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VARIABILITY IN FIRE FREQUENCY AND FOREST COMPOSITION IN CANADA'S SOUTHEASTERN BOREAL FOREST: A CHALLENGE FOR SUSTAINABLE FOREST MANAGEMENT

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ABSTRACT

As 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 recognise that it has limitations. We discuss results on fire regime and stand dynamics in Quebec's boreal forest. The large fluctuations observed in fire frequency during the Holocene limits the use of a single fire cycle to characterise 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 and structure at the landscape and regional levels. All these factors create a natural variability in forest composition and structure that should be maintained by forest managers concerned with biodiversity conservation. On the other hand, the current forest management approach tends to decrease this variability: for instance, normal forest rotations truncate the natural forest stand age distribution and eliminate over-mature forests from the landscape. In this paper we suggest that the development of silvicultural techniques that maintain a spectrum of forest compositions and structures over the landscape is one avenue to maintain this variability.

INTRODUCTION

The forest industry is heading back to nature to find a way to conciliate economic fibre production with biodiversity. 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 which has the greatest impact on forest dynamics (Engelmark et al. 1993). The North American boreal forest is generally characterised by relatively short fire cycles (50 to 250 years) 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 recognise that it has limitations. Based on research results on natural disturbances and forest dynamics in Quebec's boreal forests, we describe characteristics of boreal systems controlled by fire that contribute to increase 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 Quebec's Clay Belt.

VARIABILITY IN THE FIRE CYCLES

Dendrochronological reconstructions of fire events over the last 300 years in a 15,000 km^2 between 48^0 and 50^0 N along the Quebec-Ontario border. The 49^{th} parallel constitutes the limit between the Mixedwood boreal zone and the Coniferous boreal zones. The results showed a dramatic decrease in fire frequency during the twentieth Century. The fire cycle estimated at 62 years for the period before 1850, has increased to 121 years and has continued to lengthen during the Twentieth Century. This decrease in fire frequency is responsible for the presence of large tracks of over-mature and old-growth forests in the territory (Fig. 1).

The 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 (~1850) (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).

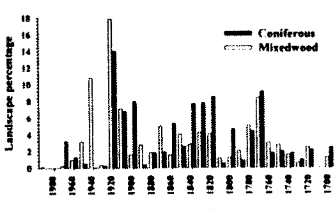

Figure 1. Current age class distribution of stands in the mixedwood and coniferous boreal regions. Notice the important proportion of the landscape in over-mature and old-growth stands

Fire cycles calculated for the periods during and after the end of the Little Ice Age do not vary significantly between the two forest types. This suggests that the transition between Mixedwood and Coniferous forests observed in the southern boreal forest cannot be explained by a difference in fire frequency, at least during the last 300 years. On the other hand, the fire regime in the Coniferous region is characterised by a few large fires whereas a high abundance of small fires are observed in the Mixedwood region (Fig.2). In the north, serotinous fire-adapted conifers such as jack pine and black spruce appear to be favored by large fires while in the south conifer species such as balsam fir and white spruce, which need to re-invade from unburned areas, would be favored by smaller fires.

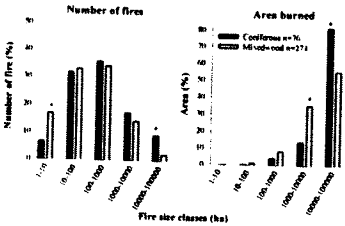

Figure 2. Comparisons of the number of fires and the area burned per class of fire size among the Coniferous and the Mixedwood regions. + indicates that significantly more fires (left) or more area burned (right) are observed.

At a longer time scale (6,800 years), the stratigraphic analysis of micro-charcoal in a laminated lake from the same area (Carcaillet *et al.*, unpublished manuscript) shows that the fire cycle has been variable throughout the Holocene. Starting after 1000 BC, the raw data show an increase in charcoal. Fire intervals dropped dramatically from Mid- to Late-Holocene at *ca.* 200 BC, from 260±208 years to 85±55 years. This change discriminates two periods corresponding to 18 events between 4800-200 BC and 24 since 200 BC. The change in fire intervals is interpreted as the result of increased drought frequency due to the more pronounced influence of the Westerlies during the Mid- to Late-Holocene. Climate forcing changes in fire intervals at this longer time scale appears to be convergent with what was observed following the end of the Little Ice Age at the secular time scale.

VARIABILITY IN STAND COMPOSITION AND STRUCTURE

A chronosequence covering more than 230 years after fire has been reconstructed for both the Mixedwood boreal and the Coniferous boreal zones using fire areas originating in different years (Fig. 3). Figure 3 summarises natural post-fire succession based on the relative importance of each species (dominance) without distinction among the surficial geology types. Succession in the coniferous zone is characterised by fewer changes in species composition because of the dominance of black spruce (Fig. 3). On the other hand, succession in the Mixedwood zone is more complex and can be characterised by a transition from intolerant hardwood to a coniferous forest over time with an increasing importance of balsam fir and eastern white cedar (Fig. 3, Bergeron and Dubuc 1989; Leduc et al. 1995).

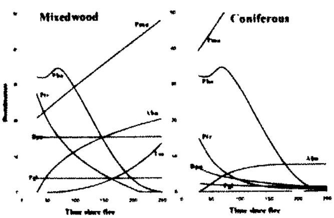

Figure 3. Comparisons of successional trends between the Mixedwood and Coniferous regions over a 250 year chronosequence. and Aba: Abies balsemea; Bpa: *Betula papiryfera*; Pma: *Picea mariana*; Pgl: *Picea glauca*; Pba: *Pinus banksiana*; Ptr: *Populus tremuloides*; Toc: *Thuya occidentalis*. Note that the dominance of black spruce is increasing linearly to attain 90% at 250 years in the coniferous zone.

IMPLICATIONS FOR FOREST MANAGEMENT

The characteristics of naturally disturbed landscapes discussed above have important implications for developing silvicultural systems that are inspired by and closely resemble natural ecosystem dynamics. First, it must be recognised that normal forest rotations dramatically change the natural forest stand age distribution. In *fact*, assuming that the probability of burning is independent of stand age (which is generally mentioned 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 close to 37% of the stands older than the fire cycle. Fire may affect some stands several times before reaching maturity while allowing other stands to survive beyond 100 years, whereas, forest harvesting will only occur at stand maturity. Assuming a 100 year rotation, proportions of over-mature stands (> 100 years), and old-growth (> 200 years) increase as the fire cycle lengthens (Fig. 4) and could cover an important proportion of the boreal forest landscape.

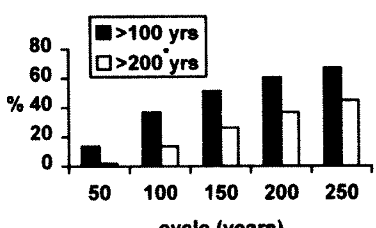

Figure 4: Percentage of stands older than 100 and 200 years increases from short to long fire cycles. With a 100 year forest rotation, none of these stands would be present.

In the Mixedwood region, on mesic sites succession towards over-mature and old-growth stands may imply a change in forest composition from deciduous towards mixed and coniferous forests (Fig. 5; Gauthier *et al. 1996*). In the coniferous forest of the north, while composition may not change, stand structure varies in relation to time since fire (Fig. 5).

These characteristics are fundamental as they imply, under fully regulated, even-aged management, the loss of over-mature forests, often judged essential to biodiversity maintenance, or a decrease in allowable cut due to longer forest rotations if the natural disturbance cycle is strictly adhered to.

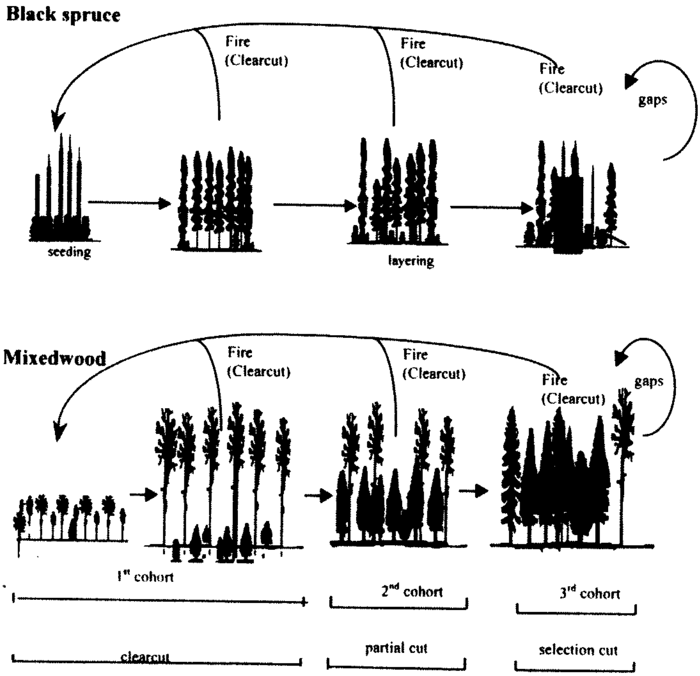

Figure 5: Examples of natural dynamics and associated silvicultural treatments for the Mixedwood and the black spruce forests. The X axis represents the time since the last disturbance.

TOWARDS A SOLUTION

The use of silvicultural practices designed to maintain specific structure or composition of over-mature stands in forests under management may provide a means of maintaining species and ecosystem diversity while only slightly modifying allowable cut (Bergeron et al. 1999). To this end it would be possible to treat some stands by clear-cutting followed by planting or seeding, homologous to fire, others by partial cutting or careful logging, which simulate the natural evolution of over-mature stands, and still others by selection cutting as a means of emulating gap dynamics in old growth. A simple example illustrating the natural dynamics and an ecosystem approach to managing the mixedwoods and the conifer forests are presented in Figure 5. The first cohort, originating from fire, is replaced by clear-cutting and planting or seeding, the second cohort by partial cutting that emulates natural succession, and the third cohort by selection cutting that mimics the natural gap dynamics of old growth stands.

The proportion of stands that should be treated by each of these silvicultural practices should vary in relation to the natural disturbance cycle and the maximum harvest age. Just as in natural landscapes where not all stands survive to a mature or old growth stage before being burned and recommencing succession, not all stands pass through the three cohorts. Re-initiation of the first cohort may be generated by clear-cutting and planting or seeding of stands of any of the three cohorts. It would thus be possible to partially maintain not only the natural composition and structure of stands, but also a forest age structure that approaches the typical distribution produced by fire.

Using Table 2 the proportion of the management cohorts as a function of fire cycle and maximum harvest age can be determined. For this exercise, the harvest age was fixed at 100 years but proportion may vary depending on commercial rotation. With a 50-year fire cycle, the great majority of the forest area is composed of the first cohort and clear-cutting is the most important silvicultural practice. This cohort is, however, relatively less important when fire cycles lengthen and thus area that should be submitted to partial or selective cutting increase.

Table 2. The desired proportion of the three cohorts submitted to different silvicultural treatments as a function of disturbance cycle. Harvest rotation is fixed to 100 years.

Cohort	FIRE CYCLE								
(%)	50	75	100	125	150	200	300	400	500
1st	86	74	63	55	49	39	28	22	18
2nd	12	19	23	25	25	24	20	17	15
3rd and more	2	7	14	20	26	37	51	61	67

Use of Table 2 should, however, take into consideration the inherent variability in the calculation of fire cycles and the temporal fluctuations in fire cycle due to climate change. Over a period of 8,000 years, the forest in the Quebec Clay Belt has been subjected to fire cycles varying between 50 and 500 years. Because vegetation can take an extremely long time to adjust to a particular fire cycle, the current landscape contains stands that are essentially relics from past fire regimes. Moreover, predictions concerning the effects of future climate change suggest changes in fire cycle (Flannigan et al. 1998). It is therefore desirable to attempt to maintain all stand types that make up the cohorts, even if strict application of the proposed model would lead to their elimination. This management strategy has three advantages: 1) permits the allocation of a portion of an area to the protection of rare ecosystems; 2) maintains a certain flexibility with respect to future modifications in the wood products market; and 3) allows preservation of the resilience of the forest landscape in the context of changing disturbance regimes.

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FIRE FREQUENCY AND THE SPATIAL AGE MOSAIC OF THE MIXEDWOOD BOREAL FOREST OF SASKATCHEWAN

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ABSTRACT

One approach to ecosystem management is to emulate the effects of natural disturbance in producing landscape patterns. This approach requires a spatial analysis of the pattern and an understanding of the processes producing the pattern. Forested landscapes exhibit mosaic patterns of both stand types and ages. This study investigates the spatial mosaic of stand ages produced by high intensity, stand-replacing fires in the mixedwood boreal forest of western Canada. A high resolution, accurately dated time-since-fire map for a large (3,461 km^2) contiguous area is used to produce the landscape survivorship distribution in which both spatial and temporal changes in fire cycle are statistically tested. Spatial multivariate analysis of the time-since-fire map is also used to investigate the spatial assembly of the age mosaic. Significant changes in fire cycle can be explained by climatic change as well as by land use change in the surrounding area. The shift from a short (15 year) fire cycle to a longer (75 year) cycle after 1890 in the northern half of the study area coincides with climatic change at the end of the Little Ice Age. In the southern half of the study area, the short fire cycle continues after 1890 due to the spread of human-caused fires from the adjacent area which was settled and cleared for agriculture during the first half of this century. Upon completion of settlement in 1945, the fire cycle becomes significantly longer due to the fragmentation of the once continuous forest that surrounded the study area and from which the majority of large fires propagated in the past. The different fire cycle histories of the two regions within the study area also explains the spatial mosaic pattern of stand ages, sizes and shapes. The extended period of the short fire cycle through the first half of this century in the southern region results in it being dominated by larger oblong-shaped polygons with irregular edges that are younger in age, characteristics that describe the pattern of large burns. The northern region generally has circular-shaped compact polygons that are older and are the remnants of larger, much earlier burns that have since been overburned. The polygons in the northern region are more similar in size and shape to adjacent polygons, but less similar in age, than are those in the southern region. Thus, this

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