Boreal Forest Ecology and Landscape Management

Sylvie Gauthier
Natural Ressources Canada, Canadian Forest Service, Sainte-Foy, Québec

Yves Bergeron
Groupe de recherche en écologie forestière, UQAM, Montréal, Québec

Brian Harvey
Unité de recherche et de développement forestiers de l'Abitibi-Témiscamingue, UQAT, Rouyn-Noranda, Québec

Alain Leduc
Groupe de recherche en écologie forestière, UQAM, Montréal, Québec

Abstract
In the context of sustainable forestry, forest management in Canada is undergoing a period of redefinition. One approach being given attention is the development of silvicultural and management principles which emulate or are inspired by natural ecosystem dynamics. In this paper, using examples from the Eastern boreal forest of Canada, we illustrate how ecological knowledge of disturbance regimes and related forest dynamics can be used to develop new management strategies that conciliate wood production with biodiversity maintenance and long-term ecosystem productivity.

Introduction

Historically, resource management and planning were undertaken within relatively short temporal and spatial perspectives. Forest practices focused mainly on timber production at the stand level and were planned over periods of 5 to 20 years. However, as a result of advances in our understanding of forest ecosystems, and of changes in social values, management practices must now take into consideration factors other than timber production, including values related to recreation, wildlife, biodiversity conservation and long term productivity (Freedman *et al.*1994; Kimmins 1992, McKenney *et al.*1994). It is now understood that most forest ecosystems, including the boreal forest, are strongly influenced by natural disturbances such as fire and insect outbreaks (Attiwill 1994 , Johnson 1992, Blais 1983, Morin 1994). Because diversity, structure and function of forests are modulated by natural disturbances, it follows that forest management should be based, in large part, on our understanding of the ecological processes of natural disturbances. One assumption of this approach is that if we can maintain the habitat diversity (landscape diversity) and the inherent ecosystem dynamics that are created by the natural disturbance regime, we will be better able to maintain the lower levels of biodiversity (species, genetic) and the long-term productivity of the system, for which knowledge is missing.

One avenue of landscape management that is currently being given attention is "*landscape ecosystem management*". LEM is aimed at developing silvicultural and management principles that emulate or resemble natural ecosystem dynamics (Bradshaw *et al.*1994, Galindo-Leal and Bunnell 1995, Bergeron and Harvey 1997). In order to develop and implement this management approach, knowledge of the effects of natural disturbances and the related forest dynamics is required. In this paper, we illustrate, using results obtained in the mixedwood and coniferous boreal forest of western Quebec, how ecological knowledge of the disturbance regime and forest dynamics can be integrated into landscape management strategies.

Study area

A number of studies aimed at characterizing the natural forest dynamics of the balsam-fir-white birch ecoregion (Amos Lowlands) and the black spruce ecoregion (Lac Matagami) of northwestern Quebec have been carried out over the last 15 years. The region is located in the clay belt of Ontario and Quebec, a large physiographic zone created by proglacial Lake Barlow-Ojibway (Veillette 1994). Commercial forestry activities began in the region after the construction of the transcontinental railway, around 1910. However, large-scale mechanized harvesting began around 1970 in the immediate region of Lake Duparquet (Harvey and Bergeron 1989). In both ecoregions, large tracts of virgin forest remains, thus providing a means of reconstituting the historical natural disturbance regime.

Disturbance regimes

Fire cycle can be defined as the time required to burn an area equal in size to a given study area. This definition implies that some sites may burn more than once during the interval while others will be left unburned. Taking this into account, and assuming that burning probability is independent of stand age, the expected age class distribution should follow a negative exponential (Van Wagner 1978). Consequently, the age class distribution is very different from that of a regulated, normal forest. For example, for a fire cycle of 100 years, about 63% of forest stands should be younger than 100 years, while 37% of the area would be composed of forest older than 100 years. This contrasts markedly with the age structure of a normalized forest on a 100 year rotation, where all stands over the rotation age would be eliminated from the landscape. Results from the fire history reconstruction work in the boreal forest of western Quebec, conducted over 15,000 km^2 and encompassing the 2 ecoregions (Fig. 1), suggest that the fire cycle in these regions is longer than 100 years. In the balsam fir-white birch ecoregion, more than 30% of the forest is older than 200 years, and about 8% is over 250 years old. Even in the black spruce ecoregion, 25% of forests are older than 200 years. Moreover, fluctuations in the fire cycle have been observed in the region over the Holocene (Bergeron *et al.* 1997).

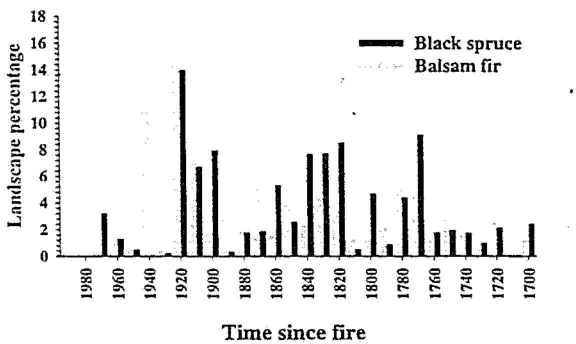

Fig. 1. Current landscape proportion occupied by forest stand originating from different fire decades.

Although fires are usually large and intense in the boreal forest, within the perimeter of a single fire, severity may vary considerably and islands of residual vegetation generally persist. In a large fire (49,000 ha) in the black spruce forest zone of Québec, for example, only 3% of the burned area was composed of totally unburned islands, but more than 25% of trees survived in about 40% of the burned area. These islands may be very important for the regeneration of species such as balsam fir and white spruce, which depend on seed dispersal for re-invasion after a fire. For example, Galipeau et al. (1997) demonstrated that the number of balsam fir stems, 70 years after fire, decreased as a function of distance from the fire margin.

Insect outbreaks, notably spruce budworm outbreaks, are another type of natural disturbance that affects boreal regions. In northwestern Québec, the occurrence of three major budworm outbreaks during this century has been documented by Morin *et al.* (1993). During the last outbreak, on average 53 % of balsam fir (> 5 cm DBH) were killed (Bergeron *et al.* 1995), creating large canopy openings in fir-dominated stands. Interestingly, the mortality resulting from the last spruce budworm outbreak was shown to be influenced by the forest mosaic. Balsam fir mortality in fir-dominated stands surrounded by deciduous forests was around 35% compared to 80 % in extensive coniferous stands. There is some evidence to suggest that this phenomenon is at least partly due to the invasion of abundant parasitoid populations from surrounding deciduous forests into the isolated conifer stands.

Stand dynamics

Post-fire forest succession has been reconstructed using fire areas originating in different years (1964, 1944, 1916, 1919, 1870, 1847, 1823, 1797, 1760), in the vicinity of Lake Duparquet (balsam fir-white birch ecoregion). In this manner, natural chronosequences covering more than 230 years have been developed for each of the main surficial deposits occurring in the area (Bergeron and Dubuc 1989, Gauthier *et al.* 1996). Results confirm that forest type dynamics differ from one surficial deposit to another (Fig. 2; Bergeron and Bouchard, 1984; Bergeron *et al.* 1983). Generally speaking however, deciduous forests dominated by pioneer species (white birch or trembling aspen), are most abundant in the first 50-100 years after a fire, depending on the surficial deposit type. The mixed-deciduous forest types increase in proportion in stands during the period of 100 to 150 years after fire and the mixed-coniferous forest type has its highest frequency after 100-150 years. Frequency of the coniferous forest type increases with time since fire, reaching a maximum after 230 years. After that time, it dominates all surficial deposit types except tills, where an equal proportion of mixed-coniferous and coniferous forests is observed (Fig. 2). It is important to note that, on any site type, the portion of each forest type varies, but all types are present in any age class. This may be the result of the size or intensity of the fires, the availability of seeds from particular species, etc. In any case, it also demonstrates that on a given site type, we can expect a variety of forest types of different ages. This suggests that, when developing forest-level management strategies, some flexibility should be exercised in establishing forest composition objectives.

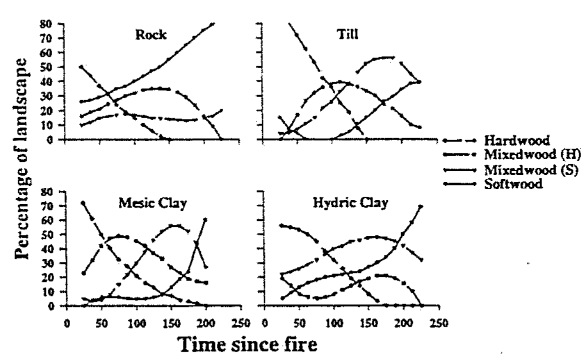

Fig. 2. Evolution of cover type as a function of time since fire (from Gauthier *et al.* 1996).

Research in the region has demonstrated that, with vegetation changes through succession, a number of stand characteristics also change. Above-ground biomass decreases as stands change from deciduous to coniferous dominance (Paré and Bergeron 1995). Nutrient availability and pH decrease over succession (Brais *et al.* 1995), conditions which may be responsible for the decrease in productivity. Outbreak severity increases with the increase in the fir component in stands ; average fir mortality may exceed 80 % in coniferous stands over 200 years old (MacLean and Ofstaff 1989, Bergeron *et al.* 1995). While outbreaks generally have the effect of increasing the hardwood component in conifer and mixed stands, greater advanced regeneration in the mixedwoods may result in an eventual increase in the softwood component in the canopy. Finally, results have shown that coniferous stands are very susceptible to invasion by competitive species after logging (De Grandpré and Bergeron 1996). This competition is particularly abundant in coniferous stands where shrub and herb layers dominated by species that are intolerant to full-light conditions are overtaken by aggressive invasion of adventitious species.

Current silviculture and proposed change

The natural dynamics of the boreal mixedwood forest can be schematized by successive rotations of deciduous, mixedwood and coniferous dominance. The rapidity of this succession is variable, and is dependent on the rate at which deciduous stands are invaded by coniferous seedlings (Galipeau *et al.* 1997). At any time during succession, fire can revert forest stands to their post-disturbance state, as aspen and birch are generally sufficiently abundant - even in older stands - to enable the return to intolerant deciduous stands (Lavertu *et al.* 1994). Jack pine can also form pure or mixed stands on these sites after fire (Gauthier *et al.* 1993). Overlaying this post-fire compositional change is the effect of spruce budworm outbreaks. Abundant advanced coniferous regeneration may permit an immediate return to a coniferous-dominated stands. However, advanced coniferous regeneration is usually insufficient (Kneeshaw and Bergeron 1996), and coniferous stands are usually replaced by mixedwoods.

Current silviculture practices ignore, in certain respects, natural ecosystem dynamics. Provincial silvicultural standards require that cut-overs be regenerated to deciduous and coniferous stocking levels similar or superior to pre-harvest levels. Moreover, despite the recent recognition of a mixed designation, in practice, mixed stands are often assimilated into deciduous or coniferous scenarios. The principal consequence of this approach is that it imposes a cyclical rotation of similarly composed stands, while in the natural system, succession generally involves a transition of stand types. The objective of regenerating coniferous stands with coniferous 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 favour growth of advanced coniferous regeneration present in intolerant deciduous stands appears as a net loss (MacDonald 1995).

In the longer term, static maintenance of deciduous or coniferous stands could induce serious problems in site productivity. Conifer presence diminishes nutrient availability and successive rotations could decrease yields. Similarly, successive rotations of aspen, a high calcium-demanding species (Paré *et al.* 1993), could cause deficiencies in calcium and reduced productivity. Moreover, the current silvicultural system could contribute to reduce the abundance of mixed stands. Not only do these stands contribute to ecosystem diversity at the landscape level, but they display a number of interesting characteristics such as lower susceptibility to spruce budworm outbreaks, abundant advanced regeneration, as well as containing significant attributes for wildlife and other values.

There is a need to develop silvicultural systems which favor the transition, on the same site, from one stand type to another. In the Lake Duparquet Research and Teaching Forest, new silvicultural approaches are currently under development. Where advanced coniferous regeneration is absent, clear-cutting, like fire, can be used to return the stand to intolerant hardwoods. However, where regeneration is present, gradual extraction of a portion of hardwood stems from the overstorey can emulate the break-up of the aspen overstorey that occurs in natural succession. As the coniferous proportion of the stand increases, partial cutting should give way to careful clear-cutting, with measures to protect the advanced regeneration and soil. This method partially mimics the effects of severe budworm outbreaks and assures the return of mixed stands. In the longer term, a clear-cut, like fire, could return the stand to its initial state.

Landscape dynamics

We have discussed stand-level silviculture without addressing how these stands should be distributed over the landscape. Here again, knowledge of natural disturbance regimes provides some clues to this question. By combining the natural dynamics of stands on each surficial deposit (Fig. 1) with the expected age class distribution of stands under a fire cycle of 100 years, we can derive a picture of the expected distribution of cover types in a situation where the forest mosaic is at equilibrium with the natural disturbance regime. In the ecological district in which the Lake Duparquet Forest is located (Fig. 3 ; landscape L49), 38% of the area would be occupied by hardwood forest, mainly in the young (< 75 years) age classes ; mixed forest (dominated either by softwood or hardwood) would represent 29% of the area, mainly in the age classes between 75 and 175 years ; and 31% of the area would be covered by softwood forest, in all age classes. Jack pine stands are important in the young age classes and balsam fir stands are more important in the older age classes.

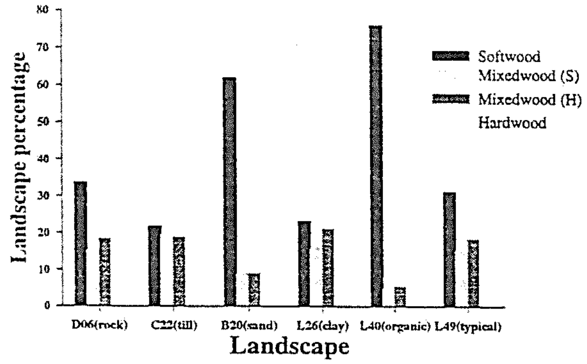

Fig. 3. Composition of 6 ecological districts (landscapes) under a 100-yr fire cycle (from Gauthier*et al.* 1996).

The computation for 6 landscapes that vary in terms of their surficial geology showed considerable differences in vegetation composition under a fire cycle of 100 years (Fig. 3). This result is due to the different dynamics observed among surficial deposit types and differences in landscape physiography (Gauthier *et al.* 1996). The derived values for each landscape may serve as forest composition targets or objectives to be maintained in each of these landscapes under management. This model does not however provide information about spatial distribution and size of stands under forest management. The area covered by natural fires provides considerable flexibility in this respect, as fire size can vary in size from a few hectares to several thousands of hectares. Most fires, however, leave many unburned islands or patches within the fire limits. More study is needed to determine how our understanding of natural disturbance occurrences can guide the spatial distribution of forestry interventions. Elements such as biodiversity conservation, and the importance of maintaining sufficiently extensive residual forest parcels to maintain interior wildlife species should be taken into consideration (Hunter 1987). Consequences of spatial distribution of coniferous stands on spruce budworm vulnerability could also provide guidance with regard to spatial arrangement of stand types.

Conclusion

Studies of natural disturbance regimes and forest dynamics in the southern boreal forest have demonstrated the importance of two processes that may be essential for long-term productivity and maintenance of biodiversity: temporal replacement of species at the stand level and the presence of a natural mosaic of stands at the landscape level. Management and silvicultural approaches for the mixedwood region should be based on knowledge of these processes and patterns. Because natural fire cycle has varied considerably over the last 8,000 years, a certain variability exists within which organisms are presumably able to adapt. Strict regulations and silvicultural standards should therefore be avoided and variations in scenarios should be encouraged. Nature itself behaves with considerable variation and should inspire different silvicultural interventions.

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