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Spatial pattern analyses of post-fire residual stands in the black spruce boreal forest of western Quebec

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Abstract. In this study, we characterised the composition and configuration of post-fire residual habitats belonging to two physiographic zones of the black spruce–moss domain in western Quebec. Thirty-three large fires (2000–52 000 ha) were selected and extracted on classified Landsat satellite imagery. The results show that a minimum of 2% and a maximum of 22% of burned areas escaped fire, with an overall average of 10.4%. The many forest patches that partially or entirely escaped fire formed residual habitats (RHs). It was found that although the area of RHs follows a linear relationship with fire size, their proportion appears relatively constant. Spatial analyses showed that the fires could be separated into two groups depending on the physiographic zones (East-Canadian Shield *v.* West-Clay Belt Lowlands). Fires in the west zone generate less RHs and appear to be associated with more extreme weather conditions. In most cases there was no association with water or wetlands; in some fires the presence of RHs is associated with the proximity of water bodies. The failure to find an association between RHs and wetlands suggests that this type of environment is part of the fuel. Coniferous woodland with moss appears particularly overrepresented within RHs. Our results suggest that the local and regional physiographic conditions strongly influence the creation of RHs; therefore, it is important to consider those differences when applying ecosystem-based management.

Additional keywords: fire pattern, physiographic zone, satellite imagery.

Introduction

Fire is one of the main natural disturbances influencing the landscape mosaic in boreal forests. The extent of area consumed by fire can be large (over 1×10^6 ha) (Johnson 1992), contributing extensively to the reshaping of the landscape (Heinselman 1973; Bergeron 1991). In the coniferous boreal forest, the fire disturbance regime is characterised by crown fires of high intensity spanning large areas (Van Wagner 1983). Recent studies have shown, however, that despite the general severity of fires, they do not burn the entire area located within the perimeter of such an event (Kafka *et al.* 2001; Leduc *et al.* 2007; Perron *et al.* 2009). Typically the burned area includes a mosaic of stands that have burned at different degrees of severity: some entirely burned habitats (with scorched or blackened canopies), other habitats burned to varying degrees (where scorched and unscorched trees are present), and habitats where all tree canopies have been spared (Van Wagner 1983; Turner and Romme 1994; Gauthier *et al.* 2001; Kafka *et al.* 2001; Leduc *et al.* 2007; Perron *et al.* 2009). Therefore, in a fire event, there are many forest patches that partially or entirely escape fire, forming residual habitats (RHs).

The larger the fire, the greater is the probability of encountering barriers impeding fire expansion (wetlands, waterways, steep slopes; Eberhart 1986). These RHs, either located within the burned area or on the periphery, play an important role in maintaining ecosystem functions through the recolonisation of tree species within the burned area (Kafka *et al.* 2001), maintaining biodiversity, and acting as animal refuges (Bendell 1974; Gandhi *et al.* 2001; Imbeau and Desrochers 2002; Nappi *et al.* 2004).

The presence of RHs is usually attributed to one of the three following hypotheses or scenarios. First, they can be generated more or less randomly (Jenkins *et al.* 2001; Meyn *et al.* 2007; Podur and Martell 2009), for instance as a consequence of a change in wind direction that occurs during the fire, which subsequently helps to preserve RHs. Second, some land cover types could be less susceptible to fire because of their fuel properties (Pyne 1984; Cumming 2001; Collins *et al.* 2007). In this case, these cover types might appear more frequently within residual patches than in the surrounding landscape. Third, the presence of natural fire breaks (such as wetlands, water or steep or rugged terrain) could protect forest patches from fire (Romme

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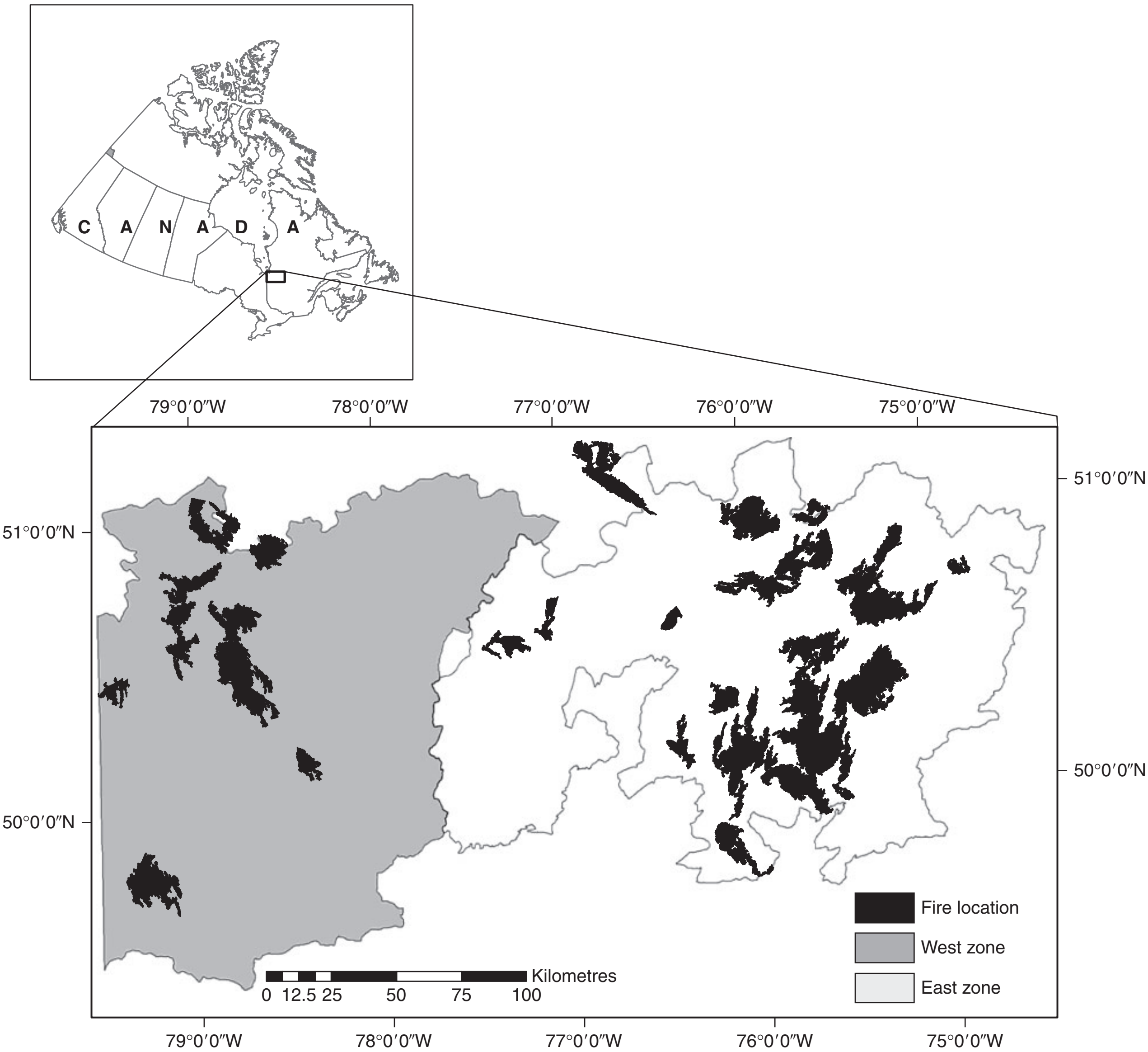

Fig. 1. Study area and location of the fires sampled.

and Knight 1981; Eberhart 1986; Román-Cuesta *et al.* 2009). In this case, we might observe a positive spatial association between RHs and water bodies or wetlands. As the importance of these elements at the landscape level may differ among physiographic units, we can hypothesise that distinct physiographic regions would also show different RH compositions and configurations (Kushla and Ripple 1997; Mermoz *et al.* 2005; Flannigan *et al.* 2009; Román-Cuesta *et al.* 2009).

The general objectives of the present study were to characterise the composition and configuration of RHs in the black spruce–moss domain of western Quebec and to examine differences between two physiographic zones, i.e. the eastern zone (Canadian Shield) and the western zone (James Bay Lowlands), using Landsat satellite imagery. There have been relatively few studies on the characterisation of RH patterns using satellite imagery within large fires. The first objective was to evaluate if factors such as weather conditions, physiographic configuration and fire conditions could explain the configuration, composition and amount of RHs after fires. The second objective was to evaluate whether RHs are created randomly or as a result of particular stand composition types that naturally deter fire or due to their proximity to natural fire breaks.

Study area

The study area located in western Quebec, between 74–80°W and 49–51°N, is part of the black spruce–feathermoss bioclimatic subdomain (Fig. 1). Considering the ecological differences that characterise the study area (deposit type, vegetative cover, wetland environment, etc.), two physiographic zones were distinguished: the western zone is associated with the James Bay Plain whereas the eastern zone consists of the Canadian Shield.

Table 1. Land cover types and physical characteristics in each zone
Physical characteristics from Robitaille and Saucier (1998). Land cover types from satellite imagery

Physical characteristics	West zone	East zone
Precipitation	<700 mm	900 mm
Temperature (°C)	−2.5–0.0	−2.5–0.0
Relief	Uniform and flat	Rugged
Slope (%)	1	7
Water bodies	Few and smaller, uniformly shaped	Different shapes and size
Peatlands (wetlands)	Large and many	Few
Land cover types	(%)	(%)
Open coniferous with moss	42.0	25.5
Medium coniferous cover with moss	25.0	20.1
Coniferous woodland with moss	18.6	5.7
Dense coniferous mature	7.0	26.2
Open coniferous with lichen	3.8	1.5
Dense coniferous mix	2.2	16.4
Medium coniferous cover with lichens	1.1	1.4
Open mix of broadleaf and coniferous	0.3	2.3
Dense mix of broadleaf and coniferous	0.1	0.9

The following characteristics are based on Robitaille and Saucier (1998). The organic deposit type, accumulated in poorly drained areas, is dominant in the west, whereas in the east the dominant surficial deposit type is thick glacial till (Table 1). Using ESRI ArcGIS 9.2 (Redlands, CA, USA), the boundaries of the two physiographic zones (west and east) were established by following the distribution of outer limits of the main deposit types. Mean annual precipitation in the west is low (less than 700 mm) whereas in the east it is 900 mm. Mean annual temperature in both zones varies between −2.5 and 0.0°C. The relief is relatively uniform and flat in the west, characterised by plains with a few scattered rocky hills. It is more rugged in the east, consisting mostly of hills. The mean slope is fairly small in the far west (<1%) whereas in the east the mean slope is greater. Main water bodies (e.g. lakes) in the east are many shapes and sizes, whereas in the west the few and smaller water bodies are more uniformly shaped or circular. In addition, the western zone contains large peatlands (Payette and Rochefort 2001).

Based on the observation of Landsat image classification (see below), the two zones show notable differences in the nature of their forest land cover (Table 1). The western zone is composed of 42% open coniferous with moss; 25% medium coniferous cover with moss; and 19% coniferous woodland with moss. Dense coniferous mature makes up only 7% of the cover. Approximately 52% of the east zone is accounted for by two co-dominant land cover types: Dense coniferous mature (26.2%) and open coniferous with moss (25.52%). In addition, medium coniferous cover with moss accounts for 20% of the area. To summarise, the landscape of the west zone is characterised by a forest with a low-density coniferous cover mixed with woodlands, whereas the east zone is composed of older coniferous stands, coupled with high-density coniferous stands. Referring to studies conducted south of the study area (Bergeron *et al.* 2004, 2006), and based on the frequency of fires observed, the current fire cycle (1940–present) should be ~400 years, and it could be longer in the western than in the eastern zone. Fires have occurred in the entire study area, with a greater number occurring in the south and north-east. The region covered by satellite images that was considered in the analyses covers 80 000 km^2.

Methodology

Fire selection

Four satellite scenes of the study area taken at different dates (1985, 1995, 2000 and 2005) and already classified with 80% accuracy (Wulder *et al.* 2008) plus a geo-referenced database including all the fires between 1940 and 2003 provided by the Ministère des Ressources naturelles et de la Faune du Québec (MRNF) were at the basis of this study. As reported by Johnson *et al.* (1998), smaller fires are the most common; however, the larger fires affect the structure and composition of the boreal forest the most. Consequently we have chosen to work with fires that are equal or superior to 2000 ha, which are responsible for 94% of the burned area for the time period observed.

The size distribution of the 724 large fires that occurred in the spruce–moss domain of western Quebec enabled us to classify the fires into four different size classes: Class I (2000–5000 ha); Class II (5000–15 000 ha); Class III (20 000–40 000 ha); and Class IV (>40 000 ha). Among them, only 37 fires were subsequently included in further analyses based on the following criteria: (1) adequate satellite scene availability, i.e. the difference between the image year and the fire year was less than 25 years (based on our personal observation, after 25 years, RHs become difficult to distinguish from post-fire revegetated areas, thereby increasing the confusion between burned habitat and RH); and (2) the post-fire stands had not been salvaged, based on forest inventory maps of the province reported spatially in the Système d'information forestière par tesselle database ($\text{SIFORT}_{\text{SOPFEU, SOPFIM, DCF}}$).

Careful examination revealed that the fire boundaries depicted on satellite images were occasionally different from the fire boundaries reported in the MRNF database. For the

Table 2. Characteristics of the 33 sampled fires

DC, Drought Code; Duration, time elapsed between the day the fire started and the day it was extinguished; L, lightning; FWI, Fire Weather Index; H, human; TSF, time since fire, with the date when the satellite image was taken. Fires resulting from lumped are numbers 7, 8, 9 and 25

Fire no.	Zone	Month	Area (ha)	TSF (years)	Duration (days)	Cause	DC	FWI
3	West	6	3114	9	30	L	195.3	8.1
6	West	6	3757	2	20	L	209.0	4.1
9	West	6	5175	3	33	L	132.0	2.7
11	West	7	5562	10	21	L	123.3	1.7
16	West	6	6674	1	16	L	77.9	4.1
19	West	8	9413	19	38	L	331.8	4.8
21	West	6	10 373	5	20	L	150.0	6.6
23	West	5	11 626	2	17	L	117.5	4.3
28	West	6	20 914	24	33	H	132.7	2.6
32	West	6	42 753	3	25	L	136.8	1.2
1	East	6	2026	5	21	L	122.3	2.7
2	East	6	2486	14	22	H	124.4	2.3
4	East	7	3162	10	10	H	206.3	5.9
5	East	6	3271	5	17	L	144.7	2.5
7	East	5	4243	<1	33	L	121.9	4.1
8	East	6	5133	5	22	L	124.0	3.2
10	East	5	5383	15	30	L	108.7	5.5
12	East	8	5591	5	25	L	219.0	2.4
13	East	5	5703	<1	28	L	122.9	4.9
14	East	5	5853	13	12	H	45.7	3.4
15	East	5	6129	6	22	H	104.9	8.1
17	East	6	6973	5	32	L	130.4	2.3
18	East	6	7376	25	25	H	108.1	9.6
20	East	6	10 177	5	22	L	119.6	3.3
22	East	5	11 220	15	45	L	156.6	5.7
24	East	6	11 565	5	31	L	125.4	2.1
25	East	6	14 194	4	39	L	106.0	2.2
26	East	5	20 152	15	35	L	109.8	3.3
27	East	6	21 262	5	19	L	108.4	8.9
29	East	5	33 325	15	41	L	121.1	3.9
30	East	6	36 325	18	48	H	145.3	5.5
31	East	6	41 631	20	53	L	196.0	5.3
33	East	5	51 882	15	44	L	117.3	4.3

purpose of this study, the boundaries were delineated on the images themselves, a step recommended recently by Podur and Martell (2009). Moreover, in order to minimise RH peripheral and isolated pixels, an inside 30 m-wide buffer zone from the perimeter of the fire was established. In addition, some fires that were very close to one another, occurring within the same month and sharing the same ignition date, were lumped together. The final list of sampling fires consisted of 33 fire landscapes (29 individual fires and 4 lumped fires) (Table 2).

Identification of post-fire RH patches

The satellite scenes used were previously classified into 48 land cover types (Wulder *et al.* 2008). For all fire images, we used an ArcGIS 9.2 generalisation function called Majority Filter. This tool replaces cells in a raster based on the majority of their contiguous neighbouring cells. We used eight neighbours (a 3×3 sliding window) with a majority replacement threshold. This operation was repeated six times in order to generalise the image sufficiently to eliminate the maximum number of isolated pixels from the fire periphery. To facilitate further analyses of spatial configuration, a contrasted fire landscape was generated by grouping the original 48 land cover types in to five different habitat types: burned habitat, residual habitat, wetland, water, and others. The robustness of this classification was verified by comparing before and after fire scenes available for eight fires, particularly to make sure that cover classes regrouped in RHs were also present before the fire event. The final classification (Appendix 1) shows that RHs are composed of cells with a forested land cover.

Spatial configuration of RHs within the fire perimeter

The within-fire configuration and fragmentation of habitats were obtained using the spatial analysis program FRAGSTATS 3.3 (McGarigal and Marks 1994). Because of potential redundancies between the results obtained with spatial indices when they are correlated (Turner *et al.* 2001), Wu (2004) suggested that indices should be carefully chosen based on their minimal correlations with other indices, their simplicity and their sensitivity to landscape variations. To minimise consequent redundancies, only 10 indices were retained, which belong to three index groups. Four indices concern the overall landscape composition: total area of fire (TA), total area in RHs (CA), percentage of landscape in RHs (PLAND), and largest patch index in RHs (LPI). Three indices concern RH configuration: Area-Weighted Mean Shape Index (AWMSI), mean nearest-neighbour distance (ENN_MN), and Interspersion and Juxtaposition Index (IJI). Finally, three indices concern the fragmentation level: number of patches, patch density, and mean patch size (MPS). Some of these indices were also computed for all habitat types (see Appendix 2).

Ordination of spatial data

To summarise the configuration characteristics, all fires described by spatial indices were submitted to a Principal Component Analysis (PCA) in a first step. In the second step, to assess the extent to which these characteristics could be influenced by the climatic conditions prevailing during each fire, post-hoc correlations between the PCA fire scores obtained and external explanatory factors (date, weather and fire danger indices) were carried out. Fire duration was defined as the time elapsed from the onset of the fire until it was declared extinguished. Fire danger data were described using the six indices of the Canadian Forest Fire Weather Index System that qualifies the effects of fuel moisture and wind on fire behaviour (Van Wagner 1987). The first three indices are the fuel moisture codes: Fine Fuel Moisture Code represents the moisture content of the litter, Duff Moisture Code represents the moisture content of the loosely compacted, decomposing organic layers of moderate depth, and Drought Code (DC) represents the moisture content of the deep and compact organic layers. The remaining three indices, which represent fire behaviour, are computed from the preceding indices and wind velocity: Initial Spread Index provides an estimation of the rate of spread, Build-up Index provides an estimate of the fuel available for combustion, whereas Fire Weather Index (FWI) is a rating of frontal fire intensity. Daily Severity Rating is a numeric rating of the difficulty of controlling fires. It is based on the FWI, but it more accurately reflects the expected efforts required for fire suppression. The values were provided by the SOPFEU (Société de protection des forêts contre les feux; Québec's fire agency) for most fires. When the data were missing they were computed using a modified version of BioSIM (Québec, QC, Canada), which now includes a routine to compute those values (Régnière and Bolstad 1994). Only the maximum values during the course of the fire were used for these variables: DC, precipitation, relative humidity, Duff Moisture Code, FWI, wind speed (WS), Build-up Index, temperature, Fine Fuel Moisture Code, Initial Spread Index, and Daily Severity Rating. The cause of fire, its start date and the fire zone (west or east) were also included in post-hoc correlation with PCA fire scores. Student's *t*-test was performed in order to compare the west and east zones regarding spatial indices, the percentage of wetland, the percentage of water, and the total percentage of wetland and water.

RH composition: are particular land cover types more likely to generate RHs?

To determine whether some land cover types are more fire resistant (subsequently creating RHs), we compared the composition (in terms of proportion of land cover) of post-fire RHs with the land cover proportions of their associated physiographic zones using the original classified images of 2000. Prior to calculating these proportions, we excluded cover types supposed not to be susceptible to fire, such as cut, water, wetlands, herb, agriculture, lichen, moss and alpine land, in addition to the regrouped classes in the 'others' category (see relabelling above).

The proportions of land cover observed in the physiographic zones were considered the 'expected values', whereas the land cover proportion within RHs for each fire were considered as the 'observed values'. A partial Chi-square was calculated using the following Chi-square test: $\chi_P^2 = (\mathrm{O}-\mathrm{E})/\sqrt{\mathrm{E}}$ (Bishop *et al.* 1975), where O is observed and E is expected. This partial Chi-square was computed for each of the nine land cover types, and the critical value with Bonferroni correction was calculated for both zones with three confidence limits ($\alpha = 0.01, 0.05, 0.001$) using the following formula: $\sqrt{ddl \times (x^2 \frac{\alpha}{nbcases})/nbcases}$ (Legendre and Legendre 1998), with 8 degrees of freedom and a case number of 18 (corresponding to two columns, i.e. the zone and the fire, and nine habitat types (2×9)). When the Chi-square value is equal to or greater than the absolute critical Chi-square value, it indicates a significant difference between the land cover proportion observed in the RH and the expected values for the zone. Positive values indicate an over-representation within post-fire RHs compared with its proportion in the zone, whereas negative values indicate an under-representation. In the case of a non-significant difference, it implies that the RH composition is proportional to the composition found in the physiographic zone.

RH spatial distribution: are RHs adjacent to water bodies or wetlands?

To determine if the occurrence of RHs is associated with land cover, we compared, for each fire, two composition vectors. The first vector describes the land cover composition in contact with RHs and corresponds to the 'observed values'. The second composition vector, corresponding to the 'expected values', describes all contacts (edge composition) of all land cover types present within a fire. Land cover composition surrounding RHs was obtained using ArcGIS 9.2 tools. First, we used the 'expand' tool to identify RH first-order neighbouring cells. This expanded fire map was overlaid with the fire map in order to identify pixels showing changes. These pixels correspond to the RH surrounding environment and their composition on the fire map constitutes the RH neighbourhood composition. To assess the total land cover contact composition observed in the entire fire, we then used the FRAGSTATS edge characterisation tool, which allowed us to calculate the sum of all pixels that showed a contact between two or more land cover types. In order to avoid a double count, RH contact pixels were removed from the total contact composition vector. To statistically compare the composition vector surrounding RHs with the total contact composition vector, the partial Chi-square calculation described in the previous section was used.

Results

Spatial configuration of RHs within the fire perimeter

The RHs occupied between 1.9 and 22.3% of the total fire area, with an average of 10.4%. With regard to wetlands and aquatic

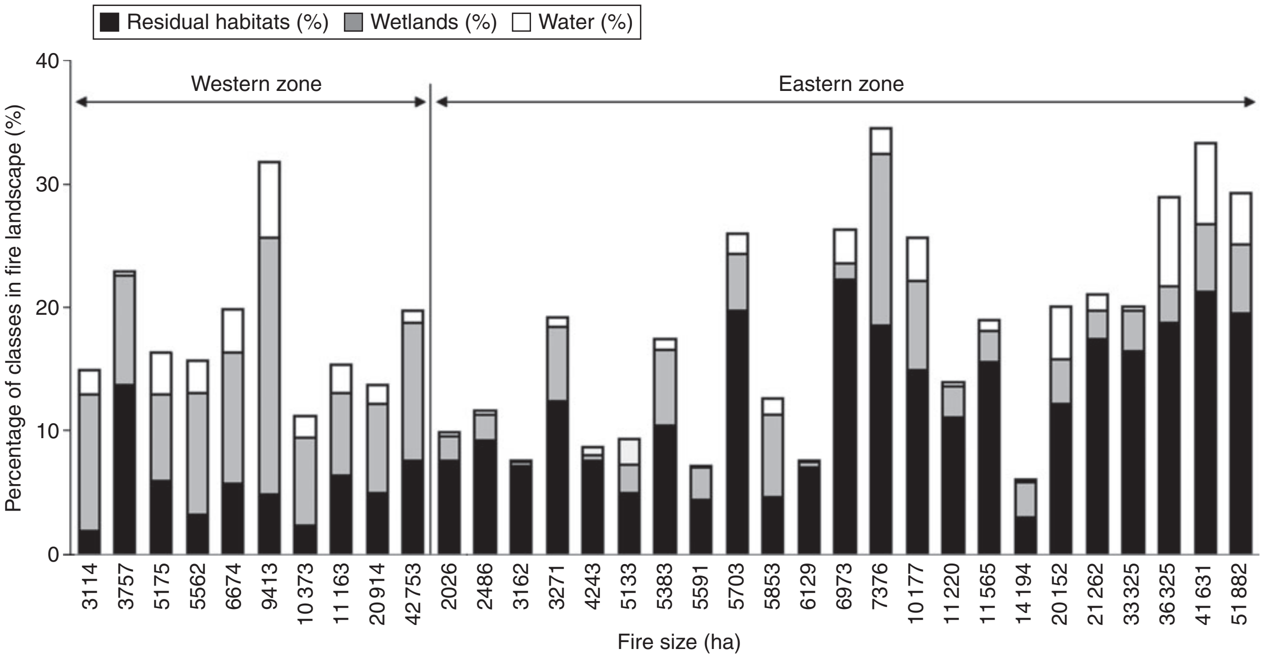

Fig. 2. Relative areas of residuals habitats, wetlands and standing water bodies for the 33 sampled fires in the black spruce–feathermoss bioclimatic subdomain of western Quebec. The fires are first ranked by region and then by size.

environments, they vary between fires from 0.3 to 28% and from 0.01 to 7.1%, with an average of 5.7 and 2% respectively (Fig. 2). Fires in the west zone generate on average 5.66% of RHs *v.* 12.42% for fires in the east zone. We observed a strong correlation between the size of fire and total RH area, implying that the larger the fire is, the larger the RH area will be ($r = 0.8379$; $P < 0.0001$) (Fig. 3*a*). However, the proportion of RHs was independent of fire size (Fig. 3*b*). Total RH area was proportional to the relative area occupied by wetlands and water (Fig. 3*c*). This implies that as these two habitat types become more abundant within fire perimeters, there will consequently be more RHs created ($r = 0.6500$; $P < 0.0001$). This correlation is due essentially to the presence of water but not to that of wetlands, as further explained below.

The first two axes of PCA expressed 73% of the variation in the 10 retained spatial indices (Fig. 4*a*). The TA, CA and the number of residual patches had high loadings on Axis 1 ($r = 0.7204$, $P < 0.0001$; $r = 0.8642$, $P < 0.0001$; $r = 0.7897$, $P < 0.0001$ respectively). The second axis appears mostly influenced by the LPI and the IJI. LPI is positively correlated with the second axis whereas IJI is negatively correlated with this axis. IJI measures the mean connectivity of patches from one class with patches from the other classes; when IJI = 0, the RH class is adjacent to a single class, whereas when IJI = 100, the RH class is simultaneously adjacent to all other classes. The second axis therefore indicates that when RHs are adjacent to a variety of other classes (high IJI), the largest patch of RH tends to be smaller (small LPI). There is also a good correlation between LPI, average RH size (MPS), and the AWMSI.

When the individual fires are shown on PCA ordination (sample scores), there is a clear size gradient (TA) (Fig. 4*b*) on the first axis and an IJI gradient on the second axis (Fig. 4*c*). The large fires (Classes III and IV) are located on the positive portion of Axis 1. With regard to IJI, fires with an index value greater than 50% (meaning high interspersion) are located in the positive portion of Axis 2 (Fig. 4*c*); whereas those with values below 50% (low interspersion) are located in the negative portion. Moreover, most of the eastern fires tend to have an IJI lower than 50%.

In order to associate this RH configuration with weather conditions, the fire scores on PCA axes were correlated with meteorological factors. The duration of the fire (with all other factors linked to it) is the only variable correlated with PCA Axis 1. PCA Axis 2 depicts a geographical gradient; the fires of the west zone are concentrated in the superior portion whereas the fires in the east zone are located in the inferior portion. In addition, the DC (Fig. 4*d*) and the average proportion of wetlands show a significant correlation with Axis 2 (threshold: $\alpha = 0.1$ and 0.05 respectively) (Fig. 4*d*). Also, wetland areas are significantly correlated with the physiographic zone ($r = 0.5958$, $P = 0.0003$).

Differences in RHs between the two physiographic zones

Many spatial indices differ significantly between the western and eastern zones as for PLAND, Largest Patch Index (LPI), MPS, AWMSI, and IJI. The fires in the western zone have generated less RHs than those in the eastern zone (PLAND). Moreover, the percentage of wetlands differs significantly, being more abundant in the western zone than in the eastern zone (Table 3). In contrast, the proportion of water is higher in the east than in the west. Patch density and mean distance to the nearest RH patch (ENN_MN) are similar for fires in both zones, but other indices vary between zones. LPI, MPS and AWMSI are smaller in the western zone than in the eastern one. LPI varied between 0 and 2% in the western zone *v.* 0 and 5% in the eastern

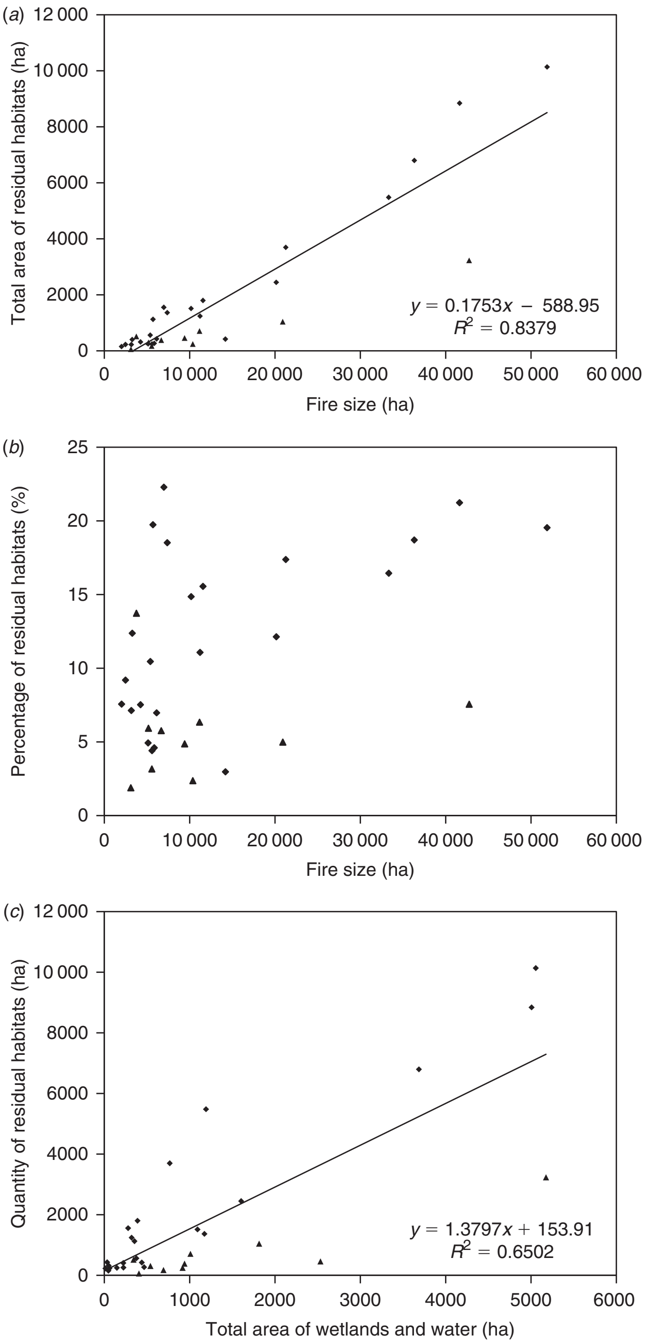

Fig. 3. Relationships between fires in the west zone (triangles) and fires in the east zone (diamonds) for: (*a*) fire size and total area of residual habitats; (*b*) fire size and percentage (%) of residual habitats; and (*c*) total area of wetlands and aquatic habitats (ha) and total area of residual habitats (ha).

zone. Fires of the western zone generated small patches (MPS) compared with those in the east. This MPS index varies between 1 and 3 ha in the west compared with 1 and 8 ha in the east. The AWMSI values indicate that RHs have a simpler shape in the western zone compared with those of the eastern zone, varying between 1 and 2 and 2 and 4 respectively. The IJI is higher for fires in the west zone compared with those in the east zone, varying between 48 and 87% *v.* 25 and 62%. The high IJI percentage for fires in the west zone suggests that they are associated with a greater number of habitat types than those in the east zone. Despite the fact that the proportion of burned habitats is the same for both zones, there are 50% fewer RHs in the west zone compared with the east zone. Similarly, even though the proportion of water is comparable in both zones, wetlands appear to be more abundant in the west zone than in the east zone.

RH composition: are particular land cover types more likely to generate RH?

By comparing the land cover composition of RHs to that of their associated physiographic zones (Table 4, Appendix 3), we tested whether some land cover types were more likely to be observed in RHs than expected under a randomness assumption. The following three land cover types were the only ones that appeared to be significantly over-represented among the RHs in the western zone, suggesting that fire tends to avoid burning these land cover types: coniferous woodlands with moss, medium coniferous cover with lichens, and open coniferous with lichen. Among the different types of forest land cover, coniferous woodland with moss appeared to be the only type with an over-representation within the RHs of the two zones, confirming a lower potential to burn.

RH spatial distribution: are RHs adjacent to water bodies or wetlands?

The adjacency analysis of RHs with other habitat types suggests that, in most cases, RHs are randomly distributed within burned area as they are mostly associated with the more prominent habitat type (i.e. burned habitats). In some fires, however, RHs show a positive association with water bodies. Among the 33 fires selected, the majority of fires (30) present an association with the burned area habitat type suggesting that RHs are dispersed randomly along fire course (Table 5, Appendix 4). However, 11 fires (33%) also have RHs showing a significant positive association with water bodies. In the western zone, 40% of the fires showed a significant association with water bodies in comparison with 30% in the eastern zone. Nevertheless, no RHs, whatever the fire zone, showed any association with wetlands, despite their high abundance in the western zone.

Discussion

Influence of the physiographic zones on the importance and configuration of RHs

In our study, RHs represent on average 10% of total fire area, regardless of fire size. In comparison to other studies, our proportions of RHs are similar to those observed by Stuart-Smith and Hendry (1998), who found that proportions varied between 0.6 and 24.9% in British Columbia. Our proportions are, however, lower than those reported by Perron *et al.* (2009) in the northern Lac-Saint-Jean region (7–37%), located east of our study area. These differences can be due to differences in analysis methods and the size of fires retained for the analysis. Perron *et al.* (2009) used relatively smaller fires (in

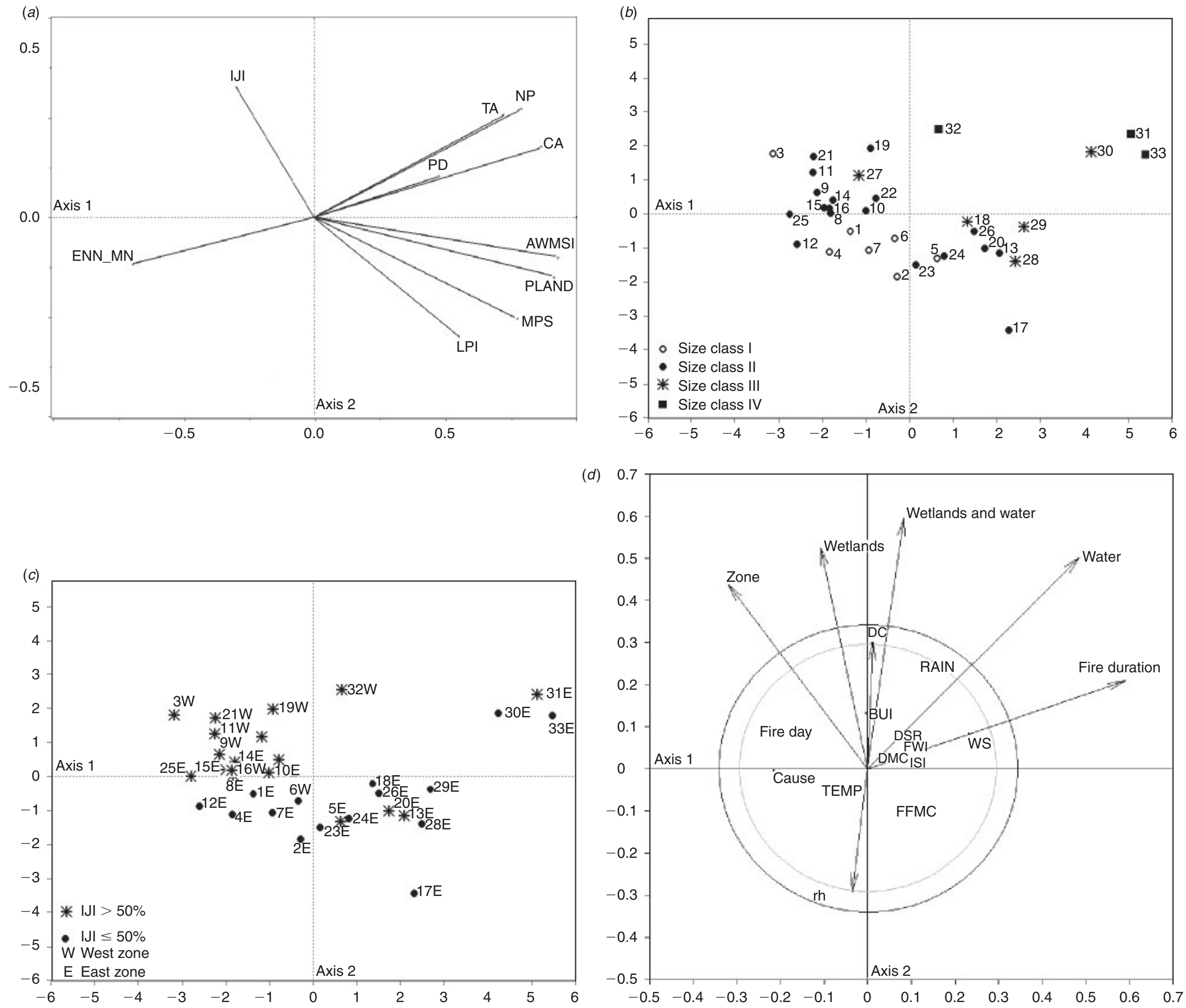

Fig. 4. (*a*) Principal component analysis of the 10 spatial indices of the 33 fires. LPI (Largest Patch Index); AWMSI (Area-Weighted Mean Shape Index); MPS (mean patch size); IJI (Interspersion and Juxtaposition Index); ENN_MN (mean nearest-neighbour distance); NP (number of patches); PD (patch density); CA (class area); TA (total landscape area); PLAND (percentage of landscape). (*b*) Ordination of fires as a function of size. (*c*) Ordination of fires as a function of their zone and the interspersion and juxtaposition index. (*d*) Correlation biplot based on the indirect ordination of fire scores and explanatory variables. Inner circle, $P = 0.1$; outer circle, $P = 0.05$. Only the correlations with $P < 0.1$ are shown with an arrow. Precipitation (RAIN), relative humidity (rh), wind speed (WS), temperature (TEMP), Daily Severity Rating (DSR), Duff Moisture Code (DMC), Drought Code (DC), Fire Weather Index (FWI), Fine Fuel Moisture Code (FFMC), Initial Spread Index (ISI), and Build-up Index (BUI).

general <2500 ha) than ours and their analysis method might have overestimated the quantity of peninsular RHs compared with the method we used. Large fires are more likely to encounter natural firebreaks such as wetlands, standing water bodies or steep slopes (Eberhart 1986). Moreover, meteorological conditions (e.g. wind direction change) prevailing during large fires could have an influence on the number and size of RHs. However, the proportion of fire in RHs appears not to be correlated with fire size, contrary to what was observed by Eberhart and Woodard (1987) and Delong and Tanner (1996).

Fires in the western zone (James Bay Lowlands) generated, on average, less RH area than those in the east zone (Canadian Shield), probably due to the different environmental conditions present in each region. Fires in the Canadian Shield had a longer duration, during which meteorological conditions (i.e. wind direction change) could vary considerably, consequently influencing fire behaviour and ultimately generating more RHs. The ecological heterogeneity of the east zone, be it physical (more rugged topography, more standing water bodies and less wetlands) or biological (differences in forest land covers), could have led to differences in fire behaviour. Conversely, in the west zone, fires were more evenly distributed, probably as a result of the initially homogeneous nature of the forest cover and the environmental conditions. The ordination analysis showed an

Table 3. Comparison (Student's *t*-test) of the mean values of the 10 spatial indices and other descriptors of the fires between the western and eastern zones

Significant values are indicated in bold. AWMSI, Area-Weighted Mean Shape Index; ENN_MN, mean nearest-neighbour distance; IJI, Interspersion and Juxtaposition Index; RHs, residual habitats

Variables	Average west	Average east	*t* student value	d.f.	*P*-value
Largest patch index	0.79	**2.07**	**2.99357**	**31**	**0.005376**
AWMSI (SHAPE_MN)	2.00	**2.83**	**3.29954**	**31**	**0.002440**
Mean patch size (ha)	1.74	**3.66**	**3.55121**	**31**	**0.001249**
IJI (%)	**65.34**	44.55	**−4.54276**	**31**	**0.000079**
ENN_MN (m)	170.18	171.02	0.05916	31	0.953206
n of patches	371.00	489.96	0.59792	31	0.554235
Patch density	3.28	3.37	0.25518	31	0.800273
Area of RHs (ha)	712.77	2152.55	1.52780	31	0.136703
Total area of fire (ha)	11 889.80	13 698.30	0.35514	31	0.724893
Wetlands (ha) + water (ha)	1436.96	999.99	−0.77243	31	0.445712
RHs (%)	5.66	**12.42**	**3.29933**	**31**	**0.002441**
Burned habitats (%)	81.84	81.35	−0.15830	31	0.875249
Wetlands (%)	**10.03**	3.79	**−4.87653**	**31**	**0.000031**
Water (%)	2.44	1.81	−0.85518	31	0.399015
other (%)	0.04	0.63	1.81061	31	0.079904
Wetlands (%) + water (%)	**12.47**	5.60	**−4.03588**	**31**	**0.000331**

Table 4. Propensity of different forest cover types to escape fire and generate residual habitats

Numbers in + and − columns indicate the number of fires for which the χ^2_P test appears significant (see Appendix 3 for details). + and − signs indicate an over- or underabundance of the forest cover type among residual habitats (RHs) compared with their availability in the surrounding landscape. NS, not significant. Values in parentheses indicate the relative difference between the importance of forest cover types within RHs and the surrounding landscape

Type of residual habitat	West zone				East zone			
	Mean importance within RHs (%)	*n* of fires			Mean importance within RHs (%)	*n* of fires		
		+	NS	−		+	NS	−
Coniferous woodland with moss	33.0 (78)	8	1	1	28.9 (407)	20	3	0
Dense mixed coniferous tendency	1.6	0	9	1	14.0	3	9	11
Medium coniferous cover with moss	17.2	1	4	5	18.3	4	11	8
Medium coniferous cover with lichens	6.1 (471)	8	2	0	0.7	2	20	1
Open coniferous with lichen	7.5 (95)	5	4	1	0.4	0	23	0
Open coniferous with moss	29.1	1	0	9	22.8	3	14	6
Dense coniferous mature	5.1	1	7	2	9.2	1	0	22

Table 5. Spatial association (proximity) between residual habitat (RHs) and water, wetlands or burned habitats

The number of fires for which the χ^2_P test was significant appears in bold (see Appendix 4 for details). Values in parentheses refer to the number of fires for which we observed a positive spatial association with water or wetlands or burned habitats that is not confirmed by a significant χ^2_P test

	No. of fires with which the RHs are associated		
	Water	Wetlands	Burned habitats (random)
Western zone ($n = 10$)	**4 (3)**	**0 (0)**	**10** (0)
Eastern zone ($n = 23$)	**7 (5)**	**0 (0)**	**20** (2)

association between the higher DC observed during fire in the west zone. The DC, which is associated with large fires, may explain in part the patterns observed in the size and shape of their RHs. The RHs have a simpler shape in the western zone compared with those in the eastern zone. This could be due to the homogeneity of the terrain and their small size (low MPS).

Influence of land cover types on RH formation

There are some forest types that are present more often in RHs despite their low availability in the landscape surrounding fire. This suggests that some land cover types are more likely to be spared from fires independently of the zone of fire. Within fires of the two zones, coniferous woodlands with moss are predominant in RHs, although their availability in the landscape is low. This type of land cover has a low tree density and may not be prone to high-intensity fires because of a lack of fuel. This avoidance exercised by fire is contrary to what has been found by other authors such as Podur and Martell (2009) who attest that fires in Ontario consume fuel types as a function of their availability (randomly), under the effect of extreme meteorological conditions that accompany large fires.

Effect of natural fire breaks on RH formation

Water bodies

Our results suggest that certain land cover types are more prone to form RHs, but their spatial distribution within the fire perimeter would mostly be random under the influence of weather conditions. The random locations of RHs within fires were also reported by other studies in boreal forests and it is attributed to variations in weather conditions. Jenkins *et al.* (2001) also lean towards the idea that the vortices that are created within a fire are likely to generate residual patches at random, whereas at the stand scale, Perera *et al.* (2009) conclude that initial forest cover characteristics, site conditions and proximity to water have no influence on RH variability.

In 33% of the fires, RHs were significantly associated with the proximity of water bodies. The relative abundance of water bodies as well as their larger size could explain this association with water. This association was mostly observed in fires that include a small number and a considerable size of water bodies, whatever the zone of fire. When comparing the 11 fires in which RHs are significantly associated with water with the 19 fires that are not, Student's *t*-test revealed significant differences in the area covered by water bodies ($P = 0.0487$). The average area of each patch of water was higher for fires in which RHs were associated with water bodies than for those that were not (9.01 *v.* 3.78 ha respectively).

Wetlands

The failure to find an association between RHs and wetlands, mainly for the west zone where they are in high abundance, suggests that these land cover types are part of the fuel that burns during fire. In addition, fires in this type of environment, especially in peatland, are caused by lightning and can only occur in extreme weather conditions. This situation shows that the factor limiting the development of RHs should only stem from a meteorological cause, as suggested by Meyn *et al.* (2007) and Podur and Martell (2009). The major influence of meteorological conditions on fire behaviour in peatland has been described in several studies. Flannigan *et al.* (2009) found a positive correlation between the abundance of peatland and the size of large fires in the western Canadian landscape, and the annual areas of peatland in this region are correlated with the drought moisture code (Turetsky *et al.* 2004); it was also found that the burn area in fens was large (Turetsky *et al.* 2004). These large fires are always associated with extreme meteorological conditions. Although burning the same area as those in the east, albeit in fewer days, the majority of fires in the west zone burned from the first fortnight of June and lasted a shorter time compared with those in the east. According to Roulet *et al.* (1992), the warmer temperatures increase evapotranspiration in peatland mosses and decrease ground water levels. This causes a decrease in surficial soil humidity and could have an indirect effect on fires in these ecosystems by altering the fuel load and the connectivity between fuel types (Flannigan *et al.* 2009). This could partly explain why we did not find any association between RHs and wetlands in our study. The other explanation may also lie in the types of wetland habitats that correspond to three types of treed wetlands: wetland with tall shrubs and trees, wetland with low shrubs, and wetland with bryoid; the fire might behave differently depending on the type of wetland it burns. Due to the low availability of wetland with bryoid in fires (9% of all wetlands, whatever the fire zone), their role as firebreaks is negligible. In contrast, wetland with low shrubs constitutes the majority of wetland habitats, whatever the zone of fire, followed by wetland with low shrubs, and this explains the lack of association of RHs with these types of environment, demonstrating once again their high combustibility during large fires, which is in agreement with Turetsky *et al.* (2004) who suggested that wet areas of boreal landscapes were burning more than previously believed.

Conclusion

This study allowed us to understand the formation of RHs within large fires and their spatial distribution in the spruce–moss forest of western Quebec. Large fires in the boreal forest never burn the totality of available fuel but leave a proportion of RH, regardless of the physiographic unit. The area of RHs depend on the size of the fire, the meteorological conditions (DC), and the physiographic zone. Fires originating from a physiographic zone characterised by a large proportion of peatland (west) generated less RHs than those in the region characterised by a rougher topography and more woodlands (east). Generally, land cover types are represented proportionally to their availability in RHs except for coniferous woodland with moss, which seems less likely to burn. This fuel type that appears to be less susceptible to fire could constitute 'micro hotspots' of biodiversity (Hörnberg *et al.* 1998; Gandhi *et al.* 2001) that need to be identified and preserved during forest harvesting. We have shown that fires behave differently between physiographic zones and that the local conditions of each zone influence the formation, the amount and the configuration of RHs. This implies that within an ecosystem-based management approach, a regional approach should be taken when developing retention targets. Also, extreme weather during large fire events has an important impact on the creation of these RHs, especially in zones with high amounts of peatlands. As climate change will also affect extreme climate events such as the frequency of droughts or heavy rains (Intergovernmental Panel on Climate Change 2007), this relationship needs to be investigated further.

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Appendix 1. Relabelling of satellite images (41 classes)

The other classes were not found in the study area, so they were excluded

Class 1 Burned habitats	Class 2 Residual habitats	Class 3 Wetlands	Class 4 Water	Class 5 Other
Burn	Dense coniferous mature	Wetland with tall shrubs and trees	Water	No data
Cut	Medium coniferous cover with moss	Wetland with low shrubs		Shadow
Tall shrubs	Medium coniferous cover with lichen	Wetland with bryoid		Clouds
Deciduous regeneration	Open coniferous with lichen			Snow and ice
Coniferous regeneration	Open coniferous with moss			Rock outcrop and rubble
Mixed regeneration	Coniferous woodland with moss			Exposed land
Low shrubs	Dense mixed coniferous tendency			Urban
Post-fire regeneration	Dense mixed deciduous with coniferous tendency			
Post-harvest regeneration	Open mixed deciduous with coniferous tendency			
Herb (perennial crops, pasture, fallow, grassland)				
Lichen				
Moss and rock				
Dense coniferous young				
Coniferous woodland with lichen				
Dense deciduous				
Open deciduous				
Dense mixed deciduous tendency				
Open mixed deciduous tendency				
Open mixed coniferous tendency				
Coniferous woodland with shrubs				
Dense young deciduous				

Appendix 2. Definition of the FRAGSTATS indices used

Index name	Index abbreviation	Definition and use	Index computed for what
Total landscape area (ha)	TA	This measure corresponds to the entire fire area, including the burned and non-burned habitats, in addition to the previously defined classes (with reference to the interior of the fire).	Entire fire
Class area (ha)	CA	Surface area of each class within the landscape (ha).	Burned habitat, Residual habitat, Wetland, Water and Others
Percentage of landscape (%)	PLAND	Percentage of ground occupied by each class type.	Burned habitat, Residual habitat, Wetland, Water and Others
Largest Patch Index (%)	LPI	Index summing up the largest patch size for a particular class. This index allows to determine a patch's dominance in a class with respect to the different patches of the same class within the fire landscape. This index can also be used to evaluate whether the aggregation is strong or weak.	Residual habitat
Area-Weighted Mean Shape Index	AWMSI	This index increases with the complexity of patch shape in landscape classes.	Residual habitat
Mean nearest-neighbour distance	ENN_MN	The ENN_MN index measures the degree of isolation of patches. This index allows for the evaluation of the mean connectivity between patches of the same type. The higher the ENN_MN, the greater probability that patches of the same type will be further from one another.	Residual habitat
Interspersion and Juxtaposition Index (%)	IJI	This index measures the mean connectivity of patches from one class with patches from the other classes. IJI = 0, when the class is adjacent to another class. IJI = 100, when the class is simultaneously adjacent to all other classes.	Burned habitat, Residual habitat, Wetland and Water
Number of patches	NP	NP = 1, when the landscape contains only one patch from its corresponding class, i.e. when a class consists of one unique patch. Meanwhile, the density of patches is more useful, because it informs us on the spatial distribution of these patches.	Residual habitat, Wetland and Water
Patch density (n 100 ha^{-1})	PD	Number of patches in a 100 ha area.	Residual habitat, Wetland and Water
Mean patch size (ha)	MPS	This index decreases with the increase of patch number, and when the landscape is more and more fragmented.	Residual habitat

Appendix 3. Comparisons of the frequency of occurrence of forest cover types within the residual habitats and in the surrounding forest landscape for the western zone and eastern zone

(– or +) $\chi^2_P = 1.3066$; significance level $\alpha = 0.05$; (– – or ++) $\chi^2_P = 1.7172$, significance level $\alpha = 0.01$; (– – – or +++) $\chi^2_P = 2.193$, significance level $\alpha = 0.001$

Type of residual habitat	Fire ID No.																			
	9		23		21		32		16		6		28		3		11		19	
	χ^2_P	*P*	χ^2_P	*P*	χ^2_P	*P*	χ^2_P	*P*	χ^2_P	*P*	χ^2_P	*P*	χ^2_P	*P*	χ^2_P	*P*	χ^2_P	*P*	χ^2_P	*P*
Western zone																				
Dense coniferous mature	–1.0329		–0.8908		–1.3036		–1.197		0.5589		–2.5811	– – –	–0.5018		–1.3658	–	1.3917	+	–0.2486	
Medium coniferous cover with moss	0.0985		0.1732		–2.4695	– – –	–0.2202		1.2924		–4.9956	– – –	–1.8173	– –	–3.0651	– – –	–2.3603	– – –	–2.1971	+++
Medium coniferous cover with lichens	1.0929		6.1016	+++	6.052	+++	1.7801	++	12.3979	+++	6.4174	+++	0.5521		3.4955	+++	6.0581	+++	4.8472	+++
Open coniferous with lichens	–1.3878	–	–0.7318		1.838	+	0.3868		0.157		10.5609	+++	–1.2481		3.5782	+++	2.7542	+++	2.7839	+++
Open coniferous with moss	–2.7147	– – –	–3.1188	– – –	–3.298	– – –	–2.0848	– –	–3.711	– – –	3.7348	+++	–1.3554	–	–2.7248	– – –	–2.9401	– – –	–1.6503	–
Coniferous woodland with moss	5.0495	+++	3.7815	+++	6.5746	+++	3.8924	+++	0.8		–4.0058	– – –	4.6196	+++	6.2321	+++	3.8166	+++	2.8005	+++
Dense mixed coniferous tendency	–0.2601		0.2062		–0.6708		–0.9514		–0.3136		–1.4751	–	0.5294		–0.4804		–0.4637		–0.2208	
Dense mixed deciduous with coniferous tendency	0.0601		0.2782		–0.0901		–0.2106		–0.0422		–0.2523		1.2293		–0.2523		–0.2523		0.3372	
Open mixed deciduous with coniferous tendency	0.0707		0.2964		–0.0273		–0.2703		–0.0238		–0.5093		0.16		–0.2212		–0.3664		0.0745	

	8		25		7		27		2		17		1		5	
	χ^2_P	*P*	χ^2_P	*P*	χ^2_P	*P*	χ^2_P	*P*	χ^2_P	*P*	χ^2_P	*P*	χ^2_P	*P*	χ^2_P	*P*
Eastern zone																
Dense coniferous mature	–4.3075	– – –	–4.8074	– – –	–1.618	–	–3.1224	– – –	–2.6364	– – –	–3.1167	– – –	–4.7489	– – –	–4.3282	– – –
Medium coniferous cover with moss	1.3206	+	–1.6502	–	0.6041		2.0955	++	0.0095		0.2756		1.6251	+	–0.0782	
Medium coniferous cover with lichens	2.223	+	–0.2556		–1.1688		–0.6358		–0.8822		–0.8377		–0.4501		–0.8636	
Open coniferous with lichens	–0.6795		–1.1142		–1.2137		–0.9824		–0.8687		–1.02		–1.0119		–1.1997	
Open coniferous with moss	–1.5574	–	–0.7269		1.6436	+	–1.5913	–	–1.438	–	–1.1797		–1.6849	–	–0.0379	
Coniferous woodland with moss	16.2897	+++	22.4943	+++	–0.0783		9.8485	+++	8.352	+++	9.282	+++	18.1608	+++	13.1325	+++
Dense mixed coniferous tendency	–3.5093	– – –	–3.5687	– – –	–0.2791		–1.673	–	–0.2167		–0.2335		–3.3019	– – –	–1.6137	–
Dense mixed deciduous with coniferous tendency	–0.8231		–0.7789		–0.3914		–0.1638		0.7714		–0.1058		–0.6879		–0.4001	
Open mixed deciduous with coniferous tendency	–1.0684		–0.7507		1.1921		0.0047		1.9714	++	1.1793	++	–1.3121	–	0.4931	

	24		14		15		22		10		31		33		29	
	χ^2_P	P	χ^2_P	P	χ^2_P	P	χ^2_P	P	χ^2_P	P	χ^2_P	P	χ^2_P	P	χ^2_P	P
Eastern zone																
Dense coniferous mature	–3.868	–––	–3.2058	–––	–4.0498	–––	–3.6181	–––	–2.9122	––	–2.695	–––	–2.5053	–––	–3.4071	–––
Medium coniferous cover with moss	0.75		–0.2784		1.0251		–2.3512	–––	–1.2634		–1.0727		–1.7539	––	–1.071	
Medium coniferous cover with lichens	–0.5406		–0.7996		–1.1688		–1.0536		–0.7824		–0.0591		–0.8385		–0.7899	
Open coniferous with lichens	–0.9275		–0.5026		–1.2137		–1.1851		–0.9888		–0.3758		–1.0198		–0.8275	
Open coniferous with moss	–0.5942		–0.1249		3.0121	+++	–2.0572	++	–0.6716		–0.0932		–1.9725	––	0.2786	
Coniferous woodland with moss	13.051	+++	13.5422	+++	2.1892	++	7.0156	+++	9.3375	+++	9.2261	+++	7.4369	+++	5.8178	+++
Dense mixed coniferous tendency	–2.1014	––	–2.7804	–––	–0.9065		2.0111	++	0.1266		–0.7762		0.6753		1.0843	
Dense mixed deciduous with coniferous tendency	–0.7565		–0.0296		–0.9243		8.2842		1.6316		0.1469		6.414		2.4686	
Open mixed deciduous with coniferous tendency	–0.4569		–0.7836		2.0468	++	6.0144	+++	1.1072		0.3806		4.0281	+++	1.3612	+

	13		26		18		30		4		20		12	
	χ^2_P	P	χ^2_P	P	χ^2_P	P	χ^2_P	P	χ^2_P	P	χ^2_P	P	χ^2_P	P
Eastern zone														
Dense coniferous mature	2.0439	++	–3.9226	–––	–4.0609	–––	–2.6588	–––	–4.4208	–––	–3.4868	–––	–5.0463	–––
Medium coniferous cover with moss	0.0534		–1.4166	–	–2.2268	–––	–1.4306	–	–2.1535	––	2.3706	+++	–2.2477	–––
Medium coniferous cover with lichens	–1.1688		–0.6553		–0.3261		–0.7236		–0.7236		1.583	+	–0.9889	
Open coniferous with lichens	–1.2137		–0.7013		0.2605		–0.9385		–1.2137		0.2896		–1.0838	
Open coniferous with moss	–0.2627		0.0448		–0.0588		–1.4998	–	–0.0583		–0.789		–0.9232	
Coniferous woodland with moss	0.9751		13.3488	+++	3.3707	+++	6.3522	+++	–0.6435		9.0741	+++	25.8757	+++
Dense mixed coniferous tendency	–1.9277	–	–1.5871	–	3.7082	+++	1.198		8.4086	+++	–2.7266	––	–3.8759	–––
Dense mixed deciduous with coniferous tendency	–0.1062		1.206		2.5042		4.233		0.4287		–0.7455		–0.9391	
Open mixed deciduous with coniferous tendency	–0.6214		0.7972		3.6879	+++	3.5765	+++	1.6069	+	–0.5684		–1.381	–

Appendix 4. Spatial association between residual habitats and other habitats within fires for western zone and eastern zone

Numbers in bold indicate significant χ^2_P test. $\chi^2_P = 1.129$, significance level $\alpha = 0.05$

Type of residual habitat	Fire ID no.											
	9	23	21	32	16	6	28	3	11	19		
Western zone												
Burned habitats	**2.1915**	**4.8998**	**3.094**	**6.0831**	**4.8356**	**2.4156**	**2.786**	**1.7858**	**2.5127**	**1.8645**		
Wetlands	−3.5373	−7.0859	−4.8372	−6.9911	−4.1419	−2.5877	−6.5970	−1.7763	−2.5848	−3.8453		
Water	**1.3727**	**1.1518**	**2.8849**	0.5114	−1.9518	−0.5911	**4.2035**	−0.0141	0.0463	0.8972		
Other	–	−0.5557	−0.8050	−0.9037	−0.1092	−1.4522	−1.9393	–	−0.4648	0.5925		
	8	25	7	27	2	17	1	5	24	14	15	
Eastern zone												
Burned habitats	**3.7551**	**2.5873**	**2.2879**	**1.377**	0.6652	**−8.3313**	**1.4851**	**2.0548**	**2.5853**	**2.9731**	**2.1035**	
Wetlands	−5.4456	−0.8196	−4.3998	−2.0096	−1.8944	−3.8498	−2.4199	−4.3779	−3.9539	−0.4150	−4.3316	
Water	0.9224	−1.2694	−0.2617	0.2476	−0.3977	−1.9511	0.2157	−0.0529	**1.9814**	−0.5956	−0.8777	
Other	−0.8393	−3.3287	−3.1619	−1.2723	−0.8393	−0.9803	–	−1.1133	0.1301	−3.3503	−0.7662	
	22	10	31	33	29	13	26	18	30	4	20	12
Eastern zone												
Burned habitats	**2.3966**	**4.954**	**4.5594**	**3.3109**	**3.1415**	**2.6726**	**6.2835**	**3.0406**	**1.4865**	0.3306	**2.4052**	**2.4476**
Wetlands	−3.6714	−8.9269	−8.5347	−4.8641	−0.6152	−5.8218	−3.0165	−8.5159	−0.5833	−1.8842	−4.0535	−3.8382
Water	0.0914	**3.1206**	0.9594	−0.2672	−2.2844	**1.3246**	**1.8559**	**2.0654**	−0.3812	**3.0026**	**1.6562**	−0.1845
Other	–	−5.4310	−2.6168	−4.5440	−3.7685	−1.5448	−0.6190	−1.3725	−2.2674	−0.3867	−0.4223	–