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Silvicultural Practices and Forest Management Strategies that Emulate Natural Disturbances

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Y. Bergeron, B. Harvey,
A. Leduc and S. Gauthier

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Sustainable Forest Management Network
G208 Biological Sciences Building
University of Alberta
Edmonton, Alberta, T6G 2E9
Ph: (780) 492 6659
Fax: (780) 492 8160
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Silvicultural practices and forest management strategies that emulate natural disturbances

by

Yves Bergeron[1]
Brian Harvey[2]
Alain Leduc[3]
and
Sylvie Gauthier[4]

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[1] Groupe de recherche en écologie forestière, Université du Québec à Montréal, CP 8888 Succ Centre-Ville, Montreal, Canada, H3C 3P8Tel: 514-987-3000 ext: 4872; Fax: 514-987-4647
E-mail: bergeron.yves@uqam.ca
[2] Unité de recherche et de développement forestiers de l'Abitibi-Témiscamingue, Université du Quebec en Abitibi-Témiscamingue, 445 boul; de l'Université, Rouyn-Noranda, Canada, J9X 5E4
Tel: 819-762-0971 ext: 2347 ; Fax: 819-797-4727 ; E-mail: brian.harvey@uqat.uquebec.ca
[3] Groupe de recherche en écologie forestière, Université du Québec à Montréal, CP 8888 Succ Centre-Ville Montréal, Canada H3C 3P8 ; Tel: 514-987-3000 ext: 1947; FAX: 514-987-4647
E-mail: r13064@er.uqam.ca
[4] Ressources naturelles Canada - Natural Resources Canada, Service canadien des forêts - Canadian Forest Service, Région du Québec-Quebec Region, 1055 du P.E.P.S., Sainte-Foy, Quebec, CANADA, G1V 4C7 ; Tél.(418) 648-5829 ; Fax: (418) 648-5849
E-mail: sgauthier@cfl.forestry.ca

ABSTRACT

Although the concept of forest ecosystem management (FEM) based on natural disturbance has generated a great deal of interest, few concrete examples exist of FEM principles being put into application. Silvicultural practices that emulate natural disturbances are proposed with examples from the principal vegetation zones of Quebec. With the exception of the large-scale use of careful logging to protect advanced regeneration in ecosystems generally controlled by fire, stand-level silvicultural practices currently used are reasonably similar to natural disturbances, although important differences exist. In contrast, at the forest-level, even-aged management, as is currently practised, rarely permits adequate reproduction of the variety of age classes, stand types, and structural components normally found in the boreal forest. A model which allows an even-aged management approach inspired by natural dynamics is proposed.

INTRODUCTION

Over the past decade we have seen an increasing interest in forest ecosystem management and, in particular, in forest management strategies that attempt to emulate natural disturbances (Attiwill 1994; Galindo-Leil and Bunnell 1995; MacDonald 1995; Lieffers *et al.* 1996; Bergeron and Harvey 1997; Angelstam 1998). Although we can not yet speak of a general consensus, there is considerable agreement that a management approach that maintains stand composition and structures similar to those that characterize natural environments could provide a means of maintaining biodiversity and the essential functions of forest ecosystems (Franklin 1993, McKenney *et al.* 1994, Gauthier *et al.* 1995). However, despite a certain interest in this approach, the concepts have yet to be put into application on a broad scale. Indeed, while most articles on the subject present guiding principles of natural disturbance-inspired forest management, few go as far as proposing silvicultural treatments and management strategies that facilitate its practical application. In the absence of concrete alternatives, it is normal that forest industry hesitates to waiver from traditional practices that have already proven themselves. In this article, we explore certain avenues that advance the links between natural disturbances, silvicultural practices and forest management strategies. We will illustrate how it is possible to use judiciously a good understanding of natural forest dynamics in forest management planning and in choosing or developing silvicultural practices. A particular emphasis will be placed on the importance of diversifying silvicultural practices thoughout the forest landscape.

SILVICULTURE ADAPTED TO DIFFERENT FOREST REGIONS

To begin, it is important to appreciate the manner in which stand level silvicultural practices have repercussions similar to the effects produced by natural disturbances. Table 1 summarizes this point in comparing the severity of diverse natural disturbances and the silvicultural treatments with which a certain commonality of effects exists. The examples are roughly drawn from a gradient of silvicultural treatments used from southern to northern Quebec; however, the same type of comparison may be applied to other forest regions in Canada.

Table 1. Relationships between characteristics of natural disturbances and silvicultural practices that resemble them.

Severity	Geographic extent	Example of natural disturbances	Associated silvicultural practices	Major differences
Without direct effects on advanced regeneration or soil	Small	Falling of a few trees creating small gaps in tolerant hardwood forests	Selection cut mimicking natural mortality of individuals or small groups of trees	Lack of exposure of mineral soil results in a loss of germination beds
	Moderate	Windthrow over small areas in the tolerant hardwood mixed-wood forest	Group selection cutting mimicking natural mortality of groups of trees (Gap selection cutting)	Lack of exposure of mineral soil results in a loss of germination beds
	Large	Spruce budworm outbreak	Careful logging with advanced regeneration and soil protection	Absence of snags and residual trees
Advanced regeneration mortality and disturbance of humus layer	Small to moderate	Surface fires in white and red pine stands	Clear-cutting with seed-tree retention	- Soil does not burn - Decrease in wood volumes Absence of snags
	Moderate	Fire of variable severity occurring in mixed forests and leaving a number of green forest island residuals	Clear-cutting over small areas followed by seeding or planting	- Soil does not burn - Decrease in wood volumes - Absence of snags
	Large	High severity fires occurring in the coniferous boreal forest that burn soil organic layers	Clear-cutting over large areas followed by seeding or planting	- Soil does not burn - Decrease in wood volumes - Absence of snags

Table 1 establishes a distinction between two general classes of disturbances: those that principally affect the forest overstory (e.g., insect outbreaks and wind-induced stem breakage) and those that affect the overstory, as well as advanced regeneration and soil organic layers (e.g., fire). It is possible to associate certain silvicultural practices with these two large disturbance classes. For example, group- or single stem- selection cutting, now a commonly used practice in most tolerant hardwood forests (Majcen 1994), has effects similar to those caused by naturally formed gaps in this forest type. In the same way, careful logging, or harvesting with soil and regeneration protection, a practice widely used in Quebec, is well adapted to pure stands of balsam fir that are naturally controlled by spruce budworm outbreaks (Baskerville, 1975, MacLean 1984, Bélanger 1993). While somewhat similar in appearance to natural disturbances, these silvicultural practices do nonetheless exhibit certain distinct features. During selection cutting, a lack of soil disturbance may limit establishment of tree species requiring exposure of mineral soil for germination and increase the dominance of species already present or those that regenerate vegetatively. Another example is provided by careful logging. Although the effects of this harvest treatment may be similar to those resulting from a spruce budworm outbreak, careful logging does not necessarily generate the vertical structure nor the abundance of characteristic snags of post-budworm stages.

In contrast, this same practice, when applied in stands normally controlled by fire, has much greater repercussions on the type of natural regeneration of these stands. Natural stands issued from fire are principally regenerated from seed as advanced regeneration is generally destroyed by the fire. This generality does not apply to stands of intolerant hardwoods (poplar and birch) however, because, as is the case after fire, these stands often regenerate vegetatively after forest harvesting. The fact that advanced regeneration of tolerant softwoods may be favoured by certain silvicultural practices can, in certain cases, accelerate forest succession by facilitating replacement of species that have difficulty regenerating in the understory (e.g., jack pine or black spruce) by species, like balsam fir, normally found in the understory. Seeding felling or clear-cutting and planting may constitute a desirable alternative for stands driven by fire. For example, clear-cutting and planting is still a widespread practice in jack pine stands where the absence of advanced regeneration does not always justify the use of careful logging techniques. However, this practice represents an additional silvicultural cost and is not always in the public favour.

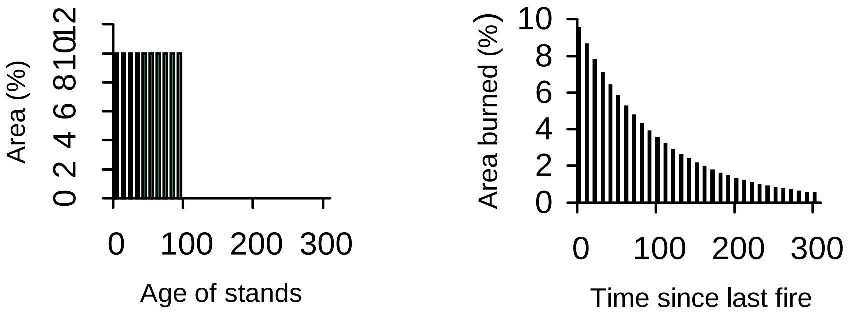
The effects of clear-cutting resemble only superficially those of forest fires. There is considerable controversy concerning the consequences of forest harvesting on nutrient recycling and long-term fertility of soils in forests that are naturally driven by fire (MacLean *et al.* 1983, Binkley and Richter 1987, Brais *et al.* 1995). It has been suggested that scarification or controlled burning prior to planting may constitute a mitigating measure against negative effects caused by clear-cutting. However, studies on post-fire, seed-origin and post-harvest, layer-origin black spruce have not demonstrated significant differences in height growth between the two types of regeneration (Morin and Gagnon 1992). Furthermore, the abundance and structure of biomass left on clear-cuts has little in common with the situation of a burned-over forest. In effect, numerous snags, as well as residual forested islands of various configurations and sizes, characterize most natural burns. There is still little known about the potential effects of the replacement of fire by clear-cutting and careful logging on the resilience and biodiversity of these forest ecosystems.

TOWARD A DIVERSIFICATION OF SILVICULTURAL PRACTICES AT THE FOREST LANDSCAPE LEVEL

Although the development of silvicultural practices inspired by natural stand dynamics represents a laudable objective for assuring the maintenance of ecological processes at the stand level, this approach alone cannot guarantee the maintenance of biological diversity. In effect, management will have to attempt to maintain the composition and structure of stands at the scale of the entire forest landscape similar to the natural milieu. When a forest region lends itself naturally to uneven-aged management, management strategies are somewhat simplified because silvicultural choices, according to stand type and site conditions, are essentially the same. Most of the challenge in managing these forests occurs basically at a local level and consists in maintaining species and stem diameter diversity during the silvicultural prescription. Thus, depending on ecological conditions, the best adapted species should be favoured. It is important, however, to vary the intensity and spatial arrangement of cuts in order to maintain species requiring different light and seedbed conditions.

When the length of the forest rotation approaches that of the disturbance cycle, even-aged management fairly closely resembles large amplitude natural disturbances like fire or insect outbreaks. Even-aged management does not produce, however, an age-class distribution equivalent to that of conditions produced under a natural disturbance regime. In even-aged management we refer to a normalized forest when stand age-classes are distributed uniformly over the entire forest area. Thus, an area managed on a 100-year rotation will contain no stands over the rotation age (Fig 1a).

The same area submitted to forest fires will have, at equilibrium, a completely different stand age-class distribution. In assuming that the probability of burning is independent of stand age (which is generally reported in the literature for boreal forest studies ; Johnson, 1992), the age-class distribution of stands issued from fire would follow a negative exponential in which 37% of stands are older than the fire cycle (Johnson and Van Wagner, 1985 ; Fig. 1b). This means that for a fire cycle equivalent to the forest rotation, forest harvesting will not leave any forest over the rotation age whereas fire will maintain greater than a third of the area over this age. This difference is fundamental because it implies, depending on the distribution, either the loss of over-aged forests often judged essential to biodiversity maintenance, or a decrease in allowable cut due to longer forest rotations. This dilemma is not without a solution. The use of silvicultural practices designed to maintain specific structural characteristics of over-mature stands in forests under management may provide a means of maintaining biodiversity while only slightly modifying allowable cut.



1a) 1b)

Figure 1. Forest age-class distribution (by 10 year period) as a function of a) normalized forest on a 100-year rotation and b) a 100-year fire cycle.

In this way it would be possible to treat some stands by seed felling or clear-cutting and planting, 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 dynamics in old growth. A simple example illustrating the natural dynamics and an ecosystem approach to managing the black spruce boreal forest is presented in Figure 2.

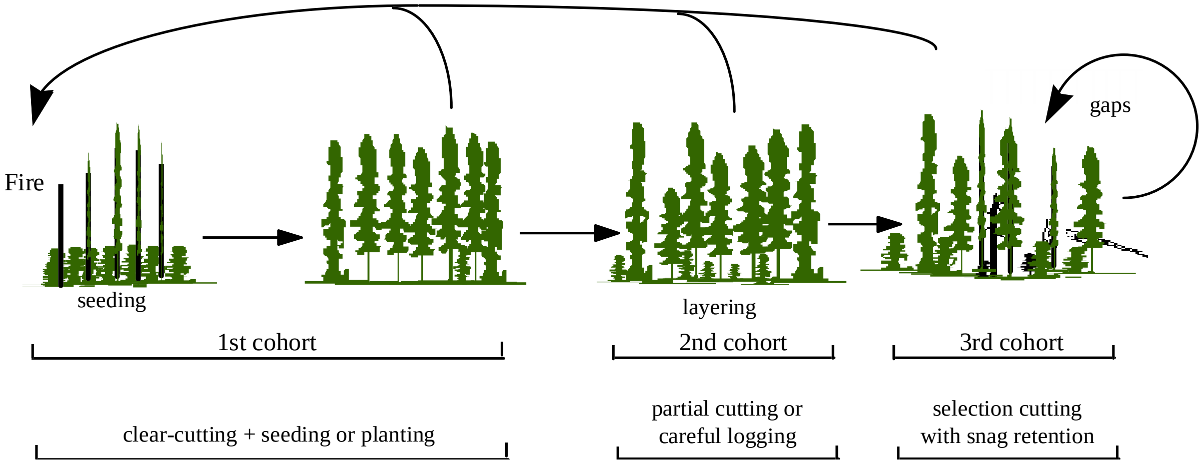


Figure 2. Natural dynamics and proposed silviculture for black spruce stands.

In assuming an invasion by black spruce after fire, an initial cohort is established, characterized by a dense and even-aged stand of seed-origin black spruce. At maturity, this stand will be gradually replaced by a more open stand composed of both seed-origin stems originating following fire and regeneration primarily of layer-origin. In the absence of fire, these stands evolve toward uneven-aged stands that are principally maintained by layering and characterized by heterogeneous structure and accumulations of woody debris. In varying silvicultural practices (Fig. 2), it would be possible to recreate comparable stand structure. Thus, the first cohort, issued from fire, is replaced by seeding cutting (or clear-cutting and planting), the second cohort by partial cutting emulating natural succession, and the third cohort by selection cutting mimicking 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. Figure 3 provides an example of possible stand age-class structure for stands having a maximum harvest age of 100 years submitted to a natural disturbance cycle of 100 years. The process provides a means of overlaying the area with subgroups of normal and even-aged forests, but in decreasing proportions as a function of time since the last clear-cut. It is important to note here that the third cohort includes all age classes over 200 years. In the case where stands take longer to reach a state of near-equilibrium, more than three cohorts could be necessary, whereas in the case of short fire cycles and rotations, two cohorts could be sufficient. It would thus be possible to partially recreate not only the natural composition and structure of stands, but also a forest age structure that approaches the typical distribution produced by fire (Fig. 1b).

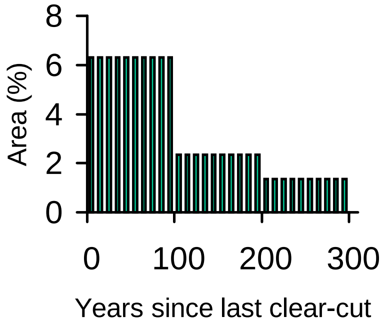


Figure 3. Forest age-class distribution (10 year periods) for decreasing 100-year forest rotations.

This approach can easily be applied to any number of situations; one only has to know the natural fire cycle and the maximum harvest age to determine the relative areas of each cohort that should be maintained over the forest landscape. Silvicultural practices would vary according to the cohort and the specific disturbance regime of a region. In Table 2, we present an abacus that allows determination of the proportion of the management cohorts as a function of fire cycle and maximum harvest age. For this exercise, the maximum harvest age is considered the age at which stand break-up begins; that is, where tree mortality results in significant loss of merchantable volume. In this sense, depending on the method used to determine it, the commercial rotation is generally shorter than the maximum harvest age.

With a 50-year fire cycle, a situation similar to that found in northern Alberta (Van Wagner, 1978), the great majority of the forest area is composed of the first cohort. This cohort is, however, relatively less important in the more humid climate of eastern Canada, for example in Labrador, where fire cycles of close to 500 years have been reported (Foster 1983). Consequently, the seeding cutting (or regeneration cutting of aspen stands) would be an appropriate practice over large portions of forests in the western Canada, whereas partial cutting with regeneration protection or selection cutting should be more widespread in the East.

Table 2. Abacus used for evaluating the desired proportion of the three cohorts submitted to different silvicultural treatments as a function of disturbance cyclce and rotation age.

	Disturbance cycle																										
Max. harvest age	50			75			100			125			150			200			300			400			500		
	cohort (%)			cohort (%)			cohort (%)			cohort (%)			cohort (%)			cohort (%)			cohort (%)			cohort (%)			cohort (%)		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
50	63	23	14	49	25	26	39	24	37	33	22	45	28	20	51	22	17	61	15	13	72	12	10	78	10	09	82
60	70	21	9	55	25	20	45	25	30	38	24	38	33	22	45	26	19	55	18	15	67	14	12	74	11	10	79
70	75	19	6	61	24	15	50	25	25	43	24	33	37	23	39	30	21	50	21	16	63	16	13	70	13	11	76
80	80	16	4	66	23	12	55	25	20	47	25	28	41	24	34	33	22	45	23	18	59	18	15	67	15	13	73
90	83	14	3	70	21	9	59	24	17	51	25	24	45	25	30	36	23	41	26	19	55	20	16	64	16	14	70
100	86	12	2	74	19	7	63	23	14	55	25	20	49	25	26	39	24	37	28	20	51	22	17	61	18	15	67
110	89	10	1	77	18	5	67	22	11	59	24	17	52	25	23	42	24	33	31	21	48	24	18	58	20	16	64
120	91	8	1	80	16	4	70	21	9	62	24	15	55	25	20	45	25	30	33	22	45	26	19	55	21	17	62
130	93	7	1	82	15	3	73	20	7	65	23	12	58	24	18	48	25	27	35	23	42	28	20	52	23	18	59
140	94	6	0	85	13	2	75	19	6	67	22	11	61	24	15	50	25	25	37	23	39	30	21	50	24	18	57
150	95	5	0	86	12	2	78	17	5	70	21	9	63	23	14	53	25	22	39	24	37	31	21	47	26	19	55
160	96	4	0	88	10	1	80	16	4	72	20	8	66	23	12	55	25	20	41	24	34	33	22	45	27	20	53
170	97	3	0	90	9	1	82	15	3	74	19	7	68	22	10	57	24	18	43	25	32	35	23	43	29	21	51
180	97	3	0	91	8	1	83	14	3	76	18	6	70	21	09	59	24	17	45	25	30	36	23	41	30	21	49
190	98	2	0	92	7	1	85	13	2	78	17	5	72	20	08	61	24	15	47	25	28	38	24	39	32	22	47
200	98	2	0	93	6	0	86	12	2	80	16	4	74	19	07	63	23	14	49	25	26	39	24	37	33	22	45

Use of the abacus 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. For example, Bergeron et al. (1998) demonstrate that, over a period of 8,000 years of the Holocene period, 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 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) privileges preservation of the resilience of the forest landscape in the context of changing disturbance regimes.

Modifications in the maximum harvest age also present an important effect on the proportion of the different cohorts over the forest landscape. Thus, for the same fire cycle, the relative area of the first cohort will be proportionally greater where the maximum harvest age is higher. For example, the proportion of the first cohort in jack pine stands presenting a higher maximum harvest age will be greater than trembling aspen stands in which break-up occurs at a younger age.

The conjunction between a high maximum harvest age and a short fire cycle places an important limit on allowable cut of a region because, especially in this situation, fires compete with the forest industry for the wood resource, and thus the proportion of the first cohort to reach harvest age is naturally smaller. Nature has done fairly well to adjust to this constraint by favouring growth of species whose age at maturity is generally lower than the fire cycle (Johnson 1992).

The values predicted in Table 2 would be modified in the case where successive cohorts have differing maximum harvest ages. This may occur if the passage of one cohort to another involves species replacement or changes in growth rates.

The proposed model emphasizes fire effects because of the omnipresence of fire in Canadian forests, but it could just as well be applied to disturbances of large amplitudes related to wind or insects that justify the recourse of even-aged forest management. In these cases, however, the negative exponential model may prove to be inadequate and the proportions of the different cohorts may not correspond to the figures presented in Table 2.

CONCLUSIONS

The management approach presented, while still fairly theoretical, may be credited for exploring concrete modes of application. These methods will have to take into consideration the various objectives of implementing sustainable forest management. In effect, we will have to change our perspective of forest ecosystem management: FEM should not consist merely of mimicking Nature, but rather of finding inspiration in natural dynamics as a means of developing strategies to maintain essential ecosystem functions (ex. productivity, resilience) and biological diversity. Attaining these objectives does not necessarily imply developing silvicultural scenarios that mimic natural disturbances. For example, if careful logging to protection advanced regeneration and soil, as is currently practised with success in eastern Canada, maintains fertility and ecosystem diversity as well as a treatment that more closely resembles the real effects of fire, it would be inappropriate, even unacceptable, to abandon the practice. In the same way, the use of more intensive treatments such as site preparation and planting should not be avoided if they meet ecosystem management objectives. Extensive silviculture is not, by definition, closer to Nature.

It is also important to consider the numerous operational constraints of forestry. In this sense, projects aimed at experimenting new silvicultural approaches inspired by natural dynamics, like those being undertaken in Alberta (Spence pers. comm.), in Ontario (MacDonald 1995) and in Quebec (Bergeron and Harvey 1997), should be developed throughout Canada. However, we can not wait for the results of these and other studies to change our forest practices. Natural forests are disappearing rapidly in this country, and we now have the responsibility to manage the forest in a sustainable fashion. Moreover, it will be much less costly in the long term to implement practices inspired by nature in our natural forests than to attempt to restore forests that have been subjected to inadequate silvicultural treatments. There is a lesson to be learned from the experience of northern European countries that are now having to invest in restoring their natural forests. Our actions must not be taken blindly however; it is important to be able to adapt our interventions as information from monitoring of treatments becomes available.

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