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Stand structure in fire refuges of the eastern Canadian boreal mixedwood forest

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ABSTRACT

Wildfires in boreal forest ecosystems usually spare tree stands called post-fire residual patches. There are two types of post-fire residual patches: (1) patches that only escaped fire by chance, probably due to local meteorological conditions unsuitable for fire spread at the moment fire reached their surroundings (random post-fire residual patches), and (2) patches with lower fire susceptibility, that escaped several consecutive fires, likely due to particular site characteristics (fire refuges). Special conservation efforts could target fire refuges owing to their old age, long ecological continuity, and potential specific biological diversity. Here we compared the stand characteristics of 13 post-fire residual patches from the eastern Canadian boreal mixedwood forest to develop guidelines and information for forest managers to differentiate fire refuges from random post-fire residual patches. Two main structural characteristics differentiated fire refuges from random post-fire residual patches: mean tree diameter and thickness of the soil organic matter layer. Thick organic matter accumulation in fire refuges is likely linked to a paludification process, which in turn reduces stand productivity, and thus, mean tree diameter.

1. Introduction

Preservation of biological diversity and consideration of natural processes are two issues that are increasingly seen as being of importance to forestry in the boreal zone (Franklin, 1993; Weber and Stocks, 1998). At the landscape level, fire suppression practices have led to major changes in species composition and stand structure (Esseen et al., 1997; Haeussler and Kneeshaw, 2003; Kardynal et al., 2011). Large-scale clearcuts over the past 50 years have homogenized the landscapes and considerably reduced the proportion of old boreal forests (Östlund et al., 1997; Cyr et al., 2009). Species associated with old forests have thus declined in abundance (Archambault et al., 1998; Martikainen et al., 2000). To prevent biodiversity loss, new forest harvesting practices have been developed that aim to reproduce the spatiotemporal patterns created by natural disturbances (Hansen et al., 1991; Franklin, 1993; Hunter, 1993; Gauthier et al., 2008).

To use natural disturbance dynamics to guide forest management decisions calls for a precise understanding of their spatial and temporal dynamics. Wildfire is the main natural disturbance in boreal forests (Zackrisson, 1977; Payette, 1992) and burned areas usually include tree patches, so-called "residual patches" that partially or entirely escaped fire (Gluck and Rempel, 1996; Burton et al., 2008). Residual patches are habitat islands with diverse structural legacies and unique environmental conditions (Foster et al., 1998; Keeton, 2000). They can serve as sources for the recolonization of burned areas (Keeton, 2000; Asselin et al., 2001), as refuges for disturbance-sensitive species (Gasaway and Dubois, 1985; Gandhi et al., 2001), and they can increase structural complexity in the forest landscape (Zenner, 2000).

In North American boreal mixedwood forests, two types of post-fire residual patches have been distinguished: (1) patches that only escaped the last fire, probably due to local meteorological conditions unsuitable for fire spread occurring at the moment fire reached their surroundings (random post-fire residual patches), and (2) patches that escaped several consecutive fires, also called fire refuges, likely due to particular site characteristics (Ouarmim et al., in press). Fire refuges can escape fire for several centuries, up to a few millennia, i.e., much longer than the fire frequency

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recorded in the surrounding landscape (Ouarmim et al., in press). These patches are characterized by long ecological continuity and specific biological diversity (Selva, 2003). Hence, they should be subjected to special conservation efforts. Recent forest management approaches include structural retention and active creation of structural and spatial complexity (e.g., Bergeron et al., 2002; Gauthier et al., 2008). However, the difference between the two types of post-fire residual patches has so far been largely ignored in conservation policies in the North American boreal forest and should be included in future forest management planning (Gasaway and DuBois, 1985; Bergeron et al., 2002; Cyr et al., 2005; Gauthier et al., 2008).

The aim of the present study was to compare the stand characteristics of post-fire residual patches from the eastern Canadian boreal mixedwood forest. Our specific objectives were to (1) establish which stand characteristics most accurately discriminate between fire refuges and random post-fire residual patches; and (2) evaluate the effects of environmental conditions and disturbance history on the characteristics of post-fire residual patches.

2. Material and methods

2.1. Study area

The study area is located within the Lake Duparquet Research and Teaching Forest (Fig. 1), in the eastern Canadian boreal mixedwood forest characterized by balsam fir (*Abies balsamea* (L.) Mill.), paper birch (*Betula papyrifera* Marsh.), white spruce (*Picea glauca* (Moench) Voss.), trembling aspen (*Populus tremuloides* Michx.), and eastern white cedar (*Thuja occidentalis* L.) as the main tree species (Dansereau and Bergeron, 1993; Bergeron, 2000). Geomorphology is characterized by the presence of a massive clay deposit left by pro-glacial Lakes Barlow and Ojibway (Vincent and Hardy, 1977). The climate is cold temperate with a mean annual temperature of 0.7 °C and mean annual precipitation of 889.8 mm (Environment Canada, 2011). The fire cycle for the Lake Duparquet area has been estimated at 63 years prior to 1870 and more than 99 years afterwards (Bergeron, 1991). Spruce budworm outbreaks occur at approximately 40-year intervals (Boulanger and Arseneault, 2004), and the last one (1972–1987) killed most of the mature balsam fir trees in the study area (Morin et al., 1993; Bergeron et al., 1995).

2.2. Identification of residual patches

Typical post-fire succession in the eastern Canadian boreal mixedwood forest involves a gradual change from pioneering stands dominated by deciduous tree species (trembling aspen and paper birch) during the first *ca.* 75 years, to mixed stands with an important white spruce component in the next *ca.* 75 years, to coniferous stands dominated by balsam fir and eastern white cedar after *ca.* 150 years (Bergeron, 2000). Thirteen post-fire residual patches were selected in young forests that burned for the last time in 1944 or 1923 AD (Dansereau and Bergeron, 1993; Bergeron, 2000) (Fig. 1). Areas affected by the 1944 and 1923 fires had previously burned in 1717 and 1760 AD, respectively (Dansereau and Bergeron, 1993; Bergeron, 2000). Post-fire residual patches were thus distinguished from the surrounding forest matrix based on forest structure and composition retrieved from ecoforestry maps (scale: 1/15 000) (Ministère des Ressources naturelles http://www.mrn.gouv.qc.ca/forets/inventaire/fiches/couches-peuplements-ecoforestiers.jsp). These patches were identified as old-growth coniferous polygons (with balsam fir or eastern white cedar) embedded in a matrix of younger deciduous forests (with trembling aspen or paper birch). The polygons on ecoforestry maps are between 1 and 8 ha in size, and thus it is possible that smaller post-fire residual patches were not identified.

Long-term fire reconstruction based on radiocarbon dating of macroscopic soil charcoal peaks identified in soil organic matter profiles revealed that 8 patches could be classified as fire refuges, although some of them burned recently (in 1717 or 1760) during severe fires (Ouarmim et al., in press). Random residual patches only escaped the most recent fire, and thus displayed shorter ecological continuity (Ouarmim et al., in press).

2.3. Data collection

Between 3 and 9 sampling points were randomly located in each of the 13 sampled residual patches, depending on their area. Sampling points were distant from each other by at least 30 m. Trees and snags were inventoried using the point centered quadrant method (Mueller-Dombois and Ellenberg, 1974). At each sampling point, four dominant trees, four suppressed trees and four snags were identified to the species level and measured (height and diameter at breast height (DBH)). Distance between trees or snags and quadrant center was measured to calculate densities per species (McRae et al., 1979). Percent occurrence was calculated for each tree species. The thickness of the soil organic matter layer was measured at six points with a meter stick for the stands with thinner organic matter layers (<30 cm), while only one measure was taken at the five sites with thicker organic matter layers (>50 cm).

Presence of coarse woody debris were sampled (CWD; diameter >7.6 cm) in each patch, along 20-m sided equilateral triangles following the line intersect method (Van Wagner, 1968, 1980; McRae et al., 1979). The diameter and length of logs were measured and the volume of logs was calculated (m^3 per triangle).

2.4. Analyses

To examine differences between patch types, multiple median comparison tests (Mann–Whitney non-parametric test) were computed on mean stand characteristics. The significant variables identified through these comparisons were used in a partitioning around medoids (PAM) analysis, which uses principal component analysis to display a predefined number of clusters in reduced space, i.e., on a two-dimensional graph (Pison et al., 1999). The value of k (number of clusters) was fixed to 2, corresponding to patch classification as either fire refuges or random post-fire residual patches. Diameter–frequency distributions of fire refuges and random post-fire residual patches were compared using a Chi-square test run on absolute frequencies of ten diameter classes.

Stand characteristics can be influenced by time since the last fire (e.g., Bergeron, 2000; Simard et al., 2007; Brassard et al., 2008). Linear regressions were used to evaluate the effect of time since the last fire (Table 2, Fig. 3) on significant stand characteristics.

All statistical analyses were conducted using the R software.

3. Results

Four stand characteristics showed significant differences between fire refuges and random post-fire residual patches: mean diameter of living trees, mean diameter of balsam fir trees, mean diameter of white spruce trees (Var14, 16, and 17), and mean thickness of the soil organic matter layer (Var36) (Table 1). Mean tree diameter perfectly discriminated the two types of post-fire residual patches, with lower values in fire refuges