Median fire size decreases as summer precipitation increases and mean maximum temperatures for May through August increase ($R^2$ = 0.5653).

#### REGIONALIZATION BASED ON VARIATIONS IN FIRE REGIMES

Mapping of the landscape units based on their lightning fire regime revealed broad ensembles that are fairly homogeneous. Six of the nine potential types of fire regimes resulting from the classification of the burn rate and fire occurrence (matrix 3 × 3) were actually identified (Figure 3a; classes B1, C1, and C2 are not observed). In general, contemporary lightning fire regimes are characterized by long fire cycles (Class A ≥ 500 y), particularly in the balsam fir domain, and a small burn rate (see Appendix I). Forty-one of the 50 landscape units are in Class A (Figure 3a); 23 of these 41 landscape units have a low fire occurrence (Class A1: 0.0-0.02 fires·1,000 $km^{-2}·y^{-1}$), 15 have an intermediate fire occurrence (Class A2: 0.02-0.07 fires·1,000 $km^{-2}·y^{-1}$), and three are in the high-occurrence class (Class A3: 0.07-0.18 fires·1,000 $km^{-2}·y^{-1}$; Table III). Five landscape units are defined by fire cycles ranging from 200 to 500 y (Class B). These are mainly located in the south-central and eastern part of the study area, where four landscape units (LU 83, 87, 131, and 139) are found in occurrence class B2 and one landscape unit (LU 124) in Class B3. Finally, four contiguous landscape units (LU 125, 133, 134, and 135) with fire regime Class C3 are located in the north-central portion of the study area. These landscape units have a fire cycle of less than 200 y and a lightning-fire occurrence varying between 0.07 and 0.18 fires·1,000 $km^{-2}·y^{-1}$. More specifically, the fire cycles of Class C landscape units vary between 135 and 191 y.

Mapping of the lightning fire regimes across the study area suggests a natural regionalization of the LU. Figure 3a illustrates a southwest/northeast gradient reflecting an increase in the occurrence of lightning fires. Lightning fire occurrence values are particularly low in the western lowlands, known as the Abitibi Clay Belt (49° 00' N, 79° 00' W), as well as in the balsam fir domain (Class A1). In the centre of the study area, fire occurrence rises in Class A2 for balsam fir landscape units and those in the south of the spruce forests. Fire occurrence increases to level 3 in the northern fringe of the spruce domain and so does the area burned, which thus define a Class C3 fire regime.

When considering the two ignition sources (humans and lightning), most changes in the regionalization are due to a change in the fire-occurrence class, as human-caused fires are numerous. Changes in fire class occurrence (*i.e.,* changes in class to a higher level) affect 29 landscape units and cover a total strictly forest area equal to 60.4% of the study area, whereas 20 of the 50 landscape units show identical fire cycle and fire occurrence classes (Figures 3a,b; see Table III, grey cells). Five landscape units in the Abitibi region (LU 75, 76, 77, 78, and 79) and three landscape units located on the periphery of Lac St-Jean (LU 89, 95, and 96) have a Class 4 fire occurrence level, that is, 0.18-0.80 fires·1,000 $km^{-2}·y^{-1}$ (Figure 3b). These Class 4 landscape units are all located in rural sections of the study area. A change in fire-cycle class (*i.e.,* change in class to a higher level) affects only eight of the 50 landscape units and covers a total of strictly forested area equal to 15.4% of the study area. More specifically, for the balsam fir domain, three landscape units (LU 86, 95, and 96) located near Lac St-Jean and one landscape unit (LU 75) in the rural part of the Abitibi region change from a Class A fire cycle to a Class B one, *i.e.,* from a fire cycle of over 500 y to one ranging from 200 to 500 y (Figure 3b). In the black spruce domain, three landscape units (LU 126, 129, and 136) in the centre of the study area likewise go from fire cycle Class A to B. Only one landscape unit (LU 87), located southwest of Lac St-Jean, goes from a fire cycle varying between 200 and 500 years (Class B) to a fire cycle of less than 200 y (Class C). The landscape units located in the northern fringe of the spruce forest do not undergo any change in their fire regimes in relation to burn rate or fire occurrence, except in the area of Lake Mistassini (Figure 3b; LU 136).

## Discussion

#### FIRE OCCURRENCE

With $R^2$ values of 0.79 and 0.60 for lightning fires and human-caused fires, respectively, the variation in fire occurrence is among the most predictable variables analyzed. The analysis of fire occurrence also generated the most distinctive models between the two types of ignition sources. The abundance of lightning fires in a given landscape unit remains strongly associated with climatic conditions: there are more lightning fires where low maximum temperature and low precipitation from May through August are observed. Although high maximum temperature would lead to drier fuel, higher precipitations are observed at lower latitude (where temperature is higher), particularly for the western part of the study area (Figure 2a). Thus, fire ignition seems to be lower in the balsam fir subdomain than in the black spruce subdomain, where conifer trees, more flammable than deciduous trees, are abundant (Kafka *et al.,* 2001). The physiography of the landscape units, namely the relative area occupied by water bodies, also influences fire occurrence. Bergeron (1991), in a study comparing island and mainland fire regimes, noted that islands tended to have a higher fire occurrence than the surrounding mainland, suggesting that bodies of

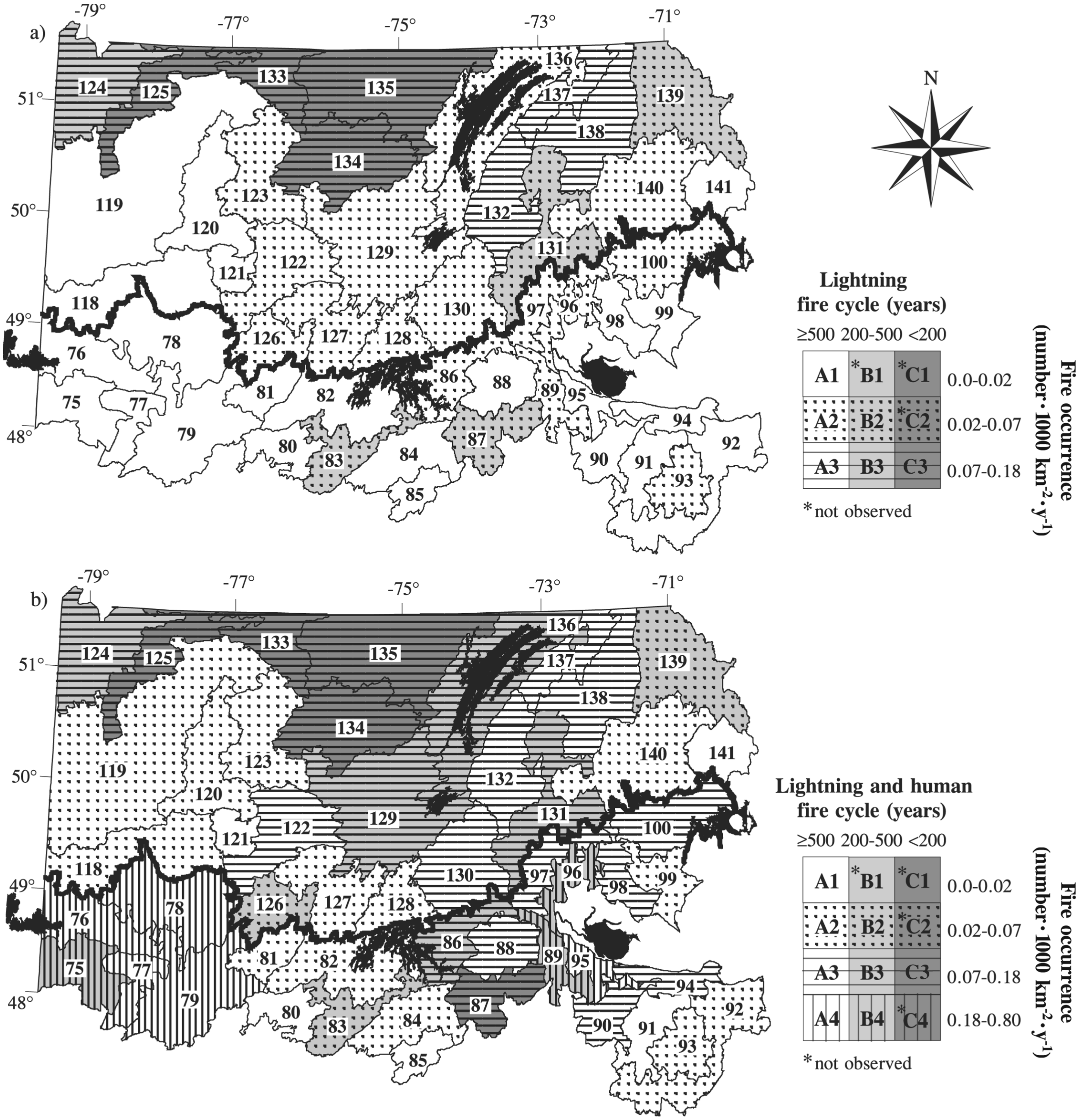


FIGURE 3. Boreal forest regionalization based on variations in a) lightning and b) lightning and human fire regimes for the 1945 to 1998 time period. Bold line represents balsam fir–white birch and black spruce–feather moss bioclimatic domain limits. The map projection is Lambert conformal conic; latitudes and longitudes are approximate and are shown in order to help reader in localizing the study area.

water, which lightning tends to avoid, act as a lightning funnel, causing an increase in the number of lightning strikes and thus in fire occurrence per area on islands. Likewise, landscape units with a high percentage area made up of water could show a higher fire occurrence per forest surface unit area because of the concentration of lightning strikes on lands next to the bodies of water.

Variations in the occurrence of human-caused fires seem to remain independent of the climatic conditions characterizing the landscape units. Only factors reflecting the extent of anthropogenic influence in landscape units, such as the density of the road network, or factors linked to the risk of ignition, such as relative areas of sand deposits, constitute explanatory factors. The density of the road network plays a primary role as a fire danger factor by establishing contact between humans and the forest matrix (Wein & Moore, 1979; Lefort, Gauthier & Bergeron, 2003). In addition, the road network infrastructure is often built on well-drained habitats such as gravel or sand deposits or eskers (Desautels *et al.,* 1996). Fires started by humans can spread in such habitats, even in the absence of extreme climatic conditions.

### ANNUAL BURNED AREA

In contrast with variations in occurrence, variation in annual burn area remains associated with climatic condi-

TABLE III. Landscape units transition based on fire regime classes for lightning-caused and lightning- and human-caused forest fires. The grey cells represent landscape unit occurrences whose fire regimes have not varied whether the ignition source is lightning or lightning and human. Cells with 0 landscape units have been suppressed for the class C fire regime.

| Fire regime | | Lightning-caused fires | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lightning-and human-caused | | a | | | b | | | c | | | Total |
| fires | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | |
| a | 1 | 5 | | | | | | | | | 5 |
| a | 2 | 8 | 5 | | | | | | | | 13 |
| a | 3 | 4 | 4 | 3 | | | | | | | 11 |
| a | 4 | 5 | | | | | | | | | 5 |
| b | 1 | | | | | | | | | | 0 |
| b | 2 | | 1 | | | 2 | | | | | 3 |
| b | 3 | | 3 | | | 1 | 1 | | | | 5 |
| b | 4 | 1 | 2 | | | | | | | | 3 |
| c | 3 | | | | | 1 | | | | 4 | 5 |
| Total | | 23 | 15 | 3 | 0 | 4 | 1 | 0 | 0 | 4 | 50 |

tions regardless of the ignition source. Increases in maximum temperature and precipitation during the active fire season, both factors that follow a spatial gradient in the study area, reduce the annual burn area. Variation in temperature also reflects a latitudinal change in vegetation domain: temperature and precipitation are higher in the balsam fir region than in the black spruce zone. On the other hand, fire is mainly controlled by fuel moisture conditions (Flannigan & Harrington, 1988; Hirsch, 2000), which is more a function of the distribution of temperature and precipitation during the fire season than of their average levels. Bergeron *et al.* (2004), in comparing balsam fir and black spruce fire regimes, reported a significantly higher daily fire severity rating for the balsam fir region, suggesting that the higher area burnt in the black spruce may not be explained easily by weather conditions alone.

Larger area burned may also be related to vegetation composition, *i.e.,* the resinous subdomain is more prone to large fires, which contribute the most to the total area burned. Payette *et al.* (1989) have shown the existence of such a latitudinal gradient for the northern portion of the Québec boreal forest, which is expressed as an integration of climate and vegetation. There is an abundant literature on the key role of climate in explaining large spatio-temporal changes in fire dynamics (Johnson, Fryer & Heathcott, 1990; Bergeron & Archambault, 1993; Harrington & Flannigan, 1993; Johnson & Wowchuk, 1993; Larsen, 1996). These studies stress the role of fluctuating large air masses rather than specific weather parameters as the main driver explaining fire regimes, an interpretation supported by the gradients we observed.

Aside from climatic components, the proportion of jack pine per landscape unit was found to be associated with areas burned by lightning. The abundance of jack pine is probably a consequence of the passage of forest fires in the landscape rather than a cause (Kenkel, 1986; Gauthier, Gagnon & Bergeron, 1993; Gauthier, Bergeron & Simon, 1996). However, the flammability of jack pine stands may also promote ignition and the spread of fires. A number of authors have suggested that jack pine stands have pyrogenic characteristics that favour fire recurrence, particularly on coarse-textured soils (Whitney, 1986; Platt, Evans & Rathbun, 1988). For the present study, however, it is difficult to establish a causal link between the extent of jack pine stands at the scale of landscape units and the fire regime, given the ubiquitous presence of black spruce, a species with pyrogenic characteristics similar to those of jack pine.

In the case of human-caused forest fires, the percentage of sand deposits in each landscape unit also affects the annual burned area, probably because it promotes the spread of fires and their final size. Many authors have observed a short fire-return interval on well-drained sites (Rowe & Scotter, 1973; Dansereau & Bergeron, 1993), which would explain the lead role played by sand deposits in the anthropogenic fire regime.

Although summer precipitation influences annual burned areas regardless of ignition source, the model of the areas burned by lightning remains more predictable ($R^2$ = 0.63) than that of human-caused fires ($R^2$ = 0.30). Considering that lightning fires were responsible for 70% of the areas burned during the study period, this shows that despite the presence of humans, climate continues to exert appreciable control over observed variations in total area burned.

### MEDIAN FIRE SIZE

In contrast with the annual burned area, the median size of human-caused fires appears to be more predictable (with an $R^2$ of 0.57) than that of lightning fires ($R^2$ of nearly 25%). In both cases, the prevailing climatic conditions in landscape units played a significant role in relation to the variations in this component of the fire regime. As with the area burned, an increase in precipitation was found to have a negative effect on fire size, regardless of ignition source. Fire detection and initial fire attack are likely to be more rapid for human-caused fires than for lightning fires, particularly in populated areas with a dense primary road network. This may explain why median fire size is smaller for human-caused fires and why the latter is more predictable.

### REGIONALIZATION OF LANDSCAPE UNITS ON THE BASIS OF THEIR FIRE REGIMES

The fire cycles described in our study are generally relatively long, more than 500 y. This may appear to contrast with some long-term fire history reconstructions, which have suggested shorter mean time since fire (Bergeron *et al.,* 2001). It is worth noting that the time span of the fire archives covers a relatively short period (1945-1998), which sometimes may result in long fire cycles. Moreover, Bergeron *et al.* (2001) and many others (see for instance Lesieur, Gauthier & Bergeron, 2002; Lefort, Gauthier & Bergeron, 2003) have reported that fire cycles have been lengthening in recent centuries, particularly since the end of the 1920s, as a result of climate change and fire suppression activity. Furthermore, Bergeron *et al.* (2001) stated that although the fire regimes have changed over the past 300 y, the relative differences in fire cycle between regions of Québec boreal forest have been maintained during this period. It is thus very likely that the boundaries of regions defined on the basis of these regimes have not fluctuated much over the years, since they are governed more by the behaviour of air masses and the physiography. Further studies on the changes in behaviour of these air masses should be undertaken to learn more about the permanence of these boundaries.

It is interesting to note that when looking in this study at the lightning fire regime or at the fire regime of both sources of ignition, we also noticed little change in the regionalization. As a rule, few landscape units change their fire cycle class (15.4% of the study area) when the two ignition sources are considered together. Human activities appear to have affected mainly the fire occurrence in landscape units (change to a higher fire occurrence class covered 60.4% of the study area), particularly in the balsam fir–white birch forest, where nearly 85% of human-caused fires were started. More specifically, 597 (68.9%) out of a total of 866 human-caused fires (Table I) occurred in the eight landscape units of the balsam fir domain that have a Class 4 fire occurrence (0.18-0.80 fires$\cdot$1,000 km$^{-2}\cdot$y$^{-1}$; Figure 3b), that is, the units located near the population centres of the Abitibi and Lac St-Jean regions. Although sectors where there is no human activity are rare, an historical analysis shows that the Abitibi lowlands and the Lac St-Jean region are the main regions that underwent massive settlement in the early 20$^{th}$ and 19$^{th}$ centuries, respectively. These regions offered conditions favourable for agricultural and forestry activities, and infrastructure development accordingly became concentrated in these two areas (Vincent, 1995). Over the decades, the migration of people into the boreal environment took place mainly in the southern fringe of the study area (LU 75-79 and 94-99), primarily in the balsam fir domain; this is reflected by the importance of the road network (Figure 1).

Although there are explanatory factors that are common to the two ignition sources, the areas burned resulting from human-caused fires are mainly located (63% of the total human-burned areas) in the balsam fir landscape units and are smaller in extent, accounting for only 29% of the total area burned *versus* 71% for lightning fires. Furthermore, this estimate of the predominance of lightning fires can be considered conservative, since detection of these fires in isolated regions of the spruce domain was likely not as effective (in the 1950s and 1960s) as detection of human-caused fires. Considering that the age structure and composition of the forest cover is more dependent on the values for areas burned than on the number of fires, and considering that the area burned values are more attributable to lightning, it appears unlikely that human activities could have significantly modified the boundaries of regions characterized on the basis of their fire regime. Human activities seem to exert influence on the fire regime only at a local scale where climate and physiography are already conducive to fire. For instance, when considering the two ignition sources, only one landscape unit (75) in the poorly drained and rich organic soils of the Abitibi region (Figures 2a,b) changed to a higher fire-cycle class, whereas the central and eastern parts of the study area, more prone to forest fires, had seven LU that changed to a higher fire cycle (Figures 3a,b).

### REGIONALIZATION AND IMPLICATIONS FOR FOREST MANAGEMENT

A number of researchers have said that the management strategies used in the boreal forest must be based to a greater extent on knowledge of the disturbance regimes and their effects on the composition and age structure of natural forest mosaics (Hunter, 1993; Bergeron *et al.,* 1999; Harvey *et al.,* 2002). Better knowledge of fire regimes and their spatial and temporal variability can facilitate the development of sustainable forest management practices and strategies and reduce merchantable volume losses resulting from forest fires. The variability in the climate and physiographic factors and in the fire regime of the boreal forest of western Québec makes it necessary to develop management strategies that are flexible and adapted to the multiple facets of the regional situation (Leduc *et al.,* 2000).

For instance, landscape units characterized by a long fire cycle and low fire occurrence are common in the western and central regions of the balsam fir bioclimatic domain. Thus, mature and overmature forests are abundant, leading to a mosaic of even-aged and uneven-aged stands. Bergeron *et al.* (1999) have proposed that management practices should be diversified to ensure that the structure and composition of the natural forest is maintained. In the Abitibi region, in addition to even-aged management that aims to emulate fire, partial and selective cutting should be carried out to encourage the maintenance and regeneration of uneven-aged stands. On the other hand, landscape units at the northern fringe of the black spruce domain (LU 125, 133, 134, and 135) and some landscape units (LU 87, 131, and 137) located in the central and eastern parts of the study area show a shorter fire cycle. According to Bergeron *et al.* (1999), regions with a natural short fire cycle could be subjected to a larger proportion of even-aged management, especially if the current rate of burn is lower than the historical one. On the other hand, as old forests are rare in those systems, conservation issues should also be considered. Also, one must ask whether it is possible to practice sustainable forestry in this system, as the recurrence of fire may cause regeneration problems. Is it possible to limit the regeneration accidents caused by the passage of fire among young development stages with our suppression capabilities? Moreover, can fires be controlled in those regions in a way that would significantly limit merchantable volume losses?

The existence of homogeneous zones in terms of burn rate is not always obvious; some authors have stated that the variability in forest fires in western Canada cannot easily be spatially characterized, because burn rates appear to be too variable from one year to the next (Armstrong *et al.,* 2003). Given that climate and physiography exert direct control over fire regimes, however, we find it difficult to imagine that large ensembles defined by a similar climate, physiography, and disturbance regime can be so unstable over time that we can not derive benefit from an understanding of the conditions that gave rise to the forests they harbour. Even if fire suppression and human activities have changed the fire cycle, the relative position of each region should remain similar through time. Although we recognize the inter-annual variability in burned areas and the influence of human activities, characterization of fire regimes should be considered a useful complement to ecological regionalization of the territory.

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APPENDIX I. Fire regime characteristics for each landscape unit (LU). Hum.: Human, Light.: Lightning.

| | Fire occurrence · 1,000 km$^{-2}$ · y$^{-1}$ | | Burn rate (%) | | Median size (ha) 50$^{th}$ percentile | | Fire cycle (y) | Fire regime | Fire cycle (y) | Fire regime |
|---|---|---|---|---|---|---|---|---|---|---|
| LU | Light. | Hum. | Light. | Hum. | Light. | Hum. | Light. | Light.[1] | Light./Hum. | Light./Hum.[2] |
| 75 | 0.005 | 0.799 | 0.002 | 0.323 | * | 120 | ≥ 1,500 | A1 | 308 | B4 |
| 76 | 0.006 | 0.501 | 0.024 | 0.121 | * | 100 | ≥ 1,500 | A1 | 690 | A4 |
| 77 | 0.009 | 0.481 | 0.002 | 0.136 | * | 130 | ≥ 1,500 | A1 | 725 | A4 |
| 78 | 0.003 | 0.209 | 0.003 | 0.083 | * | 120 | ≥ 1,500 | A1 | 1,176 | A4 |
| 79 | 0.003 | 0.338 | 0.001 | 0.199 | * | 200 | ≥ 1,500 | A1 | 500 | A4 |
| 80 | 0.008 | 0.008 | 0.001 | 0.011 | * | * | ≥ 1,500 | A1 | ≥ 1,500 | A1 |
| 81 | 0.008 | 0.017 | 0.021 | 0.025 | * | * | ≥ 1,500 | A1 | ≥ 1,500 | A2 |
| 82 | 0.013 | 0.033 | 0.067 | 0.054 | * | 1,010 | 1,484 | A1 | 826 | A2 |
| 83 | 0.034 | 0.023 | 0.233 | 0.018 | 160 | * | 429 | B2 | 398 | B2 |
| 84 | 0.009 | 0.050 | 0.118 | 0.039 | * | 130 | 844 | A1 | 637 | A2 |
| 85 | 0.024 | 0.000 | 0.055 | 0.000 | * | * | ≥ 1,500 | A1 | ≥ 1,500 | A1 |
| 86 | 0.048 | 0.021 | 0.027 | 0.202 | 70 | * | ≥ 1,500 | A2 | 437 | B3 |
| 87 | 0.042 | 0.058 | 0.309 | 0.381 | 2,150 | 150 | 324 | B2 | 145 | C3 |
| 88 | 0.024 | 0.059 | 0.054 | 0.082 | * | 160 | ≥ 1,500 | A1 | 741 | A3 |
| 89 | 0.041 | 0.203 | 0.110 | 0.188 | 2,500 | 340 | 905 | A2 | 336 | B4 |
| 90 | 0.022 | 0.058 | 0.019 | 0.016 | * | 200 | ≥ 1,500 | A1 | ≥ 1,500 | A3 |
| 91 | 0.012 | 0.000 | 0.029 | 0.000 | * | * | ≥ 1,500 | A1 | ≥ 1,500 | A1 |
| 92 | 0.009 | 0.048 | 0.025 | 0.023 | * | 400 | ≥ 1,500 | A1 | ≥ 1,500 | A2 |
| 93 | 0.029 | 0.029 | 0.021 | 0.004 | * | * | ≥ 1,500 | A2 | ≥ 1,500 | A2 |
| 94 | 0.000 | 0.144 | 0.000 | 0.059 | * | 130 | ≥ 1,500 | A1 | ≥ 1,500 | A3 |
| 95 | 0.000 | 0.408 | 0.000 | 0.119 | * | 110 | ≥ 1,500 | A1 | 800 | A4 |
| 96 | 0.048 | 0.240 | 0.008 | 0.200 | 110 | 200 | ≥ 1,500 | A2 | 481 | B4 |
| 97 | 0.038 | 0.075 | 0.007 | 0.131 | 100 | 550 | ≥ 1,500 | A2 | 725 | A3 |
| 98 | 0.000 | 0.121 | 0.000 | 0.077 | * | 170 | ≥ 1,500 | A1 | 1,282 | A3 |
| 99 | 0.007 | 0.036 | 0.001 | 0.029 | * | 320 | ≥ 1,500 | A1 | ≥ 1,500 | A2 |
| 100 | 0.034 | 0.041 | 0.053 | 0.080 | 110 | 200 | ≥ 1,500 | A2 | 746 | A3 |
| 118 | 0.008 | 0.036 | 0.020 | 0.014 | * | 130 | ≥ 1,500 | A1 | ≥ 1,500 | A2 |
| 119 | 0.024 | 0.005 | 0.060 | 0.041 | 430 | 1,210 | ≥ 1,500 | A1 | 990 | A2 |
| 120 | 0.018 | 0.018 | 0.043 | 0.036 | 2,890 | 260 | ≥ 1,500 | A1 | 1,266 | A2 |
| 121 | 0.000 | 0.000 | 0.000 | 0.000 | * | * | ≥ 1,500 | A1 | ≥ 1,500 | A1 |
| 122 | 0.044 | 0.030 | 0.086 | 0.035 | 130 | 840 | 1,158 | A2 | 820 | A3 |
| 123 | 0.043 | 0.000 | 0.100 | 0.000 | 1,010 | * | 1,000 | A2 | 1,000 | A2 |
| 124 | 0.074 | 0.005 | 0.336 | 0.012 | 2,040 | * | 298 | B3 | 287 | B3 |
| 125 | 0.097 | 0.020 | 0.524 | 0.109 | 1,320 | 4,450 | 191 | C3 | 158 | C3 |
| 126 | 0.036 | 0.006 | 0.035 | 0.278 | 350 | * | ≥ 1,500 | A2 | 319 | B2 |
| 127 | 0.030 | 0.011 | 0.009 | 0.021 | 200 | * | ≥ 1,500 | A2 | ≥ 1,500 | A2 |
| 128 | 0.044 | 0.006 | 0.106 | 0.001 | 130 | * | 939 | A2 | 935 | A2 |
| 129 | 0.049 | 0.047 | 0.174 | 0.031 | 490 | 130 | 574 | A2 | 488 | B3 |
| 130 | 0.039 | 0.046 | 0.041 | 0.080 | 360 | 470 | ≥ 1,500 | A2 | 826 | A3 |
| 131 | 0.055 | 0.014 | 0.242 | 0.014 | 380 | 970 | 413 | B2 | 391 | B3 |
| 132 | 0.079 | 0.000 | 0.152 | 0.000 | 220 | * | 657 | A3 | 657 | A3 |
| 133 | 0.177 | 0.006 | 0.741 | 0.097 | 2,900 | * | 135 | C3 | 120 | C3 |
| 134 | 0.082 | 0.016 | 0.709 | 0.026 | 4,650 | 480 | 141 | C3 | 136 | C3 |
| 135 | 0.092 | 0.010 | 0.690 | 0.044 | 750 | 3,470 | 145 | C3 | 137 | C3 |
| 136 | 0.065 | 0.034 | 0.165 | 0.065 | 450 | 270 | 605 | A2 | 435 | B3 |
| 137 | 0.067 | 0.007 | 0.018 | 0.002 | 170 | * | ≥ 1,500 | A3 | ≥ 1,500 | A3 |
| 138 | 0.099 | 0.006 | 0.118 | 0.002 | 180 | * | 851 | A3 | 840 | A3 |
| 139 | 0.053 | 0.000 | 0.282 | 0.000 | 1,300 | * | 355 | B2 | 355 | B2 |
| 140 | 0.047 | 0.013 | 0.158 | 0.016 | 140 | 450 | 631 | A2 | 571 | A2 |
| 141 | 0.000 | 0.000 | 0.000 | 0.000 | * | * | ≥ 1,500 | A1 | ≥ 1,500 | A1 |
| Mean | 0.036 | 0.087 | 0.120 | 0.070 | 918 | 576 | - | - | - | - |

* Fewer than 5 forest fires per landscape unit.
[1] See figure 3a for the fire regime class definition.
[2] See figure 3b for the fire regime class definition.