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ES Home > Vol. 2, No. 2 > Art. 6

Bergeron, Y., P.J.H. Richard, C. Carcaillet, S. Gauthier, M. Flannigan, and Y.T. Prairie. 1998. Variability in fire frequency and forest composition in Canada's southeastern boreal forest: a challenge for sustainable forest management. Conservation Ecology [online] **2**(2): . Available from the Internet. URL: http://www.consecol.org/vol2/iss2/art6/

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Insight, part of Special Feature on Sustainability and Resilience in Boreal Regions

Variability in Fire Frequency and Forest Composition in Canada's Southeastern Boreal Forest: A Challenge for Sustainable Forest Management

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ABSTRACT

Because some consequences of fire resemble the effects of industrial forest harvesting, forest management is often considered as a disturbance having effects similar to those of natural disturbances. Although the analogy between forest management and fire disturbance in boreal ecosystems has some merit, it is important to recognize that it has limitations. First, normal forest rotations truncate the natural forest stand age distribution and eliminate over-mature forests from the landscape. Second, in the boreal mixedwoods, natural forest dynamics following fire may involve a gradual replacement of stands of intolerant broadleaf species by mixedwood and then softwood stands, whereas current silvicultural practices promote successive rotations of similarly composed stands. Third, the large fluctuations observed in fire frequency during the Holocene limit the use of a single fire cycle to characterize natural fire regimes. Short fire cycles generally described for boreal ecosystems do not appear to be universal; rather, shifts between short and long fire cycles have been observed. These shifts imply important changes in forest composition at the landscape and regional levels. All of these factors create a natural variability in forest composition that should be maintained by forest managers concerned with the conservation of biodiversity. One avenue is to develop silvicultural techniques that maintain a spectrum of forest compositions over the landscape.

KEY WORDS: fire regime; boreal forest; mixedwood; holocene vegetation; sustainable forestry; management for biodiversity.

INTRODUCTION

The forest industry is heading back to nature to find a way to reconcile economic fiber production with biodiversity (Kimmins 1992, Freedman et al. 1994, McKenney et al. 1994). One of the avenues being explored is the development of silvicultural systems that are inspired by, and closely resemble, natural ecosystem dynamics (Attiwill 1994, Galindo-Leal and Bunnell 1995, Bergeron and Harvey 1997). In the boreal forest, fire is the disturbance agent that has the greatest impact on forest dynamics (Engelmark et al. 1993). The North American boreal forest is generally characterized by relatively short fire cycles (50 - 250 yr) and stand-replacing fires (Heinselman 1981, Johnson 1992, Payette 1992). Because some consequences of fire resemble the effects of industrial forest harvesting, forest management is often considered as a disturbance having effects similar to those of natural disturbances.

Although the analogy between forest management and fire disturbance in boreal ecosystems has some merit, it is important to recognize that it also has limitations. The contrasting effects of fires and cutting on many ecosystem processes have already been raised (MacLean et al. 1983, Binkley and Richter 1987, Brais et al. 1995, Reich 1998). More recently, we have seen an interest in the important differences that exist, at the larger landscape scale, in the composition and structure of forest mosaics caused by fire and forest management regimes. This phenomenon takes on even greater importance for many organisms for which interventions at this scale determine habitat quality (Rolstad 1991, Franklin 1993). Boreal systems are intrinsically cyclic (Ludwig et al. 1997, Pastor et al., this issue), and the effect of forest management is often to decrease this natural variability. Using research results on natural disturbances and forest dynamics in Quebec's southern boreal mixedwoods, we describe in this paper three characteristics of boreal systems controlled by fire that contribute to increased variability. We then suggest several avenues that should be explored to develop silvicultural systems that are inspired by, and closely resemble, natural ecosystem dynamics. Although the general principles presented here can be extended to the boreal forest in general, the empirical results presented apply mainly to the southern part of Quebec's Clay belt.

VARIABILITY OF THE FOREST AGE STRUCTURE

In managed forests, forest rotation is determined primarily by the harvest age of stands. In a forest composed of even-aged stands, a normal forest structure occurs when all age classes of stands are evenly distributed over the territory. Thus, a normal forest having a rotation age of 100 yr would theoretically have an equal percentage of its land base in each age class between 0 and 100 yr (Fig.1a). In contrast, an area subjected to stand-replacing forest fires will have, at equilibrium, a completely different age class distribution. In effect, assuming that the probability of burning is independent of stand age (which is generally assumed in studies on the boreal forest; see Johnson 1992), the age class distribution of the burned area will follow a negative exponential distribution (Van

Wagner 1978), with nearly 37% of the stands older than the fire cycle, that is, >100 yr old (Fig.1b). Fire may affect stands several times before their maturity, while allowing some stands to survive beyond 100 yr, whereas forest harvesting will only occur at stand maturity. Proportions of over-mature stands (> 100 yr old), and old growth (> 200 yr old) increase as the fire cycle lengthens (Fig. 2) and could cover an important proportion of the boreal forest landscape (see *Variability in the Fire Cycles*).

Fig. 1. Forest age class distribution (10 yr) as a function of (a) 100-yr forest rotation and (b) a 100-yr fire cycle.

a), part of Special Feature on Sustainability and Resilience in Boreal Regions

b), part of Special Feature on Sustainability and Resilience in Boreal Regions

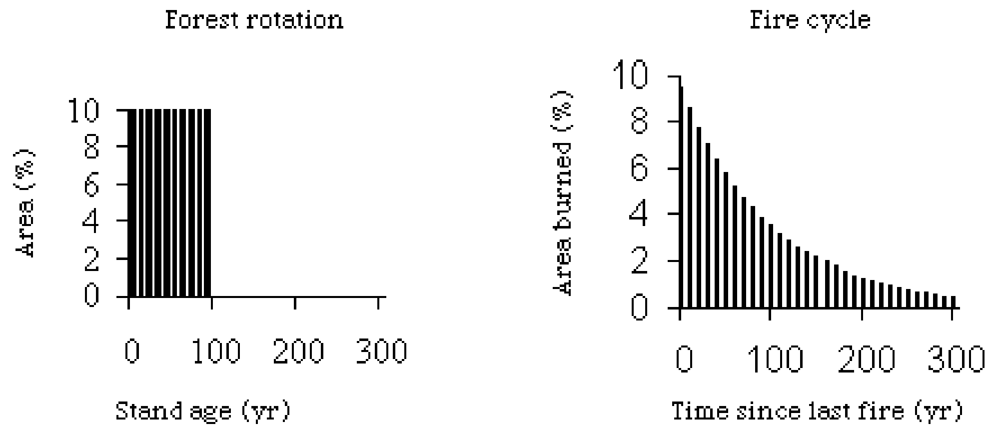
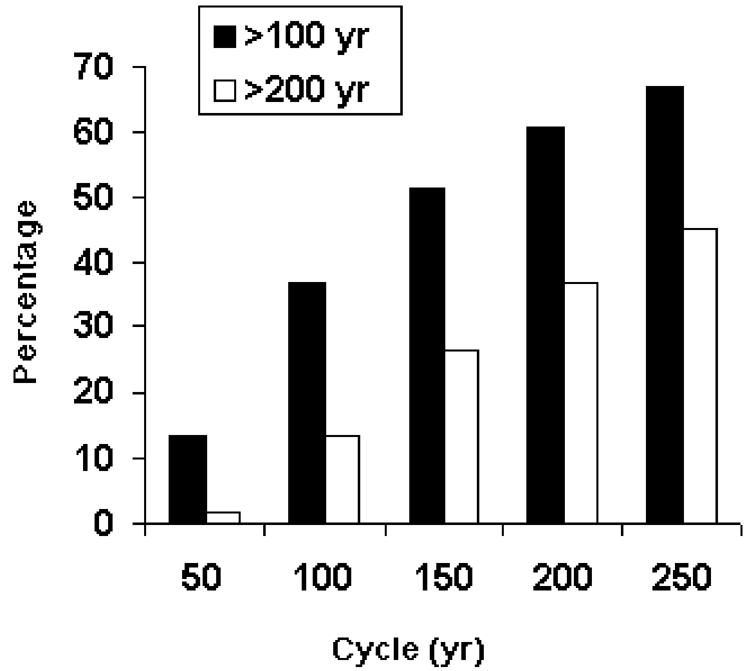


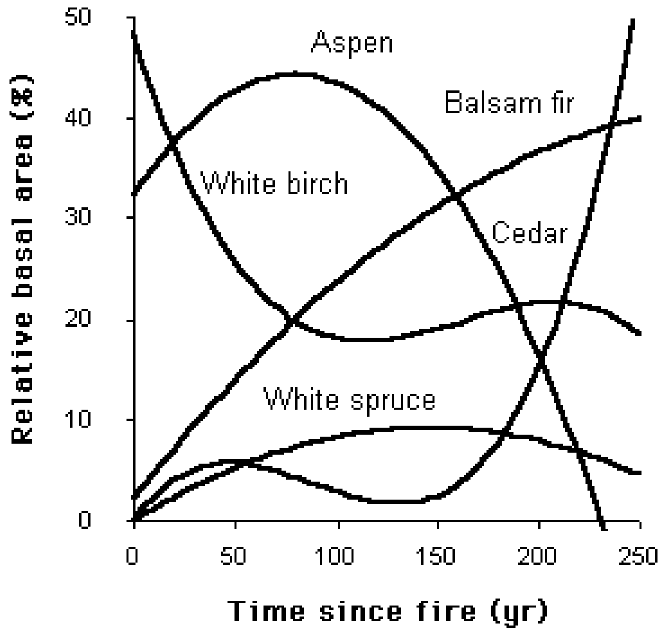
Fig. 2. The percentage of stands older than 100 and 200 yr increases from short to long fire cycles. With a 100-yr forest rotation, none of these stands would be present.



VARIABILITY IN STAND COMPOSITION

A natural chronosequence covering > 230 yr after fire have been reconstructed for Quebec's southern boreal forest using fire areas originating in different years (Bergeron and Dubuc 1989, Leduc et al. 1995). Fig. 3 summarizes natural succession for mesic, "mixedwood" (MacDonald 1995) sites. Intolerant hardwoods (trembling aspen and white birch) dominate the canopy during the first 100 yr. Stand breakup occurs gradually over a number of years. Following their mortality, a second cohort of hardwoods, as well as fir and white spruce recruited in the understory, attain the overstory to form mixedwood stands. Only after 200 yr, following mortality of the second and even third intolerant hardwood cohort, are stands dominated by softwood species. Natural dynamics can thus be schematized by successive cohorts of hardwood, mixedwood, and softwood dominance. In some respects, current silviculture practices ignore natural ecosystem dynamics. In Quebec, provincial silvicultural standards require that cutovers be regenerated to a hardwood and softwood stocking level similar or superior to preharvest levels. The consequence of this approach is that it imposes a cyclical rotation of similarly composed stands, whereas succession in the natural system generally involves a transition of stand types.

Fig. 3. Proportion of different species as a function of time since the last fire. Data are from stands growing on mesic clays soils in Quebec's southwestern boreal forest (Leduc et al. 1995).



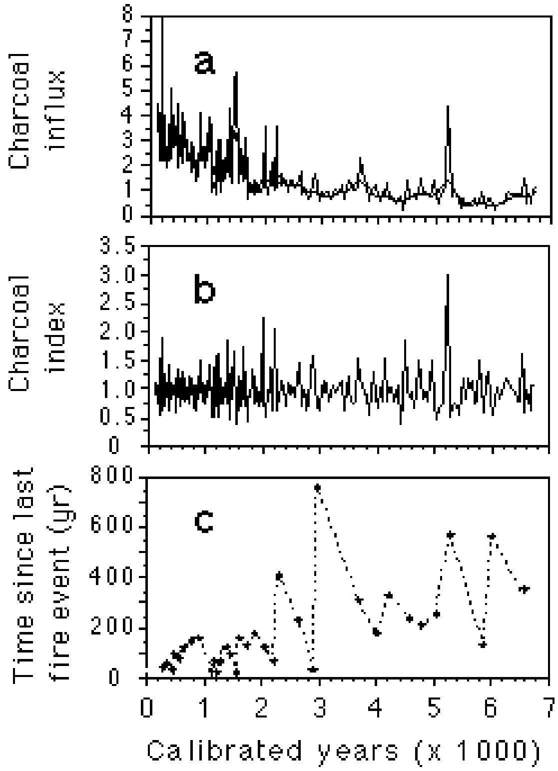
This lack of attention to natural dynamics is, in part, responsible for some of the forest renewal problems in the region. For example, the objective of regenerating softwood stands (on upland mixedwood sites) with softwood species often necessitates artificial regeneration and chemical or mechanical control of intolerant hardwoods. Plantation establishment, especially on mesic clay soils, is usually hindered by aggressive and abundant competition (Harvey et al. 1995). On the other hand, management that does not favor growth of advanced softwood regeneration in intolerant hardwood stands appears as a net loss (MacDonald 1995). In the longer term, static maintenance of hardwood or softwood stands could induce serious problems in site productivity. Conifer presence diminishes nutrient availability, and successive rotations could decrease yields (Pastor et al. 1987) In the same way, successive rotations of aspen, a high calcium-demanding species (Paré et al. 1993), could cause deficiencies in calcium and reduced productivity.

VARIABILITY IN THE FIRE CYCLES

The few studies from Quebec's southwestern boreal forest have demonstrated the great variability in fire frequency and associated forest composition during the Holocene. Dendrochronological reconstructions of fire events over the last 300 yr in the Lake Duparquet area (Bergeron 1991, Dansereau and Bergeron 1993) showed a dramatic decrease in fire frequency during the 20th century. The fire cycle, estimated at 63 yr for the period before 1870, has continued to lengthen, and the last major fire occurred in 1944. This increase in the fire cycle appears to be due to a reduction in the frequency of drought events since the end of the Little Ice Age, about AD1850 (Bergeron and Archambault 1993). This climatically induced increase in the fire cycle appears to be a general phenomenon in the eastern boreal forest. Moreover, it supports simulations using the Canadian General Atmospheric Circulation Model that predict a decrease in forest fire activity, for this region, with future warming (Flannigan et al. 1998).

At a longer time scale, the stratigraphic analysis of microcharcoal in a laminated lake from the same area (C. Carcaillet, P. J. H. Richard, B. Fréchette, Y. Bergeron, S. Gauthier, and Y. Prairie, *unpublished manuscript*. Fig. 4) shows that the fire cycle has been variable throughout the Holocene around that lake. Preliminary analysis of the charcoal record yielded 34 local fire events, with widely varying fire intervals during the last 6700 yr over an equally varying, but generally increasing, background of charcoal abundance through time. Average fire intervals were longer (332 +/-195 yr, *n* = 14 fires) during the mid-Holocene than during the last 2100 yr (99 +/-53 yr, *n* = 20 fires). Changing the threshold value to pinpoint local fire events over the background (Fig. 4b) changes the number of fires identified, but the long-term structure of fire intervals remains unchanged.

Fig. 4. Data from Lake Francis (Abitibi, Quebec, 48º31'35"-78 º28'20"). (a) Distribution of charcoal influx ($mm^2 \cdot cm^{-2} \cdot yr^{-1}$; thin line) and the low-frequency filter series computed with inverse Fourier transformation. (b) Charcoal index ($mm^2 \cdot cm^{-2} \cdot yr^{-1}$); the high-frequency curve is obtained by detrending the raw data using the low-frequency filter. (c) Fire chronology is computed by applying a threshold of 1.25 on the high-frequency curve.



Using the negative exponential distribution and the expected change in forest composition with age (see Fig. 3), Leduc et al. (1995) have predicted the landscape forest composition according to change in the fire cycle (Fig. 5). During short fire cycles (50 - 100 yr), the landscape is dominated by postfire species such as aspen, birch, or jack pine, whereas at very long fire cycles (> 300 yr), balsam fir, black spruce, and white cedar are dominant. Maximum landscape diversity is observed between these two extremes (Gauthier et al. 1996). Variations in fire cycles appear to explain some of the major vegetation changes observed during the Holocene. According to regional pollen analysis (Richard 1980), the longer fire interval observed in the mid-Holocene is associated with an exceptional abundance of white cedar, a late-successional species in the area (Fig.6). Shorter fire intervals (Fig. 5) may explain a recent increase in jack pine (Fig. 6). All species appear to be able to cope with the observed variability in the fire cycle, as is demonstrated by their constant abundance throughout the Holocene (Richard 1980, Liu 1990).

Fig. 5. Estimated effect of fire cycle changes on the proportion of different species in a typical landscape from Quebec's southern boreal forest (Leduc et al. 1995).

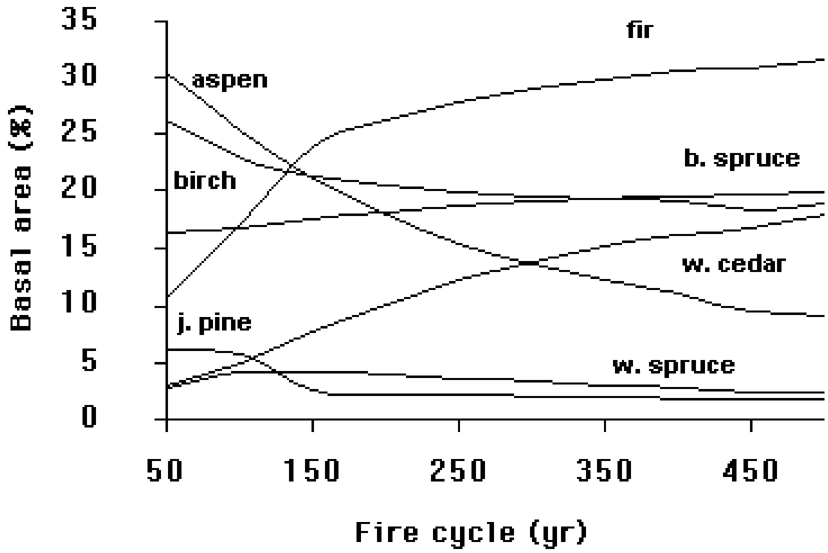
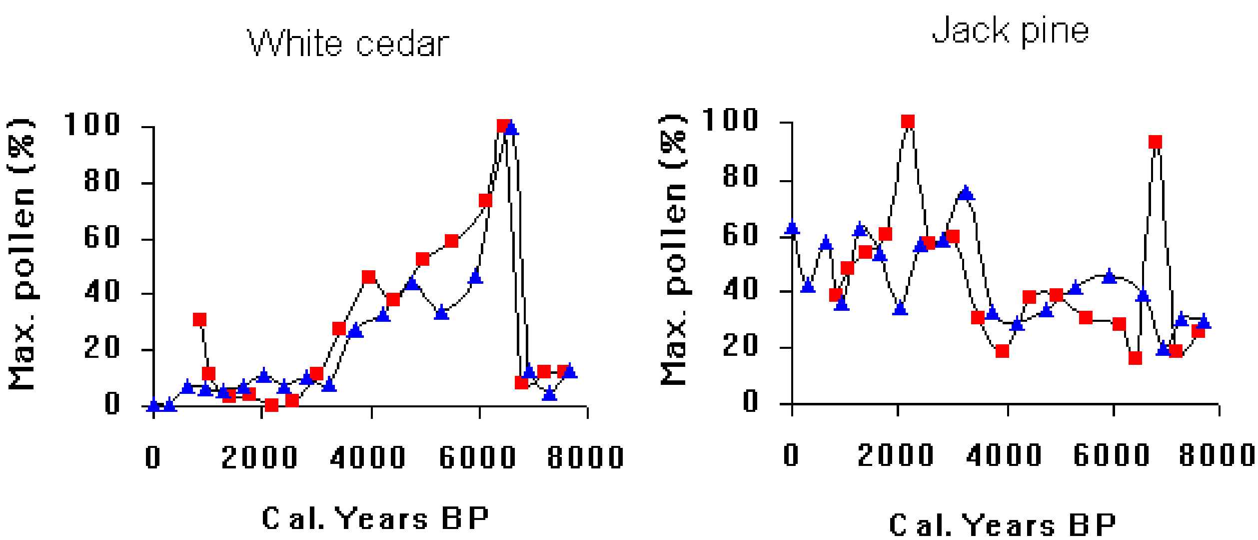


Fig. 6. Standardized pollen percentage for white cedar (left) and jack pine (right) at Lakes Clo (square) and Yelle (triangle). Data are modified from Richard (1980).



IMPLICATIONS FOR FOREST MANAGEMENT

The three characteristics of naturally disturbed landscapes that we have discussed have important implications for developing silvicultural systems that are inspired by, and closely resemble, natural ecosystem dynamics. First, it must be recognized that normal forest rotations dramatically change the natural age distribution of the forest stand. This difference is fundamental because it implies, depending on age class distributions, either a loss of overmature stands, which may be essential for biodiversity maintenance, or inversely, fiber loss as a result of longer rotations. This dilemma is, however, not without a solution. In effect, silvicultural measures aimed at maintaining characteristics of overmature stands while maintaining economically viable forest rotations are possible. Second, natural forest dynamics following fire on mesic sites involve a gradual replacement of stands of intolerant broadleaf species by mixedwood and then softwood stands. Current silvicultural practices promote successive rotations of similarly composed stands.

More appropriate silvicultural approaches would favor species replacement by succession at the stand spatial scale, while maintaining a reasonable balance between hardwood and softwood stands at the landscape scale. Such a system is being tested in the Lake Duparquet Research and Teaching Forest, where a silvicultural strategy has been proposed that involves the use of clear-cutting and partial cutting on the same site, similar to the processes of stand reinitiation by fire and natural succession (Bergeron and Harvey 1997). Third, the large fluctuations observed in fire frequency during the Holocene limit the use of a single fire cycle to characterize natural fire regimes. Besides, the spatial variability of fire frequency at the scale of the entire Holocene is far from being appropriately assessed with the few microcharcoal analyses available. The short fire cycles generally described for boreal ecosystems do not appear to be universal; rather, shifts between short and long fire cycles have been observed. This naturally occurring variability should be maintained by forest managers by adopting silvicultural techniques that maintain a spectrum of forest compositions over the landscape.

One avenue is to try to maximize diversity at the landscape level. In the Quebec mixedwood forest, this would appear to be attained with a fire cycle between 100 and 200 yr (Fig. 5; see Gauthier et al. 1996). A more diverse landscape might be more resistant to disturbances (De Grandpré and Bergeron 1997) and could provide some flexibility in the event that targeted species composition has to be changed following change in climate or in management objectives.

CONCLUSION

It is theoretically possible to develop forest management systems that are inspired by natural disturbances. However, it is important to recognize that this approach cannot justify the even-aged, (relatively) short-rotation regime that is currently the standard of boreal forestry. Nature is more variable, and the maintenance of this variability should be a major objective of forest management. It is essential to go further and to attempt to reconstruct a forest mosaic that more closely resembles the natural composition. Although it is not possible nor desirable to perfectly mimic natural disturbances, strategies that preserve their associated processes and diversity should be implemented.

RESPONSES TO THIS ARTICLE

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Acknowledgments

This work is supported by the Natural Sciences and Engineering Research Council Network of Centres of Excellence in Sustainable Forest Management and by the Canadian Forest Service. The paper is a contribution of the Industrial Chair in Sustainable Forest Management of UQAM and UQAT. We thank Brian Harvey for his comments on a first draft of the manuscript.

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